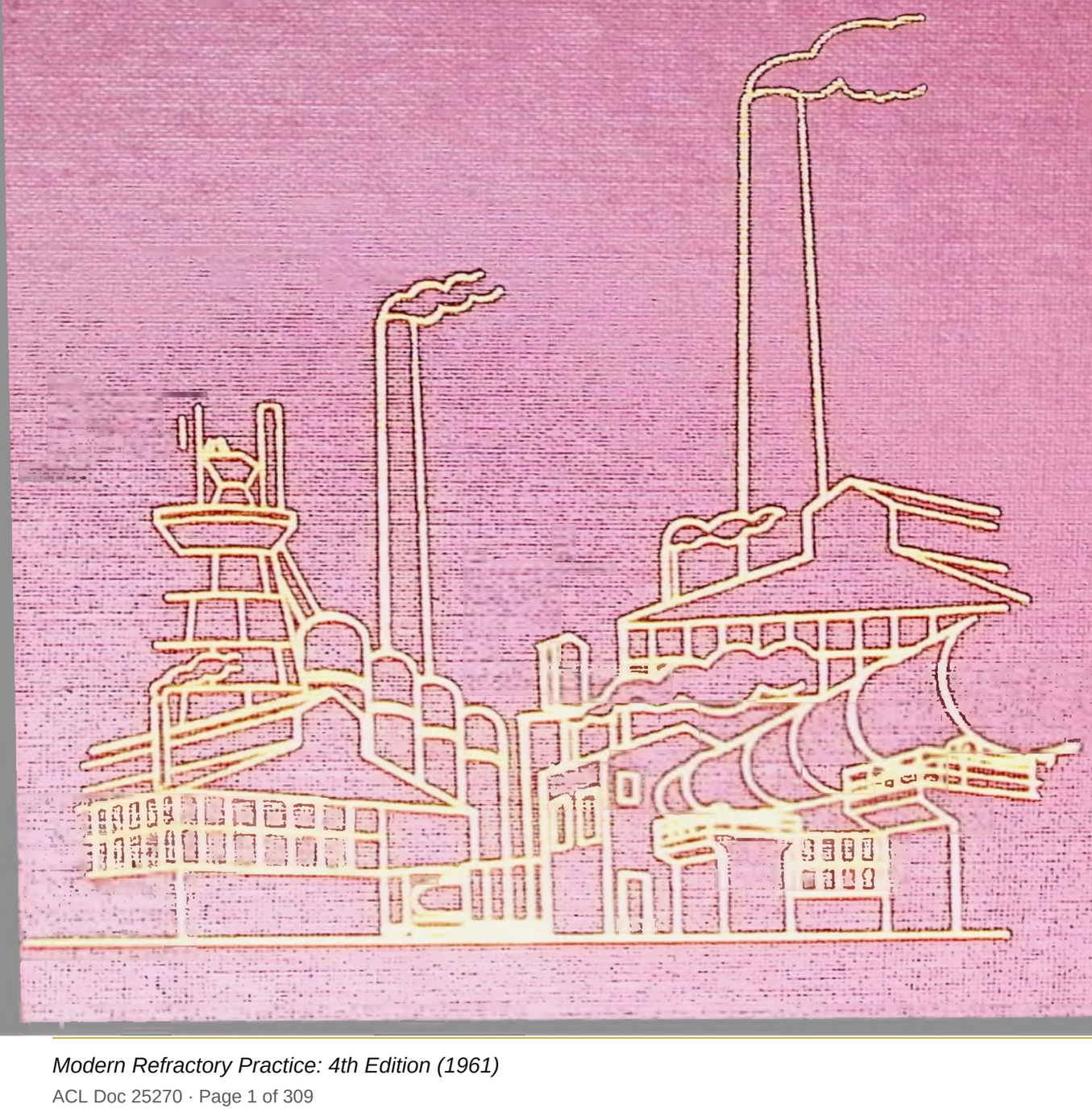
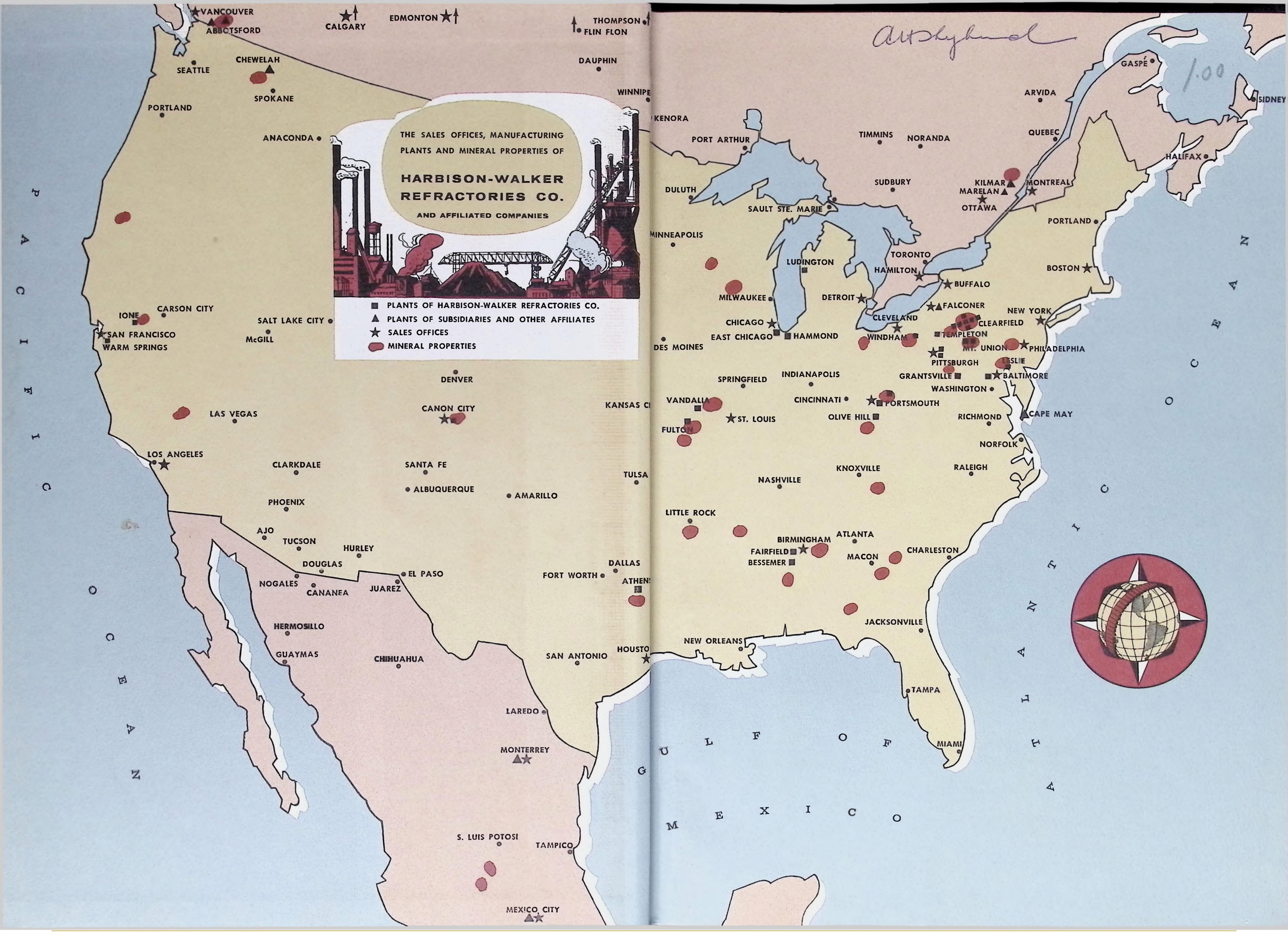
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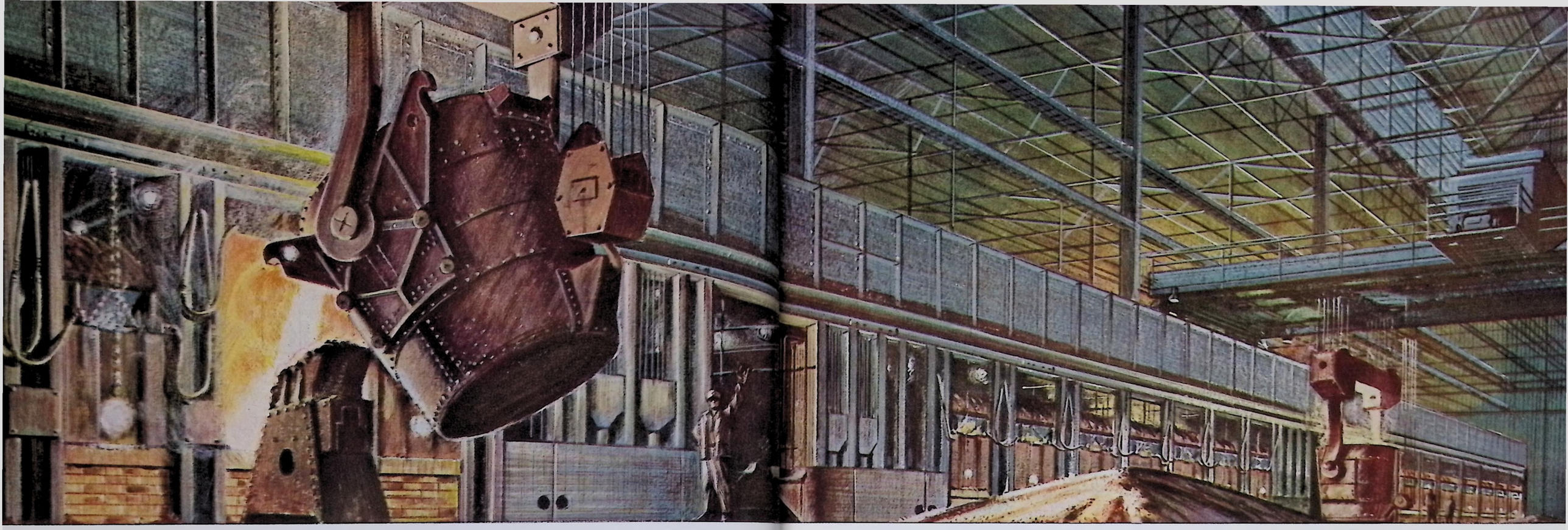
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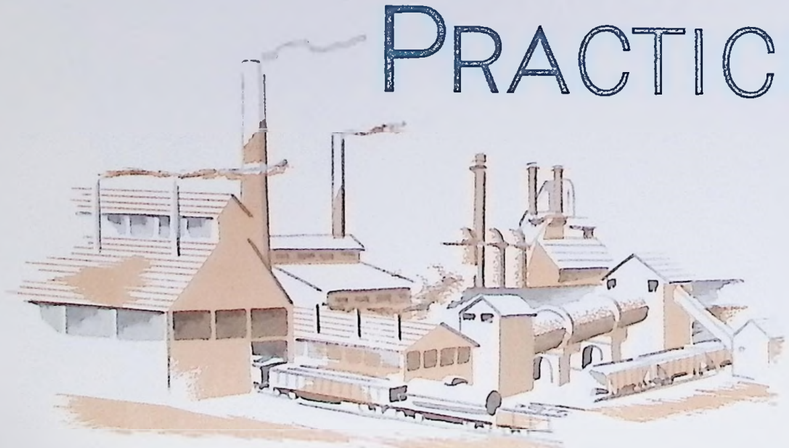
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MODERN REFRACTORY PRACTICE



WITH SPECIAL REFERENCE TO THE PRODUCTS OF

HARBISON-WALKER REFRACTORIES COMPANY

PITTSBURGH, PENNSYLVANIA

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HARBISON-WALKER REFRACTORIES COMPANY

and Subsidiary and Affiliated Companies

Harbison-Walker Refractories Company	*Pittsburgh, Pennsylvania*
Harbison-Walker Sales Company	*Pittsburgh, Pennsylvania*
Thermal Refractories Company	*North Bergen, New Jersey*
Northwest Magnesite Company	*Pittsburgh, Pennsylvania*
Harbison-Carborundum Corporation	*Falconer, New York*
Canadian Refractories Limited	*Montreal, Quebec, Canada*
Clayburn-Harbison Limited	*Vancouver, British Columbia, Canada*
Western Refractories Limited	*Winnipeg, Manitoba, Canada*
Fabrica de Ladrillos Industriales y Refractarios Harbison-Walker-Flir, S.A.	*Monterrey, Mexico*
Harbison-Walker-Flir de Mexico, S.A.	*Mexico City, Mexico*
Refractarios Peruanos, S.A. (Repsa)	*Lima, Peru*
Refractarios Chilenos, S.A. (Recsa)	*Santiago, Chile*
Ceramica Carabobo, C.A.	*Valencia, Venezuela*

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Warm Springs, California
Canon City, Colorado
East Chicago, Indiana
Hammond, Indiana
Olive Hill, Kentucky
Baltimore, Maryland
Grantsville, Maryland
Leslie, Maryland
Ludington, Michigan
Fulton, Missouri
Vandalia, Missouri
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Falconer, New York*
Portsmouth, Ohio
South Webster, Ohio
Windham, Ohio
Barrett, Pennsylvania
Clearfield, Pennsylvania
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Mount Union, Pennsylvania
Templeton, Pennsylvania
Athens, Texas
Chewelah, Washington*

Abbotsford, British Columbia, Canada*
Kilgard, British Columbia, Canada*
Kilmar, Quebec, Canada*
Marelan, Quebec, Canada*

Mexico City, Mexico*
Monterrey, Mexico*
Lima, Peru*
Santiago, Chile*
Valencia, Venezuela*

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California	Kentucky	North Carolina	Pennsylvania	Wisconsin
Canada*	Chile*	Mexico*	Peru*	Venezuela*

LABORATORIES

RESEARCH AND PRODUCT DEVELOPMENT
Garber Research Center, Pittsburgh, Pennsylvania
Falconer, New York*
Abbotsford, British Columbia, Canada*
Marelan, Quebec, Canada*
Monterrey, N. L., Mexico*
Valencia, Carabobo, Venezuela*

CONTROL
Hays, Pennsylvania
One or more in each manufacturing district.

**Subsidiary or Affiliated Company.*

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Boston, Massachusetts
Buffalo, New York
Canon City, Colorado
Charlotte, North Carolina
Chicago, Illinois
Cleveland, Ohio
Detroit, Michigan
Edmonton, Alberta, Canada*
Hamilton, Ontario, Canada*
Houston, Texas
Lima, Peru*
Los Angeles, California
Mexico City, Mexico*
Monterrey, Mexico*
Montreal, Quebec, Canada*
New York, New York
Ottawa, Ontario, Canada*
Philadelphia, Pennsylvania
Pittsburgh, Pennsylvania
Portsmouth, Ohio
St. Louis, Missouri
San Francisco, California
Santiago, Chile*
Toronto, Ontario, Canada*
Vancouver, British Columbia, Canada*

Agency offices are maintained in many countries.

WAREHOUSES

Baltimore, Maryland*
Birmingham, Alabama
Boston, Massachusetts
Buffalo, New York
Chicago, Illinois
Cleveland, Ohio
Detroit, Michigan
Edmonton, Alberta, Canada*
Hamilton, Ontario, Canada*
Jacksonville, Florida*
Los Angeles, California
Mexico City, Mexico*
Monterrey, Mexico*
Montreal, Quebec, Canada*
North Bergen, New Jersey*
Philadelphia, Pennsylvania
Pittsburgh, Pennsylvania
Portsmouth, Ohio
Toronto, Ontario, Canada*
Vancouver, British Columbia, Canada*

Warehouse stocks are carried by dealers in many other cities throughout the United States and Canada.

**Subsidiary or Affiliated Company.*

PRODUCTS

REFRACTORY BRICK AND SHAPES

FIRECLAY BRICK
All classes including Superduty, High-Duty, Semi-Silica, Medium-Duty, and Low-Duty—Pouring-Pit Refractories.

HIGH-ALUMINA BRICK
All classes, including those with alumina contents of 45-48%, 50%, 60%, 70%, 80%, 85%, and 90%—Mullite Class—Corundum Class.

SILICA BRICK
Conventional and Superduty; Coke-Oven Class.

BASIC BRICK
Fired and Chemically Bonded; Plain and Metal Encased, and Metal Encased with Internal Plates.
All standard classes, including Periclase, Magnesite, Chrome, Magnesite-Chrome, Chrome-Magnesite, Forsterite. Special compositions, including Spinel-Bonded Periclase, Forsterite-Bonded Periclase, and others.

SPECIAL TYPES OF REFRACTORY BRICK
Silicon Carbide, Zircon.

INSULATING MATERIALS
Furnace Insulating Brick of Groups 16-20, 20, 23, 26, 28, 30, and 33.
Insulating Silica Brick. Insulating Magnesite Brick.
Bulk Insulation—Block Insulation.

ACID-PROOF BRICK
Chemical-Resistant Brick and Shapes.

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REFRACTORY MORTARS

Heat-Setting and **Air-Setting Mortars** in a wide range of compositions, suitable for laying every class of Fireclay, High-Alumina, Silica, and Basic Brick, special types of refractory brick and furnace Insulating Brick.

MONOLITH-FORMING PRODUCTS

PLASTIC REFRACTORIES

Heat-Setting and Air-Setting.

Fireclay Base: Standard Class, Super Class, Semi-Silica—Fireclay Base with Graphite—High-Alumina Base.

RAMMING MIXES

Many types, including Fire Clay, High-Alumina, Silica, Periclase, Magnesite, Forsterite, Chrome, Silicon Carbide, Zircon.

CASTABLES

For service limits up to 3200°F.

Fire Clay, High-Alumina, Chrome, Chrome-Magnesite, Silicon Carbide, Insulating.

GUNNING MIXES

Fire Clay, High-Alumina, Silica, Magnesite, Chrome, Chrome-Magnesite.

OTHER PRODUCTS

LUMP AND GRANULAR MATERIALS

Quartzite, Calcined Flint Clay, Dead-Burned Magnesite, Periclase, Chrome Ore, Mullite.

SPECIAL CLAYS

Ground, Weathered, Calcined.

MOLDING MEDIA

Forsterite and Alumina-Silica Grains and Flour.

FUSED-CAST REFRACTORIES

BLOCKS AND SHAPES

Fused-Cast Beta Alumina Blocks.

Fused-Cast Alpha and Beta Alumina Blocks.

Fused-Cast Zirconia-Alumina Blocks.

Fused-Cast Chrome-Alumina Blocks.

GRANULAR PRODUCTS

Fused Bubble Alumina for Insulating Castables and other Refractories.

Aluminum Oxide Mortar Material.

Aluminum Oxide Ramming Mix.

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FOREWORD

WITH the publication of this, the Fourth Edition of MODERN REFRACTORY PRACTICE, Harbison-Walker Refractories Company presents an extensive compilation of data on refractories and their applications, with special reference to its own products.

As in all earlier editions, the primary purpose of this volume is service to users of refractories. The book contains information which can be of value to individuals responsible for the most efficient operation of industrial furnaces. Selectively, it serves as a buyer's guide. Contained in its pages are information and data of particular interest to plant operators, plant and design engineers, and research engineers. It will be useful as a text in engineering schools.

Steady growth has marked the history of Harbison-Walker. From a single small plant built in Pittsburgh in 1865 for the manufacture of fireclay brick, the company has developed into a multi-plant organization making hundreds of products, representing virtually every type of refractory. The plants, including those of subsidiaries and affiliates, are located in fourteen states across the nation, in Canada, and in several other countries.

The company's mineral resources consist of reserves sufficient to insure a supply of highest quality raw materials of all types needed and of uniform quality, for years to come. The reserves are maintained by a program of continuous prospecting and drilling. The mining operations consist of many mines, open-pits, and quarries widely distributed geographically in the United States and elsewhere. In addition, the company produces large tonnages of high-purity refractories from magnesia obtained by chemical treatment of sea water and deep-well brine.

A major factor in Harbison-Walker's success and growth is a continuous research program, conducted always with the goal of improving the performance of the company's products, and of developing new products to meet specific needs.

Since the construction of the Garber Research Center, the research program has been greatly accelerated. The result of extensive research is that many Harbison-Walker brands—both veterans in the service and more recent additions—are widely recognized as leaders in their fields.

Harbison-Walker's manufacturing facilities comprise the most modern and efficient plants. The plant operators have the benefit of skills derived from the accumulated experience of a hundred years in the manufacture of refractories in the company's own plants. A continuous program of construction and modernization keeps the plants up-to-date, and abreast of technologic advances. Highest standards of quality and workmanship are maintained by rigid control testing, beginning with the raw materials while still in the ground, and extending through each step of the manufacturing process.

The company's sales organization is staffed with competent refractories engineers, who are readily available to assist in the solution of problems related to the applications of refractories. Harbison-Walker's complete line of products permits unbiased choice to secure balanced furnace life and lowest refractories costs. Sales offices are located in all the large industrial centers of the United States, and in Canada, Mexico, and other countries. The manufacturing plants and complementary warehouses are so widely distributed geographically that they can make deliveries to any destination over a wide area with most favorable delivery time and transportation costs.

All of these factors contribute their important parts to *The World's Most Complete Refractories Service*. They are the basis on which your patronage is solicited.

HARBISON-WALKER REFRACTORIES COMPANY

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INTRODUCTION AND ACKNOWLEDGMENTS

SINCE the publication of the Third Edition of MODERN REFRACTORY PRACTICE in 1950, important technologic advances have been made in many industries. There has been great progress in metallurgy, and in the manufacture of glass, petroleum products, and many other basic materials. New products have been developed, new processes adopted, and furnace design and operation have been improved. These evolutionary developments, many of which involve the use of higher furnace temperatures and other more severe furnace conditions, have placed additional demands on the refractories. To meet the requirements, some refractories have been improved, new products have been added, and numerous product-modifications with highly specialized properties have been developed to fit particular needs.

In this, the Fourth Edition of MODERN REFRACTORY PRACTICE, much of the text has been completely rewritten and enlarged to bring it completely up to date. No single chapter of text has escaped a considerable degree of revision. Particular effort has been made to include such engineering and technologic data as will be most useful to those interested in refractories and their uses. Considerable new data on the properties of refractories were obtained especially for this volume.

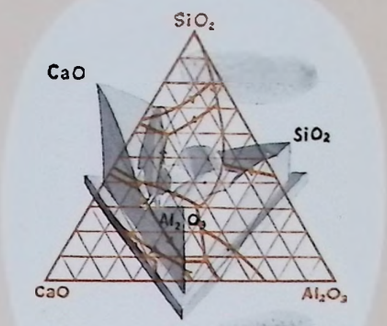
Because of the complexity of the subject, it has been helpful to consult with many individuals. Our thanks are extended to all of the many members and friends of the Harbison-Walker organization who helped in many ways, with information, advice, and assistance in the preparation of the manuscript and drawings.

As in all previous editions, W. F. Rochow and J. Spotts McDowell were the editors and wrote a large part of the text. Frederick E. Eyman served as assistant editor. The drawings were prepared by Stanley J. Rogers.

HARBISON-WALKER REFRACTORIES COMPANY

E. A. Barber.

Chairman of the Board



HARBISON-WALKER RESEARCH

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X-ray and spectrographic equipment, used for research in both mineral identification and chemical analysis. Accessory equipment permits investigation of the stability of minerals, while at high temperatures, by X-ray diffraction.



Garber Research Center, which contains the most advanced and complete assembly of instruments and equipment dedicated to the single purpose of research in the science of refractories.

HARBISON-WALKER RESEARCH

One of the striking aspects of modern civilization is its dependence upon higher and higher temperatures for the production and processing of many things essential to daily life. Metals and alloys, ceramic ware, glass, portland cement—all these and many other necessary products owe their existence and utility to high-temperature heat treatments in furnaces built of heat-resisting materials—refractories.

In industrial furnaces, the refractory lining materials must be capable not only of withstanding high temperatures, but also of adequately resisting various other destructive conditions. They may be subjected to chemical attack by slags, molten metals, dusts, or furnace gases; to thermal shock resulting from rapid heating and cooling; to the impact of hard solid lumps of materials charged into the furnace; or the abrasive action of moving solids or dust-laden gases. The economic use of refractories in a particular application may depend also upon various high-temperature characteristics, such as heat exchange properties, thermal conductivity, thermal expansion, and stability of mineral composition.

All of these different factors and many others are involved; they present a complex field for research on the high-temperature properties and applications of refractories.

Early Research: The importance of experimentation in the development of refractories and of control testing during their manufacture was

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early recognized by the founders of Harbison-Walker. The thousands of chemical analyses recorded in the company's notebooks between 1877 and 1910 give evidence of the great interest taken in chemical composition and its relation to the quality of the products.

It soon became clear to these early workers that the heat-resisting quality of a refractory could not always be estimated accurately from its chemical analysis. In 1890 and following years, Harbison and Walker, as the firm was then known, developed additional procedures for determining their properties, including a high-temperature reheat test to observe the behavior of the brick at temperatures of 3000°F. and higher. The test was used to evaluate raw materials and to control the quality of finished refractory brick.

During the closing years of the nineteenth century and the early years of the twentieth, many hundreds of experimental mixes were made and tested for the purpose of developing and improving the company's products.

In 1909 a central laboratory for research and control was built at Hays, Pennsylvania. The history of the company's Research Department since then has been one of accelerated growth. From time to time the Hays Laboratory was enlarged to meet increasing needs.

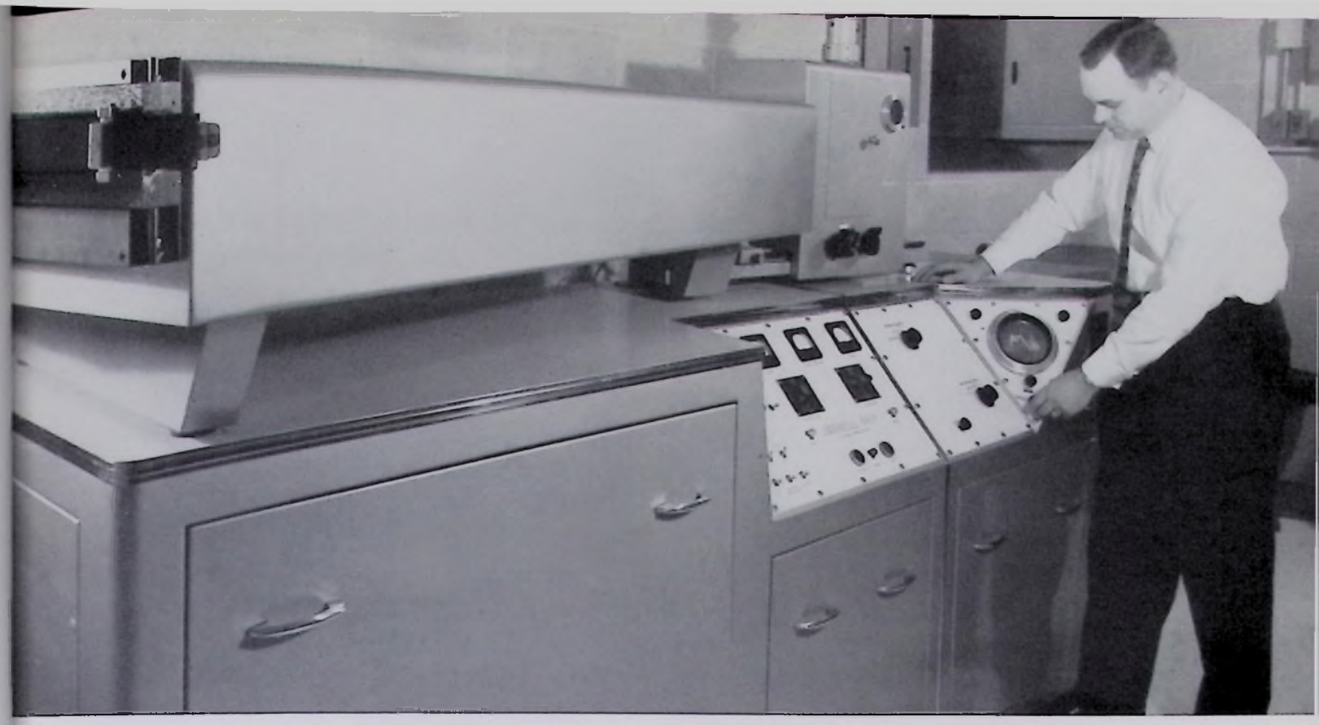
Among the achievements of Harbison-Walker research at the Hays Research Laboratory were the results of fundamental studies in high-temperature mineralogy and chemistry leading to a broader understanding of high-temperature properties of refractories; the computation of grain-sizing formulas for the control of some of the properties of refractory brick; the forming of brick shapes in vacuum or by vibration; the development of forsterite brick and superduty silica brick; and the various stages in the improvement of metal-encased basic brick, first marketed by Harbison-Walker in 1916.

Garber Research Center: The current great interest in research is reflected in Harbison-Walker's newer laboratories comprising the Garber Research Center, which began operations early in 1959. This is a unique laboratory; it contains the most advanced and most complete assembly of instruments and equipment in the world dedicated to the single purpose of research in the science of refractories.

The Research Center is situated on a twenty-acre tract of land, providing ample space for future expansion. The laboratories are functionally divided between two main buildings; air-conditioned offices and instrumental research areas are in one, and a complete pilot plant with associated laboratories for product development are in the other. Both buildings are constructed of a pleasing functional combination of buff brick, polished granite, and enameled aluminized steel to provide about 50,000 square feet of working area.

The Research Department is staffed by research engineers and scientists trained in ceramic and chemical engineering, in physics, chemistry, physical chemistry, mineralogy, petrography. and ore dressing. The department has cooperated actively with Committee C-8 of the American Society for Testing Materials in the development of tests for evaluating the properties of refractories. The new and improved products which have been introduced and the numerous inventions and contributions to the technical literature by members of its staff are evidence of the intense activity and excellent accomplishments of the department.

The traditional organization for refractories research is based on classified departments to assure that work is in continuous progress in the separate fields of fireclay, silica, high-alumina, insulating, basic, and speciality products. In the operation of the Garber Research Center the staff has been augmented to superimpose on the customary structure a grouping of research men concentrating their efforts in specific fields of refractories use. Thus there is full-time continuous research on glassmaking refractories, as well as on refractories for the separate and distinct metallurgies of steel, copper, aluminum, nickel, and other metals.



Emission spectrograph, which provides a rapid method for qualitative and quantitative chemical analyses. Such analyses are useful for research and for technical guidance in the selection of refractories for particular needs.

Problems for Research: The company's long-time principle of participating actively in studies of heating, melting, and refining operations has made it a partner in the development of many processes which have since attained great industrial importance. Customer service is not just an annex to the main research effort, but rather a yardstick used continuously to evaluate research projects and plans.

The relatively recent adaptation of basic refractories to the open-hearth main roof has been a revolutionary success, allowing steelmaking temperatures to be greatly increased. Production in tons per hour has been doubled in some furnaces. A traditional emphasis within the company's Research Department on chemical and mineral factors has had much to do with the successful development of refractories for this application. However, as even greater temperatures and production rates are sought—by use of bulk oxygen, for example—it is expected that the capacities of the newest X-ray, spectrographic, and microscopic equipment will be taxed in efforts to understand the changed courses of reaction in service.

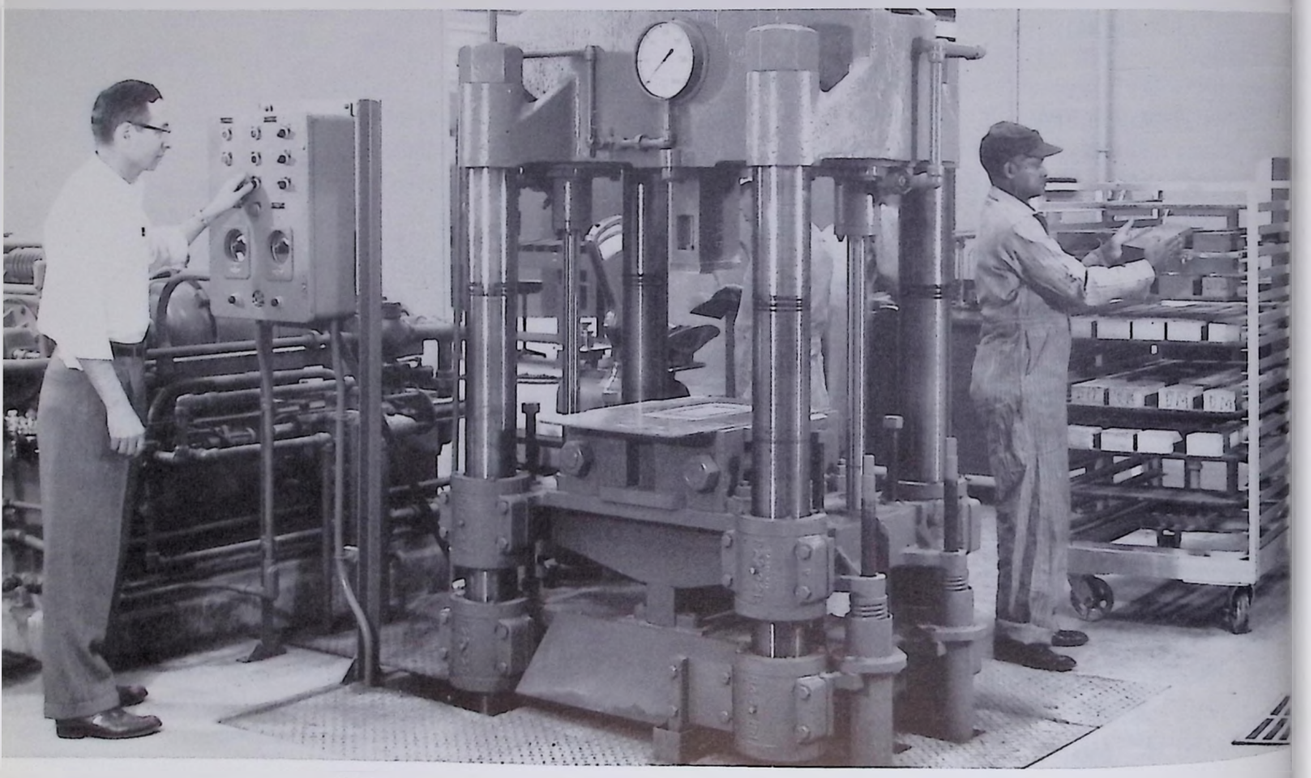
Further, as appreciation has grown of the importance of high brick density in refractories for various services, it has become necessary to study the size grading of brickmaking materials down to particles far below ordinary screen measurements. For this purpose, a separate laboratory has been set up in the fine instruments section to study subsieve particle sizings by the newest and finest techniques.

Wholly new refractories were introduced for

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the new oxygen steelmaking processes which have made such rapid progress in recent years. In current practice, brick for oxygen-process vessels are made of organically-bonded mixtures of basic materials. The organic part of the refractory is held to be of such importance that staff members with training in organic chemistry intensively investigate this phase. The resistance of the inorganic base materials to molten metal and slag is evidenced by X-ray and microscope.

The long-time load-bearing capacity of refractories at high temperatures is of great importance in many applications. Some highly advanced apparatus has been developed for its measurement. These include furnaces in which full-sized brick, loaded at 25 psi, are heated routinely to 3400°F. (1870°C.), and to higher temperatures when desired. A fully controlled automatic electric load-test furnace is especially suited for making long-time load tests such as are not practicable with ordinary equipment. Alkali impurities, as is well known, must be held to a minimum in such refractories as semi-silica fireclay brick and silica brick on account of their detrimental effects upon the ultimate refractoriness and load-bearing capacity of the brick at high temperatures. A photometric



Pilot plant hydraulic press, equipped with automatic pressure and cycle control. This press is used for making brick of various sizes under completely controlled conditions including pressures considerably in excess of commercial practice.

method devised sometime ago by the Research Department is kept in constant use checking the compositions of raw materials which are used in the manufacture of coke-oven and various other brick and in analyzing experimental refractory batches.

In studying the effects of aluminum, copper, nickel, and other nonferrous metals and their alloys and slags in the molten state upon their refractory containers, a number of chemical, mineral, and physical tests are used. Recent work with laboratory holding hearths, in which refractories are kept in contact with molten metal or alloy for weeks at a time, have led to important findings. A new 85 per cent alumina brick and corresponding mortar are examples of important products which have resulted from work with aluminum alloys in this special equipment.

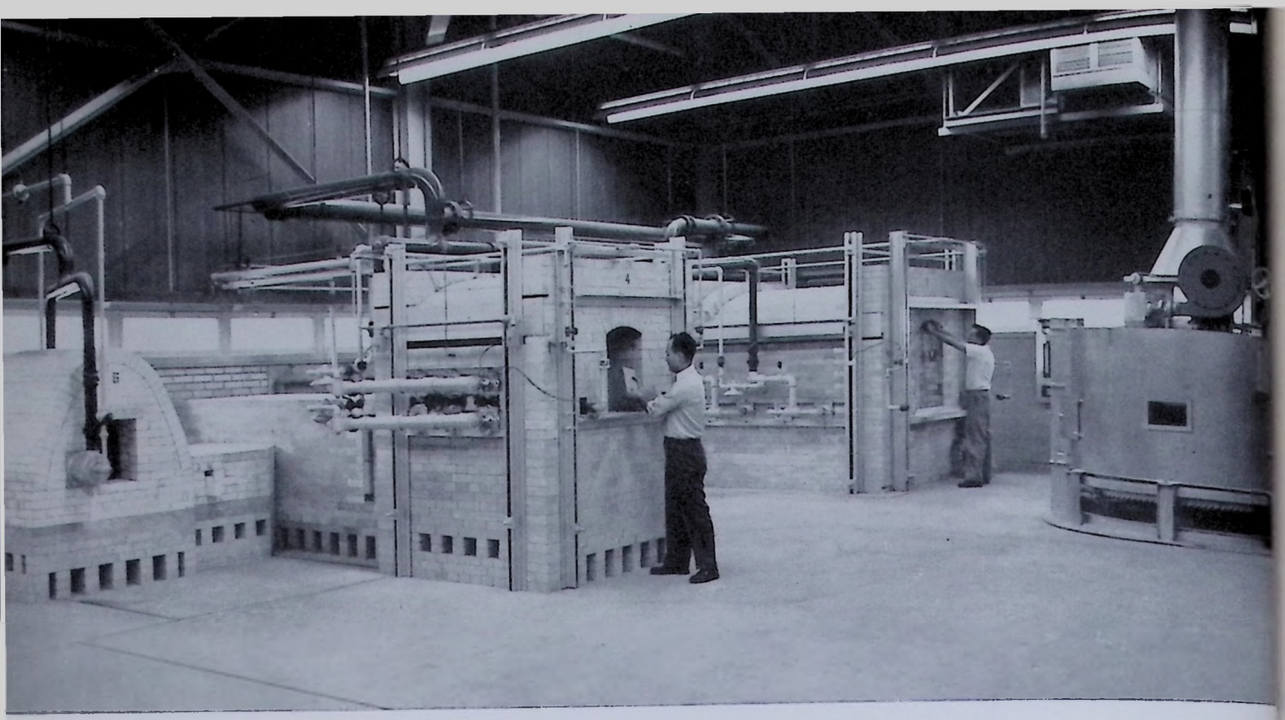
Extremely high working temperatures, and use of refractories in vacuum or in contact with special gaseous atmospheres, are problems in the new metallurgical fields. Test furnaces are available with capacity to heat brick to above 3500°F. when the circumstances require it. In essence, the problem is one of supplying extremely pure refractories of stabilized mineral composition, with the desirable physical properties developed to the highest degree. The experience accumulated in the evolution of the seawater magnesia operation at Cape May, New Jersey, has been important in work with magnesia produced from inland brine in the plant at Ludington, Michigan.

The ceramic industries, including glass and portland cement, also are large users of refractories. In research in this field physical, chemical, and mineral studies are all important. In addition, much attention is given to testing methods which provide conditions simulating those to which the refractories are exposed in service. The corrosion of refractories resulting from long contact with molten glass is a problem which requires high-temperature equipment of special design. Regenerator refractories are usually contaminated gradually by batch carryover and are altered in physical properties in the process.

Resistance of a refractory to rapid temperature change is a property which is almost always desirable, but which is of particular importance for malleable furnace bung brick, incinerator linings, electric furnace roofs, and various other applications. The A.S.T.M. panel spalling test is much used in work with this property but has distinct limitations as would be expected from some of the special conditions involved. For this reason, a unique rotating-hearth furnace has been developed which is much more massive and versatile, and can be operated with more severe testing conditions when necessary. Also requiring special equipment are tests to determine the effects at high temperature of changes in the oxidation-reduction potential of furnace gases, such as occur in any regenerator system. This is a field in which Harbison-Walker research has contributed pioneering concepts.

There are many different ways to form refractories bodies, and it has been found that often the method of forming is a critical factor. During the past few decades, the power-press process has effected a revolution in the manufacture of refractories. However, in making some refractories, such as glass-tank paving brick from zircon, or ceramic kiln furniture from silicon carbide, it has been found that the inherent lack of plasticity of the base material is best handled in vibrating or impact-type presses. Slip-casting makes possible the manufacture of refractory furnace parts of extremely high density, and those of intricate design.

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Part of test kiln area. To maintain a comprehensive testing program, a variety of kilns of different types is required. The catenary arch chamber, shown at the left, is designed to heat full-sized commercial brick at temperatures up to 3500°F.

Monolith-forming refractories are roughly defined as all refractory products which are supplied in other form than brick and mortars for bonding them. They include plastic firebrick, castables or refractory concretes, ramming mixes, and special gunning mixes. These so-called monolithic materials are usually classified on the basis of their properties rather than by usage because they are applied in so many and varied applications. For example, one problem involved the manufacture of a high-purity castable for lining petroleum cracking vessels where the operating temperatures are not high, but where even traces of certain impurities can poison the catalyst.

The refractory castable for the construction of the Cape Canaveral pad from which America's first satellites were launched, was the product of a research project aimed at developing the optimum combination of resistance to high temperature and high velocity blast, combined with the ability to withstand outdoor weathering.

Special equipment, such as vibrators or pneumatic guns are used at the Research Center to study methods of installing the various monolith-forming refractories, and special tests are needed to determine consistency, workability, and curing procedures. A test of unusual interest measures the tendency of some monoliths to spall explosively when heated suddenly before complete drying.

The Future: Industrial processes are continually changing. Operating temperatures of furnaces always tend to become higher and the conditions to which refractories are exposed become increasingly severe. The Harbison-Walker research staff is always on the alert for new scientific information which may point the way to improved products. The company today supplies many materials which are superior to those available just a few years ago, and the creative skill of research can be depended upon to provide refractories suitable for the far more exacting requirements of the future.



QUALITY CONTROL

HARBISON-WALKER REFRACTORIES COMPANY

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← *Entering Data on Control Chart at the Press.*

SUPERIOR REFRACTORIES THROUGH QUALITY CONTROL

In the manufacture of Harbison-Walker products, each step from the extraction of the raw materials from the ground to the shipment of the finished refractories is under careful technical control, with the aid of instrumentation and precise laboratory testing. The quality control program is never static; it is continually being improved, with the constant goal of producing even better and more uniform refractory materials.

The term "quality control" had not yet been born back in 1866 when S. P. Harbison entered the employ of the Star Fire Brick Works at Pittsburgh. This organization, the first unit of Harbison-Walker, soon recognized the necessity for controlling the quality of its products. By means of chemical analyses and data obtained from reheat tests, the refractoriness of the brick made was brought under a degree of control then rare in the industry.

Throughout the ensuing years, quality control work has been continued, and simultaneously coordinated with laboratory research for improvement of existing products, and development of new ones. A central laboratory at Hays, Pennsylvania, built in 1909, was greatly expanded in later years. It served initially not only for research and development, but also for quality control of raw materials and finished products. In the late 1920's the company began the installation of control laboratories at the various plants. The first three of these were located at Templeton and Clearfield, Pennsylvania, and Vandalia, Missouri.

For many years, quality control was one of the functions of the Research Department. In 1950, a separate quality control staff was organized, and in 1959, following construction of the research laboratories at the Garber Research Center, the Hays Laboratory was remodeled and converted into General Headquarters for all the company's work on Quality Control. The company's control division now operates many laboratories, of which there is at least one in each producing district.

Statistical Quality Control: Variation is a fundamental law of nature. No two people, no two trees, even no two leaves are exactly alike. Manufactured products are no exception to this universal law of variation. It is true for screws, bolts, metal parts for machines, steel shapes, automobiles, and even for refractory products.

The most obvious difference between two manufactured units of the same lot is frequently a difference in dimensions. Therefore, many specifications include requirements as to permissible variations in size; that is, a "size tolerance." Since excessive variation in dimensions or other properties of a manufactured article may detract from its usefulness, the variations must be kept within minimum practicable limits; that is, the manufacture must be "controlled." Until relatively recent years, however, the establishment of logical and workable tolerances was often a matter of considerable difficulty.

For several decades, statisticians had been studying the mathematics of the variations in properties of both natural and manufactured objects, and through studies based on the laws of probability, they developed powerful statistical techniques for dealing with problems of variability. These techniques had become simplified by the early 1940's to such a degree that they could be applied generally to manufacturing control; and when so used the methods became known as "statistical quality control."

These relatively new quality control methods

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are used to determine the degree of precision which reasonably can be expected from a given raw material or process of manufacture; they permit the establishment of workable control limits; and they tell when a material or a process is "out of control." The methods are useful in problems of mining, production, specification, and inspection. Under controlled manufacture, variations in a product can be kept within known limits, determined by studies of statistics. Directly and indirectly, statistical quality control helps to make a better product.

Harbison-Walker has continued and expanded the older methods of control, and has added the modern statistical techniques to control of raw materials and manufacturing operations. Control testing begins with core drilling and testing the raw material still in the ground, follows through each stage of mining, processing, and manufacturing, and ends only when the finished products are loaded on cars or trucks for shipment.

CONTROL OF RAW MATERIALS

Refractory raw materials follow nature's fundamental law of variability. The company must extract these more or less variable minerals from mines, open pits and quarries, and through selection, beneficiation, and blending produce raw materials of uniform quality to meet specific standards. For each material there are definite standards of quality.

So many different materials are used by Harbison-Walker, and so many different control tests are applied, that it is not practicable to discuss all of them here. However, a brief description is given of the control methods followed in the production of one typical raw material used in large quantities.

Hard or flint clays constitute the essential raw material for the manufacture of most superduty and high-duty fireclay refractories. These clays are the hardest of all clay materials, and are among the most refractory. The fact that the particles produced in grinding do not break down appreciably in water permits accurate control of grain sizing in the manufacture of brick. Deposits in general are relatively small and of irregular shapes, and include not only the high-quality flint clay, but also flint clay of lower refractoriness, and masses of waste rock. The control problems in the different mining areas are not identical, and in each case the control program is adjusted to meet local conditions.

The program followed in the company's Missouri operations is typical for thoroughness. During the prospecting of a minable deposit, the testing of the drill cores will have established the fact that a sufficient tonnage of high-quality clay is present. Before mining begins, additional test holes are put down on closely spaced centers. Samples of the drill cores are subjected to a series of laboratory tests and designated as "acceptable" or "not acceptable." The acceptable clay is classified further as to type. A single deposit may contain as many as three types of flint clay, in addition to plastic fire clay and high-alumina diaspore clay. Since drill holes can never be spaced closely enough to show all the changes that occur in the character of the clay, either vertically or horizontally, careful control is required during the mining operation.

Generally, the clay is trucked to a stock pile at the plant, or at some shipping point. Each truckload is weighed and sampled upon receipt. The samples consist of two types, (1) "lump samples" of any material that may indicate a change in type or appear questionable for any reason, and (2) "average samples."

"Lump samples" are fired in a test kiln the same night. Visual examination the following morning indicates the relative density of the fired lumps and shows the presence of harmful impurities. If any samples are of unacceptable quality, mining at the particular operation is suspended until the working faces are sampled and the precise location where the offending material occurs is determined.

"Average samples" are tested promptly for refractoriness (as measured by the P.C.E. test*) and for firing shrinkage. Later, when the clays are used in manufacture, they are blended on the basis of the test data to obtain mixtures of desired refractoriness and burning properties.

**For description of the P.C.E. test see Glossary.*

Chart No. 1 shows firing shrinkage data for a typical stock pile of flint clay. The chart shows (1) the results of tests on the daily average samples of clay direct from the mines, as taken from the trucks during the stockpiling, and (2) the test results on samples taken during withdrawal of the clay from the same stock piles for use.

From the firing data, the average linear firing shrinkage and its "standard deviation" are calculated. The standard deviation has several uses, but for the present purpose it may be considered merely as a measure of variability. Theoretically, 95 per cent of the values lie within the range of plus or minus two times the standard deviation from the average. Reference to Chart 1 shows that the *average* shrinkage of the clay as determined on samples taken before and after stockpiling was identical, i.e., 1.20



"Lump Samples" of Clay Received From the Mine, Being Examined After Test-firing.

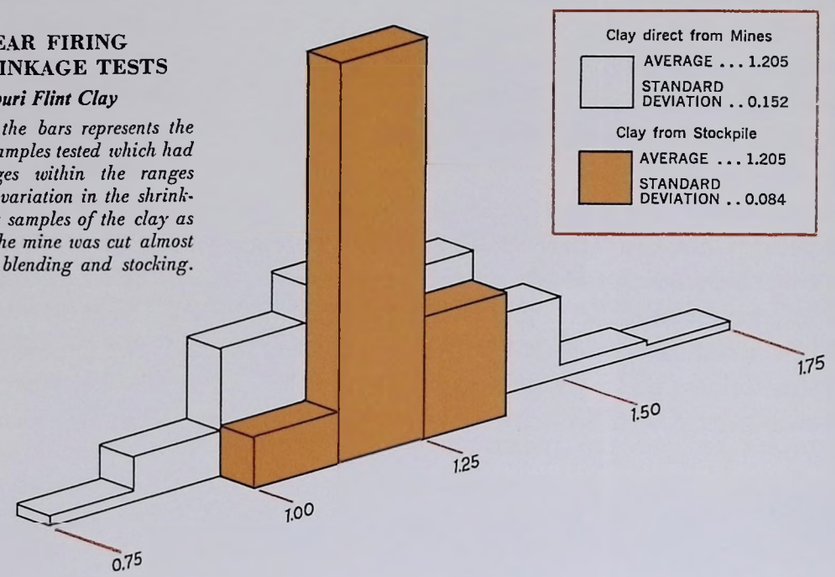
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inches per foot. However, the standard procedure of stocking and working the clay from the pile greatly reduced the variability, and the standard deviation value shows that the variability from the average shrinkage in this case was reduced almost one half. Further improvement in the uniformity of the product is obtained by using clay from several stock piles, each of known firing shrinkage, refractoriness, and chemical analysis.

Chart 1. **LINEAR FIRING SHRINKAGE TESTS**

Missouri Flint Clay

The height of the bars represents the percentage of samples tested which had firing shrinkages within the ranges indicated. The variation in the shrinkage of different samples of the clay as it comes from the mine was cut almost in half by the blending and stocking.



CONTROL IN RAW MATERIALS PREPARATION

Calcining: Some of the refractory raw materials used are subjected to a high-temperature heat treatment called "calcination," before use in making brick and other products. This heat treatment effects mineral decompositions and recombinations, transformations and inversions; and it brings about volume changes which would otherwise occur later when the brick are fired. High-alumina diaspore clays, flint fire clays, and kaolins are calcined for use in making certain products. In Harbison-Walker's plants, calcining is done in modern efficient rotary kilns.

Since one of the purposes of the calcining process usually is to shrink the material and so to make possible the closer control of dimensions of the brick, the density or weight per unit volume of the calcines is the common control test. Using a rapid method, the local control laboratory determines the density on samples taken as frequently as every 15 minutes throughout the day, or possibly only once a day, depending on the nature of the clay material. The rotary kilns are equipped with temperature measuring instruments, variable speed and feed controls, and other devices that enable the operator to make any changes that may be indicated by the control tests.

Crushing, Grinding, and Screening: The raw materials for refractories are ground and screened to the proper sizings for use in brick-making or for incorporation in ramming or castable compositions. The properties of the finished refractories are influenced to a large degree by the grain sizing; that is, the relative proportions of particles of different sizes. Research has determined the effect of the grain sizing on such properties as resistance to spalling, strength, density, and shrinkage at high temperatures, and has established a standard "grind," or size grading, for each product. The quality control program includes regular screen analyses of all products throughout the grinding and screening processes.

Batching and Mixing: These important steps in the preparation of raw materials for the manufacture of refractories are adaptable to accurate control. Each material used in a batch is weighed, the weighed batch is delivered to the mixer where water and other bonds are added at definite intervals, and finally, the prepared batch is discharged from the mixer for delivery to the presses or other equipment in which the brick are formed.

CONTROL IN MANUFACTURE

Pressing and Forming: Since most refractory brick are made by the power-press process, this method has been chosen for illustration of control in manufacture. The carefully prepared batches are fed into the mold boxes and the brick are formed under high pressures. The forming operation is an important control point in the manufacturing process. If the pressure is too low, the brick may be low in density or strength; if the pressure is too high, the brick may be laminated or "pressure cracked." If the right amount of material is not charged to the mold, the brick may be undersize or oversize.

At regular intervals, a supervisor weighs and measures samples of the brick being made. The weight of the brick and its thickness (the dimension that may be varied by the pressing operation) are plotted on the control charts, which are posted at each press in such position that they can be easily seen by both the Press Operator and the Foreman. As shown in Chart 2, the control charts show both the upper and lower limits that are acceptable for each item. So long as the points fall within these limits, the process is "in control" and a satisfactory product is being made. Should the points fall outside the range, the process is "out of control." Production is interrupted, and the cause is sought for, found, and remedied.

Drying: The drying of refractory brick is a critical step in the manufacturing process, and must be carefully controlled. In most of the company's plants, the brick are placed on cars immediately after having been molded, and pass through tunnel driers on definite time-temperature schedules with controlled humidity. Numerous recirculating fans along the length of the drier tunnels direct the stream of warm air into desired paths, and insure uniform removal of moisture from the brick without cracking. The control instruments on the driers include recording hydrometers, base-metal thermocouples, recording and indicating thermometers, pressure gauges, and recording ammeters (which indicate the load on the fans). Regular determinations of the moisture content of the brick coming from the driers serve as a guide to the drier operation.

Firing: The time, temperature, and other conditions of firing determine many of the important physical properties of the products. In their passage through the tunnel kilns, the

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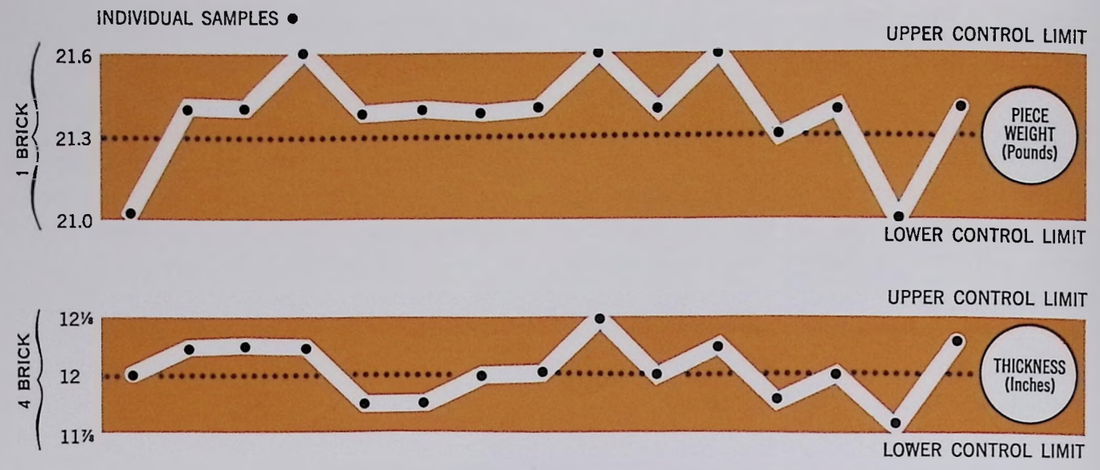


Chart 2. **CONTROL CHART FOR PRESSING OF A BLAST-FURNACE SHAPE**

As the brick come from the press, a supervisor periodically weighs and measures the thickness of samples. The weight of the brick and the thickness are plotted on the control chart and posted at the press. The control charts show both the upper and the lower limits that are acceptable.

brick are heated gradually to a maximum temperature, held there for a definite length of time, and then properly cooled to the temperature at which they are removed from the kiln. In the firing of refractories, there are critical temperature ranges in which the rates of temperature change must be carefully controlled. Therefore, it is necessary to heat and cool the ware in accordance with time-temperature schedules based on the firing properties of the particular kind of brick. The kiln atmosphere also has an effect on the properties of the brick, and must be controlled.

The modern tunnel kiln for firing refractories utilizes advanced principles of combustion, heat conservation, and temperature and draft control. Among the operating control instruments are recording and indicating pyrometers, air-fuel ratio instruments, automatic pressure controls, and draft and pressure-control gauges. Various of these instruments also serve as controls in periodic kiln firing.

The quality control tests that are regularly used to check and control the burning operation and coordinated with other manufacturing procedures are size, bulk density, apparent specific gravity, porosity, and modulus of rupture of the burned brick. Use of the tests for control of burning involves the comparison of the properties of brick taken from different parts of the setting, and of brick coming from the kilns during successive periods of time.

PRODUCT TESTING

Tests of the finished refractory products are numerous and varied. In addition to those already listed are included tests for resistance to abrasion, load-bearing ability at high temperatures, expansion or contraction after reheating to high temperatures, resistance to spalling, and various other tests, depending on the end use of the specific product. Additional tests are

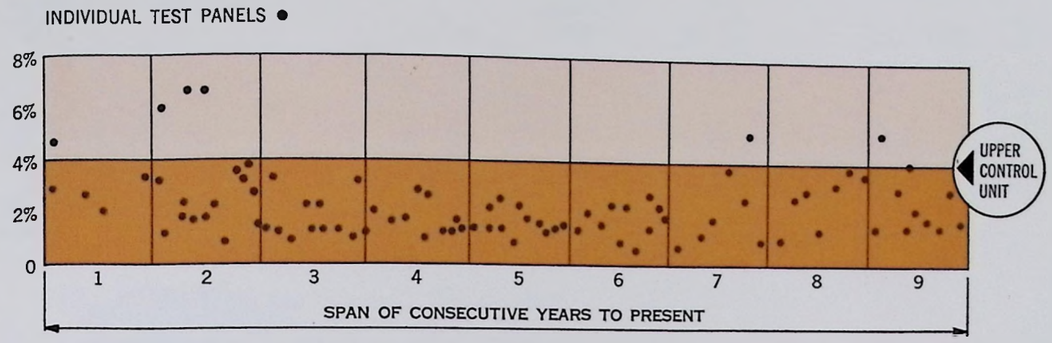


Chart 3. **PANEL SPALLING TESTS ON ALAMO SUPERDUTY FIRECLAY BRICK**

One of the important properties of superduty fireclay brick is high resistance to spalling when subjected to rapid temperature change in service. The brick are tested for this property by a laboratory "panel spalling test." The results of control of raw materials and manufacture, for ALAMO *brand of superduty fireclay brick, are shown in the chart.*

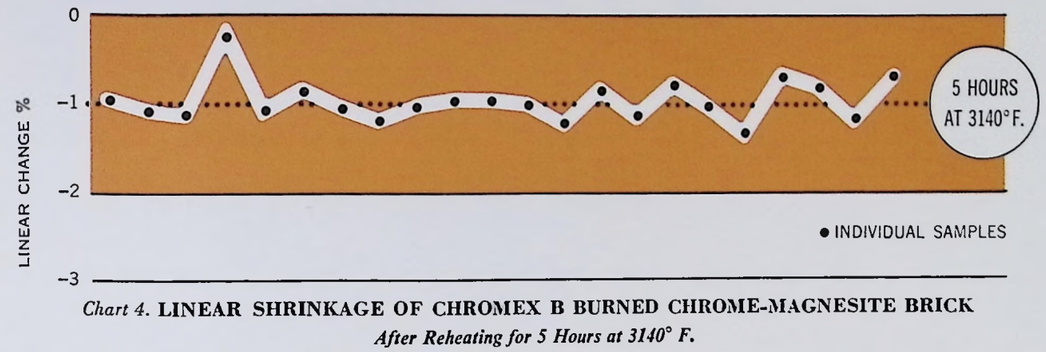


Chart 4. **LINEAR SHRINKAGE OF CHROMEX B BURNED CHROME-MAGNESITE BRICK**
After Reheating for 5 Hours at 3140° F.

The reheat test at 3140°F.—a temperature attained in relatively few industrial furnaces —provides a means of evaluating the volume stability of basic brick at extremely high furnace temperatures. In this severe test, the shrinkage of CHROMEX B *is almost negligible.*

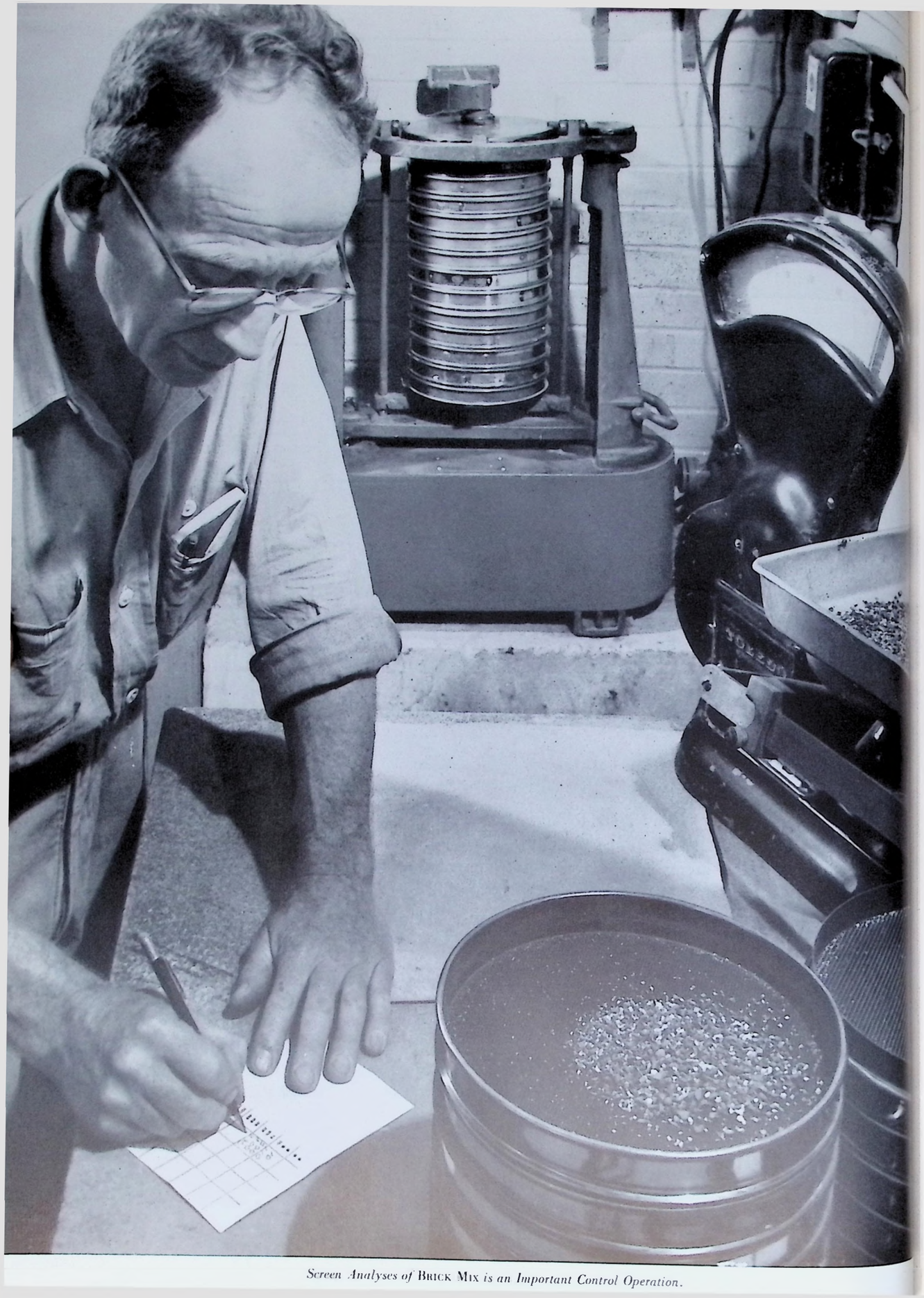
regularly made as a check on results, to increase knowledge of correlation of properties and to improve control. Accomplishments resulting from such studies are illustrated in Charts 3 and 4. On Chart 3, spalling test results are plotted for ALAMO brand of superduty fireclay brick. On Chart 4 is shown the linear shrinkage of CHROMEX B chrome-magnesite brick (a fired product) after having been reheated for 5 hours at 3140°F.—a temperature considerably higher than that at which most industrial furnaces normally operate.

Harbison-Walker's control program will continue to evolve with changing conditions, and its aim will always be the same as now:

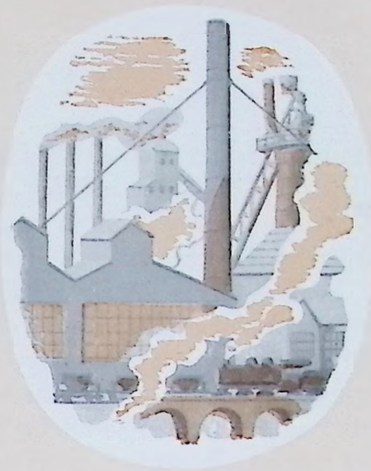
SUPERIOR REFRACTORIES THROUGH *QUALITY CONTROL*

HARBISON-WALKER REFRACTORIES COMPANY

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Screen Analyses of BRICK MIX *is an Important Control Operation.*



INDUSTRIAL REFRACTORIES

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INDUSTRIAL REFRACTORIES

Refractories are defined as "nonmetallic materials suitable for the construction or lining of furnaces operated at high temperatures." Stability at high temperatures—both physical and chemical—is the primary requirement for refractory materials. They may be called upon, while hot, to withstand pressures from the weight of furnace parts or contents, thermal shock resulting from rapid heating or cooling, other stresses induced by temperature change, mechanical wear resulting from movement of furnace contents, and chemical attack by heated solids, liquids, gases, or fumes.

It is appropriate to mention the role of refractories in present-day civilization, our national economy, and our individual lives. Refractories are indispensable for substantially everything that is manufactured. Their need is obvious for the smelting of ores, refining of metals, generation of steam power, and the production of glass, portland cement, pottery, and building brick. Directly and indirectly, though less obviously, refractories are equally important in many other industries. They provide a vital need in the production of paper, lumber, textiles, plastics, and nearly all other manufactured materials.

Refractory materials of various kinds are needed for the many and widely diversified industrial applications. Those in greatest tonnage demand are classified on the basis of composition or properties into a few main types, known as fireclay, high-alumina, silica, basic, and insulating refractories, in each of which there are different classes. In addition, there are various special refractories, including silicon carbide, graphite, carbon, zircon, zirconia, fused-cast products, and several others.

Refractory materials are supplied mainly as preformed shapes. Other products include special-purpose clays, bonding mortars, high-temperature cements, plastic refractories, ramming mixes, hydraulic-setting castables, gunning mixes, and the granular materials dead-burned magnesite, dead-burned dolomite, and ground quartzite.

Refractory shapes are classified on the basis of their physical form as standard sizes, rectangular tile, and special shapes. The standard sizes are brick of certain definite dimensions and relatively simple design which are used in sufficient amounts to permit quantity production. The brick most extensively used are the standard 9 x 4½ x 2½-inch and 9 x 4½ x 3-inch straights and the corresponding series of standard sizes, including arch, wedge, and key brick, and certain others.

All shapes of nonstandard dimensions are regarded as rectangular tile or special shapes. They include a wide variety of brick regularly used for specific services, such as by-product coke-oven shapes, baffle tile for boilers, checker brick for blast-furnace stove regenerators, and many others; together with shapes of special design manufactured on particular orders from designs submitted by the user.

Not included in the broad classifications of standard sizes and special shapes are several specific-service refractory products, usually made at plants which specialize in their manufacture. These products include glass-tank blocks, glass pots, kiln furniture (setting tile and others), crucibles, muffles, laboratory ware, pyrometer tubes, and many others. Saggers for use in the ceramic industry and zinc retorts are generally made by the users.

CHARACTERISTIC PROPERTIES OF REFRACTORY BRICK

Type	Class	Characteristics
Fire Clay	Superduty	Highest refractoriness of any fireclay brick. Stability of volume at high temperatures. Low thermal expansion; excellent to good resistance to thermal spalling. Good load-bearing properties. Fair resistance to acid slags; moderate resistance to basic slags.
Fire Clay	(1) High-Duty (2) Medium-Duty (3) Low-Duty	The chemical and physical properties of fire clays vary between wide limits; hence, fireclay brick with widely varying combinations of properties are available. Most high-duty fireclay brick have relatively low thermal expansion; fair spalling resistance and thermal insulation value; fair resistance to acid slags and fluxes, and relatively lower resistance to basic slags and fluxes.
Fire Clay	Semi-Silica	Rigidity under load and volume stability at high temperatures. Moderate thermal expansion. Excellent resistance to structural spalling. High temperature of incipient vitrification. High resistance to penetration and attack by volatile alkalies or fumes, within its temperature range.
High-Alumina	(1) 45-48% Alumina (2) 50% Alumina (3) 60% Alumina (4) 70% Alumina (5) 80% Alumina (6) 85% Alumina (7) 90% Alumina (8) Mullite (9) Corundum	High refractoriness increasing with increasing alumina content. Thermal expansion low up to 80 per cent Al_2O_3; higher above 80 per cent Al_2O_3. High mechanical strength and excellent load-bearing properties at high temperatures. Fair to excellent resistance to spalling. High resistance to corrosion by many basic slags and fluxes; fair resistance to acid slags.
Silica	(1) Superduty Regular Hot Patch (2) Conventional Regular Hot Patch (3) Lightweight	Melting temperature only slightly below that of pure silica. High mechanical strength and resistance to abrasion at high temperatures. Fairly high thermal expansion. Not subject to thermal spalling above 1200°F. Most silica brick have poor resistance to thermal spalling below 1200°F.; "hot-patch" brick have high resistance to spalling for this type of refractory. Lightweight silica brick have only about half the thermal conductivity of regular silica brick. High resistance to corrosion by acid slags, and to iron oxide in an oxidizing atmosphere. Readily attacked by basic slags.
Silicon Carbide	(1) Bonded (2) Recrystallized	High refractoriness. High strength at furnace temperatures. High thermal conductivity. Low thermal expansion. High resistance to spalling. Susceptibility to oxidation at critical temperatures.
Zircon		High refractoriness. Moderately high thermal conductivity. High resistance to some alkaline fluxes. Low thermal expansion.
Insulating	(1) 1600°F. (2) 2000°F. (3) 2300°F. (4) 2600°F. (5) 2800°F. (6) 3000°F. (7) 3300°F.	Densities and thermal conductivities range from very low to moderate; higher for the higher temperature classes. Low thermal expansion. Very high resistance to thermal spalling.

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CHARACTERISTIC PROPERTIES OF REFRACTORY BRICK

Type	Class	Characteristics
Magnesite (Periclase)	A. Regular (1) Fired (2) Chemically Bonded B. Spinel Bonded (1) Fired (2) Chemically Bonded	Extremely high refractoriness and high thermal conductivity. High thermal expansion. The spinel-bonded brick have superior resistance to thermal shock. Good resistance to corrosion by basic slags; poor resistance to siliceous slags.
Chrome	(1) Fired (2) Chemically Bonded	Moderate thermal expansion and thermal conductivity. High resistance to corrosion by basic and moderately acid slags and fluxes. In general, basic slags do not adhere to chrome brick. Under certain conditions, iron oxide is absorbed and causes a damaging expansion.
Magnesite-Chrome	(1) Fired (2) Chemically Bonded	Relatively high thermal expansion. High mechanical strength and stability of volume at high temperatures. High resistance to corrosion by basic slags.
Chrome-Magnesite	(1) Fired (2) Chemically Bonded	Relatively high thermal expansion. High mechanical strength and stability of volume at high temperatures. High resistance to corrosion by basic slags.
Forsterite	(1) Fired (2) Chemically Bonded	High refractoriness. Excellent strength at high temperatures. Relatively high thermal expansion. Moderate thermal conductivity. Excellent resistance to corrosion by volatile alkalies and glass-batch carry-over. Fair resistance to most basic slags; attacked by acid slags.

NOTE 1: Basic refractories in general are less resistant to thermal shock than fireclay and high-alumina refractories. However, the spall resistance of some basic brick of special compositions is fully equal to that of superduty fireclay brick.

NOTE 2: Basic brick of any class may be metal encased, or metal encased and internally plated, as desired. Such brick have much better resistance to spalling than brick without the casings. Most metal-encased basic brick are of magnesite-chrome compositions.

FIRECLAY REFRACTORIES

Fire Clay: Refractory fire clays consist essentially of hydrated aluminum silicates with minor proportions of other minerals. The general type formula of these aluminum silicates is $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$, corresponding to 39.5 per cent alumina (Al_2O_3), 46.5 per cent silica (SiO_2), and 14.0 per cent water (H_2O). Kaolinite is the most common member of this group. At high temperatures the combined water is driven off, and the residue theoretically consists of 45.9 per cent alumina, 54.1 per cent silica. However, even the purest clays contain small amounts of other constituents such as compounds of iron, calcium, magnesium, titanium, sodium, potassium, and lithium, and usually some free silica. Refractory clays containing an appreciable proportion of the silica mineral quartz are known as "siliceous clays"; and those containing the high-alumina mineral diaspore $Al_2O_3 \cdot H_2O$ are known as "diaspore clay," "burley clay," or "nodule clay."

The clays of greatest importance as refractories are flint and semi-flint clays, plastic and semi-plastic clays, and kaolins.

Flint clay, known also as hard clay, derives its name from its extreme hardness. It is the principal component of most of the superduty and high-duty fireclay brick made in the United States. Most flint clays break with a conchoidal or shell-like fracture. Their plasticities and drying shrinkages, after they have been ground and mixed with water, are very low; their firing shrinkages are moderate. The best clays of this type are low in impurities and have a Pyrometric Cone Equivalent (P. C. E.)* of Cone 33 to 34-35. Deposits of flint and semi-flint clays occur in rather limited areas in Pennsylvania, Maryland, Kentucky, Ohio, Missouri, Colorado, and several other states.

Plastic and semi-plastic refractory clays, often called "soft clays" or "bond clays" vary considerably in refractoriness, plasticity, and bonding strength. Drying and firing shrinkages are usually fairly high. The P.C.E. of clays of this type ranges from Cone 29 to Cone 33 for the most refractory varieties, and from Cone 26 to Cone 29 for many clays of high plasticity and excellent bonding power. Certain clays with a P.C.E. which is even lower are widely used for special purposes, such as the production of ladle brick and certain other pouring-pit refractories for steel plants. Important deposits of plastic and semi-plastic refractory clays occur in Pennsylvania, Ohio, Kentucky, Missouri, West Virginia, Alabama, and in various other states.

Kaolins consist essentially of the mineral kaolinite. They are usually moderately plastic and have extremely high drying and firing shrinkages. Siliceous kaolins shrink less and bauxitic kaolins shrink more than kaolins which consist almost wholly of kaolinite. Refractory kaolins in general have a P.C.E. of Cone 33 to 35; less pure varieties with a P.C.E. of Cone 29 to 32 are common. Among the largest deposits of refractory kaolin are those which occur in Georgia and Alabama.

Most of the commercial deposits of flint and plastic refractory clay occur in sedimentary strata, in association with coal beds. Usually, the individual occurrences are relatively small and of irregular form. In the north-central Ozark region of Missouri bodies of refractory clay occur in the form of isolated sink-hole deposits. The kaolin deposits of Georgia and Alabama occur in the form of lens-like bodies.

Fireclay Brick: As presently defined by the American Society for Testing Materials, there are five standard classes of fireclay brick, known as superduty, high-duty, semi-silica, medium-duty, and low-duty fireclay brick. Fireclay pouring-pit refractories in general are not included in this classification. Fireclay brick of the several classes cover the approximate range of about 44 to 18 per cent alumina, and from about 50 to 80 per cent silica.

High-duty and superduty fireclay brick are commonly made of a blend of clays. Flint clays and high-grade kaolins impart high refractoriness; plastic clays facilitate forming and impart bonding strength; calcined clays control the drying and firing shrinkages. The relative proportions of these used in a blend depend upon the character and quality of the ware to be made. Most semi-silica brick are made of siliceous kaolin. Some fireclay brick, especially those of the low-duty class, and most pouring-pit refractories, are made of a single clay.

Superduty Fireclay Brick: The outstanding properties of fireclay brick of the superduty class are high refractoriness, alumina content of 40 to 44 per cent, strength and stability of volume at high temperatures. Many of these brick have superior resistance to cracking or spalling when subjected to rapid changes of temperature. Their refractoriness, in terms of their P.C.E. value, may not be less than 33. In the class of superduty fireclay refractories are several modifications, including brick which

* *For explanation of "P.C.E.," see Glossary.*

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are fired at temperatures several hundred degrees higher than the usual product. The high temperature of firing enhances the high-temperature strength of the brick, stabilizes their volume and mineral composition, increases their resistance to fluxing, and renders them practically inert to disintegration by carbon deposition in atmospheres containing carbon monoxide gas.

High-Duty Fireclay Brick: The P.C.E. value of high-duty fireclay brick may not be less than 31½, and ordinarily varies from 31½ to 32½—33. These refractories are used in larger quantities and for a wider range of applications than any other single type of refractory material. Even for furnace temperatures which are relatively moderate, economy of operation may dictate the use of high-duty brick. For example, because of their higher resistance to thermal shock, high-duty fireclay brick may often be used with better economy than medium-duty brick for the linings of furnaces operated at moderate temperatures over long periods of time but subject to frequent shutdowns.

Medium- and Low-Duty Fireclay Brick: Fireclay brick of the medium-duty class have P.C.E. values of 29 to 31. They are serviceable in applications where they are exposed to conditions of moderate severity. Within their serviceable temperature ranges, medium-duty brick may withstand abrasion better than many brick of the high-duty class.

The P.C.E. values of low-duty fireclay brick cover the range from 15 to 27-29. They find application as backing for brick of higher refractoriness, and for other service where relatively moderate temperatures prevail.

Semi-Silica Fireclay Brick: Semi-silica fireclay brick contain about 25 to 18 per cent alumina and 72 to 80 per cent silica, with a low content of alkalies and other impurities. They have excellent load-bearing strength and volume stability at high temperatures, with notable resistance to shrinkage. Their maximum temperature limit in service is somewhat lower than that of the more aluminous high-duty fireclay brick. Within their temperature limits, they have high resistance to vitrification, to structural spalling, and to penetration by alkaline fumes and dusts.

Pouring-Pit Refractories: These include ladle brick, hot tops, nozzles, sleeves, stoppers, runner brick, and certain other shapes required in transferring molten steel from the furnaces to the ingot molds. All of these are usually made of fire clay except the stopper heads, which generally consist of clay-graphite compositions. The sleeves and most of the runner brick are of high-duty quality. However, in general, the ladle brick, nozzles, and sometimes the runner brick are made from plastic clays uniquely suited for these services but for the most part having refractoriness values in the lower ranges. Most large steel ladles are lined with brick which become somewhat pyroplastic and swell in service, thus increasing the tightness of joints between brick. Generally, some pyroplasticity of the nozzles is considered desirable, for tight seating of the stoppers.

Granular Clay Products: Various special clays, both raw and calcined, find widespread industrial application as refractories. Ground refractory clays serve as mortar materials, for the preparation of plastic refractories, ramming mixes and castables, for the manufacture of pottery saggers and zinc retorts, for daubing and patching, for filling tapholes, as molding media, and for various other uses.

HIGH-ALUMINA REFRACTORIES

Industrially, the term "high-alumina brick" is used to designate products which are formed by the molding of granular high-alumina materials. Shapes formed by casting electrically fused materials are commonly known as "fused-cast" refractories. These are discussed briefly in a later section.

The materials used in the manufacture of high-alumina refractories include the following:

- Diaspore ($Al_2O_3 \cdot H_2O$).
- Bauxite (probably $Al_2O_3 \cdot H_2O + Al_2O_3 \cdot 3H_2O$).
- Diaspore Clay (Refractory fire clay containing disseminated nodules of diaspore. Called "nodule clay" in Pennsylvania).
- Bauxitic Kaolin (Kaolin containing disseminated nodules of bauxite).
- Kyanite ($Al_2O_3 \cdot SiO_2$).
- Sillimanite ($Al_2O_3 \cdot SiO_2$).
- Refined Calcined Alumina (Al_2O_3).
- Granular Fused and Sintered Alumina (Al_2O_3).
- Synthetic Mullite ($3Al_2O_3 \cdot 2SiO_2$).

Most high-alumina refractories are made from bauxite or diaspore clay, or a mixture of the two, blended with flint or plastic clay according to the properties and alumina content desired in the finished product. On account of the high firing shrinkage of diaspore clay and bauxite, essentially all of it is precalcined before being used in the manufacture of refractory products. In some cases, fused or calcined alumina is added to high-alumina mixes to enhance certain properties.

Refractory products of the alumina-silica group which contain more than about 45 per cent alumina are known as "high-alumina" refractories. Various grades of high-alumina brick are available, including classes which contain approximately 45-48, 50, 60, 70, 80, 85, 90, and 99+ per cent alumina. The class name of "mullite" is applied to certain refractories which consist mainly of the mineral mullite (71.8 per cent Al_2O_3, 28.2 per cent SiO_2). The term "corundum" is used to designate the class of refractories which contain 99+ per cent alumina. This brick consists almost entirely of the mineral corundum (crystalline Al_2O_3), which melts at approximately 3720°F. Except for the mullite and corundum classes, the permissible variation in alumina content is plus or minus 2½ per cent.

High-alumina brick of all classes are more refractory than fireclay brick, approximately in proportion to their content of alumina. The different classes of high-alumina brick offer the advantages of a stepwise progression in refractoriness, covering a range in softening temperatures of more than 400°F. They are multipurpose refractories, which may be used for service extending to about 3600°F. High-alumina brick are highly resistant to chemical attack by various slags and fumes, and in general, have greater resistance to pressure at high temperature than fireclay brick. Some brands are highly resistant to thermal shock.

"Mullite" refractories, consisting mainly of the mineral mullite ($3Al_2O_3 \cdot 2SiO_2$) in well-developed crystalline form, are made both from natural minerals and from synthetic mullite. The alumina content of the theoretically pure mineral is 71.8 per cent; that of the usual mullite brick ranges from about 60 to 71 per cent. "Fortified" mullite brick, which contain small percentages of free alumina, have an alumina content of about 71 to 78 per cent. Mullite-type brick have outstanding load-bearing properties, volume stability, and resistance to fluxing at high temperatures. High-alumina products used for monolithic linings are supplied in a wide range of compositions and physical properties. Among these products are ramming mixes, castables, gunning mixes, and plastic refractories.

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SILICA REFRACTORIES

The raw material used in the manufacture of silica refractories consists essentially of the mineral quartz, in finely crystalline form and of a high degree of purity. Deposits suitable for the production of refractories occur in various states. The raw silica minerals are usually obtained by open-pit mining, and are commonly washed to remove extraneous materials.

Silica brick are fired products in which the original quartz has been converted largely into other crystalline forms of silica. Three classes of silica brick are produced commercially:

(1) Superduty brick, containing about 0.2 to 0.5 per cent total of alumina, titania, and alkalies (soda, potash, and lithia).
(2) Conventional brick, containing more than 0.5 per cent and less than 1.0 per cent total of alumina, titania, and alkalies.
(3) Brick containing about 1.4 per cent to 2.5 per cent total alumina, titania, and alkalies. These are used only for special purposes, and in relatively small quantities.

Silica brick are especially well adapted to service in various high-temperature furnaces because of their high refractoriness, high mechanical strength and rigidity at temperatures almost up to their melting point, ability to resist the action of basic dust and fume, and relative lightness of weight. Their thermal expansion is relatively high at low temperatures, but is almost negligible above 1000°F. Most silica refractories are susceptible to thermal spalling if heated or cooled rapidly at temperatures below about 1200°F.; modifications of both superduty and conventional brick are supplied which have remarkably high resistance to spalling for this type of refractory. Above 1200°F. silica brick are practically free from thermal spalling.

Ground silica ganister is used extensively for the construction of the hearths or bottoms of various types of furnaces, especially where acid slags are present. Silica mortars or "cements" are used for laying silica brick.

BASIC REFRACTORIES

Raw materials used in the production of basic refractories include magnesite, brucite, chemically precipitated magnesium hydroxide, chrome ore, olivine, and dolomite. Each of these except olivine and chrome ore requires a preliminary dead-burning to drive off carbon dioxide or combined water, and to convert the residue into grains of high density and of suitable characteristics for further processing or for the end use.

Commercial basic refractory products embrace refractory brick of many classes, together with mortars, ramming mixes, castables, gunning mixes, and dead-burned basic grains.

Magnesite: The highly refractory oxide magnesia (MgO) with a melting point of about 5070°F. (2800°C.) has long been an important refractory material. Refractories composed mainly of magnesia are generally known commercially as "magnesite" products. They derive this name from the fact that refractory magnesia was formerly produced exclusively from the naturally occurring mineral magnesite ($MgCO_3$). This name persists even though dead-burned magnesite is now produced in large quantities from magnesium hydroxide precipitated from sea water, bitterns, or inland brines.

Dead-burned magnesite is composed mainly of the stable mineral periclase, the crystalline form of magnesia.

The mineral magnesite in theoretical purity would contain 47.6 per cent magnesia (MgO) and 52.4 per cent carbon dioxide (CO_2). Large deposits are operated in Washington, Nevada, and Quebec, and in various countries overseas. Natural magnesium hydroxide, which consists of 69.0 per cent magnesia, 31.0 per cent water, occurs in the form of the mineral brucite ($MgO \cdot H_2O$). Deposits of commercial size are rare, and this mineral is used only to a limited extent in the manufacture of refractories.

In order to render the magnesian raw materials suitable for commercial use as refractories, they must first be dead-burned. This process consists of subjecting the raw magnesite rock or the natural or artificial magnesium hydroxide in a rotary or vertical shaft kiln to a temperature sufficiently high not merely to drive off the carbon dioxide or the water of combination, but also to form a dense sintered product, resistant to atmospheric moisture and carbon dioxide. Sometimes a small percentage of sintering or bonding agents is added to the charge fed to the rotary kiln. The temperature of dead-burning varies from about 2800° to 3350°F., depending upon the type and purity of the product. The dead-burned magnesite, as discharged from the kilns, ordinarily consists of rounded agglomerates varying in size.

Dead-burned magnesite is shipped in the form of a mixture of hard, inert grains varying in size from about ½ to ⅜ inch in diameter to very fine particles. It is used both for making basic brick (either alone or in mixtures with other materials) and as a monolithic hearth material for furnaces. Finely ground dead-burned magnesite, either alone or with small amounts of added plasticizing and/or bonding agents, serves as a mortar material.

Chrome Ore: An essential raw material used in the manufacture of chrome-containing refractories is generally called "chrome ore." It consists mainly of chrome spinel (chromite) and other spinels. Much of the refractory chrome ore now used in the United States is imported from the Philippine Islands; other sources of supply are South Africa and Turkey.

In ores used as refractories the sum of the chromic oxide and alumina in general is not less than 58 to 60 per cent. Some of the ores of highest quality contain only 31 per cent to 35 per cent chromic oxide (Cr_2O_3), with 28 per cent to 30 per cent alumina (Al_2O_3); other excellent ores contain 42 per cent Cr_2O_3 or more, with correspondingly lower amounts of Al_2O_3. The magnesia (MgO) content of refractory chrome ores varies from about 14 to 20 per cent. Silicate minerals in minor quantities function as a bond.

"Special furnace chrome," used mainly as a mortar, but also as a maintenance material for the banks of open-hearth furnaces, consists essentially of finely ground refractory chrome ore with or without added plasticizers.

Olivine: The mineral olivine is used for the manufacture of refractories consisting essentially of forsterite ($2MgO \cdot SiO_2$). Pure forsterite has the composition 57.3 per cent magnesia, 42.7 per cent silica, and a melting point of 3450°F. (1900°C.). In nature, forsterite rarely occurs alone, but usually contains some fayalite ($2FeO \cdot SiO_2$) in solid solution. Natural mixtures of the two minerals in which forsterite predominates are known as "olivine."

A relatively pure low-iron olivine is used in the manufacture of forsterite refractories. The rock is obtained mainly from the western part of North Carolina; smaller quantities have been obtained from the State of Washington.

Dolomite: Dolomite, or magnesian limestone, is a double carbonate of calcium and magnesium, having the theoretical composition 30.4 per cent lime (CaO), 21.7 per cent magnesia

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(MgO), and 47.9 per cent carbon dioxide (CO_2). Among the largest deposits are those of northwestern Ohio. Deposits of commercial importance occur also in Pennsylvania, West Virginia, Michigan, Missouri, and other states.

For the production of dead-burned or sintered dolomite, the crushed raw material is passed through rotary kilns with the addition of 4 to 12 per cent iron oxide. The temperature in the firing zone of the kilns is about 3000°F.

Dead-burned dolomite is an important refractory in the steel industry. Large quantities are used annually for maintaining the hearths and banks of open-hearth furnaces.

Basic Brick: Basic brick are made of dead-burned magnesite, chrome ore, and their mixtures, and olivine-magnesite mixtures, with and without small additions of other materials. Some magnesite brick are made with a magnesium-aluminate bond. Dead-burned dolomite is used to a small extent in making brick.

The basic brick most widely used contain both dead-burned magnesite and chrome ore. In these "magnesite-chrome" and "chrome-magnesite" refractories the component which predominates is named first.

Basic brick of any of the several classes may be given a ceramic bond by firing, or they may be bonded chemically, with omission of the firing procedure. In service, the portions of chemically-bonded brick exposed to high temperatures lose their chemical bond and develop a ceramic bond through sintering or reaction of adjoining particles.

Chrome brick, made with the addition of little or no magnesia, are generally bonded by firing. Brick of some chrome-magnesite compositions are fired at approximately 3000°F.

Brick consisting mainly of the mineral forsterite ($2MgO \cdot SiO_2$) are available in several modifications. They are made essentially from the mineral olivine with additions of magnesia, or with additions of minerals which combine at high temperatures to form magnesium aluminate spinel. For the most part, they are bonded by firing at high temperatures.

Basic brick of any class, either fired or chemically bonded, may be metal encased by the well-known METALKASE principle, originally developed by Harbison-Walker in 1916. However, most metal-encased brick are made of magnesite-chrome compositions and are chemically bonded. The metal casings, which consist of mild steel, usually cover three or four faces of the brick, but not the ends. Also available are basic brick of various classes, made with either one or two internal steel plates, and enclosed in a steel casing on the four longitudinal sides.

The distinguishing characteristics of basic brick as a group are high bulk density, high melting points, great resistance to chemical attack by basic slags and oxides, relatively high rates of thermal expansion, and high to moderate thermal conductivity. The burned brick have better load-bearing qualities and greater volume stability than brick of similar compositions which are chemically bonded, while in general the latter have better resistance to spalling. However, some burned forsterite-bonded and spinel-bonded magnesite brick have unusually good resistance to thermal shock.

Metal-encased brick generally have superior resistance to spalling. In service, the metal at the exposed end oxidizes and melts, and combines with the magnesia to form a magnesio-ferrite bond. Farther back in the wall the steel remains rigid and reinforces the brickwork.

ACID-PROOF BRICK

Most acid-proof brick and tile are made from dense-burning clays of moderate refractoriness. The essential properties of the brick are low porosity and high resistance to the corrosive action of acids and various other liquids and gases. They must be practically nonabsorbent and impervious to penetration by acids or other corrosive chemicals. Acid-proof brick are used for lining acid tanks, sumps, stacks, acid towers and chemical equipment, for packing acid towers, and for floors in acid and other chemical plants.

FURNACE INSULATING MATERIALS

Insulating firebrick are lightweight, porous refractories having much lower thermal conductivity and heat-storage capacity than other refractories. There are a number of classes or groups graduated as to insulating value and refractoriness. They are classified by the American Society for Testing Materials as Groups 16, 20, 23, 26, and 28. The "Group Number" multiplied by 100 represents the nominal maximum temperature to which the brick may be exposed in service at their hotter faces. Insulating brick which are not included in the A.S.T.M. Classification are also available commercially. Among these are brick with maximum temperature limits of 3000° and 3300°F., and also insulating silica brick.

Insulating firebrick are made of diatomite, expanded vermiculite, perlite, refractory fire clay, kaolin, high-alumina minerals, bubble alumina, quartzite, and other materials. Several methods are used to obtain decreased density in insulating firebrick. The most common one is to add to the brick mix a combustible material such as sawdust, or fine coke which burns out during the firing process. Another common method is to include in the brick mix, materials of low bulk density such as diatomite or expanded forms of vermiculite, perlite, clay, or high-alumina minerals. In the production of some insulating firebrick, foaming agents are used, generally in conjunction with burnout material to achieve the desired pore structure.

Insulating firebrick are formed by pressing, extrusion, or slip-casting and are dried and fired under carefully controlled conditions. The final sizing of many brick is accomplished by cutting with high-speed saws or grinders; other brick are formed to size and require no later cutting.

Insulating firebrick are used most extensively as backing for brick of higher refractoriness and higher thermal conductivity. Almost without exception, insulating firebrick of the various classes may be used also for the inner linings of furnaces, but only when they are not subjected to erosion by molten metal or slag, or to abrasion or corrosion.

The principal advantages in the use of insulating firebrick where they are applicable instead of the heavier fireclay brick are (a) fuel economy through lower heat losses and lower heat-storage capacity of the furnace brickwork, (b) increased production due to shorter heating up time, (c) closer control of operation because of rapid response of the furnace to temperature cycles, (d) decrease in size and weight of furnace binding because of lighter weight of insulating brick, and (e) economy of space, because of thinner walls made practicable by higher insulating efficiency.

There is available a group of insulating castables, supplied in ready-mixed form and re-

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quiring only the addition of water to allow them to be cast into place.

The most common other furnace insulating materials are asbestos, calcined diatomaceous earth, and mineral wool. They are supplied in bulk, as cements, and in block form. In general, these materials have greater insulating value than insulating firebrick, but are less refractory and more fragile. They are used as insulating backing for outside furnace walls.

SPECIAL TYPES OF REFRACTORIES

Refractories such as silicon carbide, zircon, zirconia, carbon and graphite, fused alumina, fused silica, and fused-cast alumina-silica and basic refractories are included in this group since they are used in relatively smaller quantities than other types of commercial refractories.

Silicon Carbide: Silicon carbide is made by the reaction of coke and silica sand in electric resistance furnaces. Among its outstanding properties are superior strength at high temperatures, high thermal conductivity, and low rate of thermal expansion. Silicon carbide is not attacked by most acidic fluxes but is less resistant to molten steel and basic slags. It is extremely hard and therefore highly resistant to abrasion.

Silicon carbide refractories are used in such applications as muffles and retorts, ceramic posts and setter tile, and in boiler furnaces, heat-treating, annealing, and forging furnaces. Silicon carbide is used to best advantage in neutral or reducing atmospheres, as it is subject to oxidation and growth under some conditions in oxidizing atmospheres.

Carbon: Several forms of carbon find application as refractory materials. Carbon in the form of flake graphite is used with a clay bond to make crucibles and ladle stopper heads. Graphite is added to some firebrick and plastic refractory mixes.

Several kinds of coke are used in the manufacture of carbon brick and blocks. Carbon can withstand temperatures above 6000°F. without softening or melting if a reducing atmosphere is maintained; however, it is susceptible to oxidation at industrial furnace temperatures by oxygen, water vapor, or carbon dioxide.

Zircon and Zirconia: Zircon (zirconium silicate) is highly refractory and resistant to thermal shock, siliceous fluxes, and some alkaline dusts and fumes, but is susceptible to attack by iron oxide and by basic slags. Zirconia (zirconium dioxide) is extremely refractory. It is strong, hard, and resistant to chemical attack, particularly by molten silicates.

Fused Grains: Fused alumina, fused magnesia, and fused zirconia are prepared by melting the oxides in electric-arc furnaces. The fused materials are crushed, sized, and fabricated into special blocks and shapes for use where extreme refractoriness, high load-bearing ability, or special properties are required. They are also used in granular form in some mortars and monolith-forming products, including castables and ramming mixes.

Fused-Cast Brick: Fused-cast refractories are produced in alumina, mullite, zirconia-alumina, chrome-alumina, and chrome-magnesia compositions. All except the last named find application in glass-tank furnaces. Some compositions are employed also in applications where the refractories must possess high resistance to abrasion or to corrosion. Fused-cast brick of magnesia and chrome compositions are used successfully in certain vulnerable positions in electric and open-hearth furnaces.

REFRACTORY MORTARS

Refractory mortar materials are of two general classes: heat-setting and air-setting.

Heat-setting mortars have only moderate cold strength. Their ultimate bonding strength is dependent upon a ceramic bond formed at high temperature. Heat-setting mortars include finely ground refractory fire clays, blends of highly refractory bonding and calcined clays, high-alumina mortar materials, silica mortar materials, finely ground dead-burned magnesite, and finely ground chrome ore. Small amounts of plasticizing agents are usually added to increase the workability of mortars made of nonplastic materials. Maximum bonding strength develops usually somewhat above 2200°F.

Air-setting mortars (also called high-temperature cements) consist of finely ground refractory materials with chemical binders added. Some are shipped in dry form and are prepared for use by the addition of water and thorough mixing; others are shipped in plastic form ready for use. On drying, the mortar hardens and develops a strong air-set. Upon firing, the strength of the initial bond decreases, while a strong ceramic bond develops. Among the various air-setting mortars, there is a wide range in composition and refractoriness.

Special mastic materials, which are air-setting mortars of stiff putty-like consistency, are suited for plastering with a trowel. They are used to advantage for various purposes, such as sealing walls of boilers between the tubes and the steel shell, sealing cracks in brickwork, and for pointing and patching brickwork.

MONOLITHIC LINING MATERIALS

Among the refractory materials used for forming monolithic linings are plastic refractories, ramming materials, castables, gunning mixes, and granular materials. In the services for which they are applicable, the use of these materials shortens installation time, eliminates joints, and facilitates repairs.

Plastic Refractories: Plastic refractories are refractory materials prepared in stiffly plastic condition of the proper consistency for use without further preparation. Various grades are supplied commercially, corresponding in composition to high-duty and superduty fireclay brick, high-alumina brick, and chrome brick.

Plastic refractories of the various classes are made from mixtures of raw and calcined refractory clays, of clay and high-alumina materials, of clay or high-alumina materials with added graphite, or from a chrome-base material. Most grades of plastic refractories are supplied in both heat-setting and air-setting forms. For use, plastic refractories are generally rammed into place with a pneumatic hammer to form monolithic furnace linings, but may be pounded into place with a mallet.

Ramming Mixes: Ramming mixes consist essentially of ground and sized refractory materials, with minor amounts of other materials added to make the mixes workable and self-bonding. The base materials of these compositions include silica, refractory fire clay, high-alumina minerals, fused alumina, periclase, dead-burned magnesite, chrome ore, silicon carbide, zircon, and others. Some ramming mixes are shipped wet, ready for use without any additions. In general, however, they are shipped in dry form, and are prepared for use by adding the proper amount of water and mixing. When rammed into place, they harden or set upon drying, or upon drying and heating,

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to form well-bonded, monolithic refractories.

Special ramming mixes of high magnesia content are widely used for making the bottoms of open-hearth and electric steel furnaces to the working contour, and for maintenance of the bottoms, sidewall banks, and tapping holes.

A product which has wide usage both for open-hearth bottoms and particularly for deep-hole patching is made of periclase grains bonded with highly refractory but quick-setting combinations of ferrites and calcium silicates. It is installed dry, and at moderate temperatures becomes dense and hard.

Castables: Refractory castables consist of ground and sized refractory materials in dry form containing bonding agents which provide a strong hydraulic set at room temperatures and a strong ceramic bond at high temperatures. They are classified primarily in accordance with their base materials, which may be refractory clay, high-alumina materials, insulating aggregate, chrome ore, chrome-magnesite mixtures, or silicon carbide. Further classification is based upon service limits, which vary from 2300° to 2800°F. for fireclay castables; 2800° to 3200°F. for high-alumina castables; and 1700° to 3000° F. for insulating castables. There is also a product known as "refractory concrete" intended for service up to 1500°F.

Refractory castables are mixed with water to prepare them for use and are generally cast or poured, frequently with the aid of a vibrator. They may also be troweled, tamped into place with an air hammer, or applied with an air gun.

Gunning Mixes: Various types of refractory materials are being used in large tonnages for installing complete walls and maintaining existing walls by means of pneumatic guns. These materials are furnished in hydraulic-setting, air-setting, and heat-setting classes. Special basic gunning mixes are supplied for maintaining open-hearth and electric furnace walls while fireclay and high-alumina gunning mixes are used in the maintenance of walls and arches in slab-heating furnaces, soaking pits, special heat-treating and boiler furnaces.

Calcined Flint Clay and Kaolin: Calcined clays are supplied both in lump and dobie form and also ground to specifications. Rotary kilns are generally used for calcining.

Calcined clay is used in the manufacture of various refractories, including refractory blocks for the glass industry, retorts and condensers for the zinc industry, saggers for the pottery industry, and plastic firebrick and castables for a variety of applications.

Ground Silica Ganister: This material is prepared by crushing and screening quartzite of high purity. The size most in demand is that which will pass a ⅜-inch screen (including fines). In the steel industry, mixtures of ground ganister and plastic bond clay are used for making monolithic bottoms of acid open-hearth and electric steel furnaces and in ladle linings. In foundry cupolas, these ganister-clay mixtures are commonly used for daily maintenance of the melting zone, and are generally applied by means of an air-placement gun.

FORMING AND FIRING REFRACTORY BRICK

For forming refractory brick, many types of machines are used. These include the power press, hydraulic press, impact and vibrating presses, extrusion machine, repress, and piercing-and-forming press. Nearly all of these, with the exception of most extrusion machines, exert vertical pressure to form the various sizes and shapes of brick.

The several "manufacturing processes" employed for making the brick shapes derive their names in most cases from the methods of forming. The most important of these are the power-press process (frequently called dry press), the extrusion process, and the hand-molding process. Other processes include air-ramming, slip-casting, and fusion-casting. Formerly, practically all refractory brick were made by hand. Present-day machine methods have effected great improvements in quality, uniformity, and workmanship.

Power Pressing: The power press is the machine most commonly used for forming standard brick sizes; it serves also for forming many special shapes. Presses of this type work best with free-flowing mixes of relatively low moisture content. The brick mix is fed into recessed molds, and the compressive force is exerted vertically through the action of toggles in the press mechanism. Many power-pressed brick are formed under a high vacuum which removes much of the entrapped air, and thereby enhances some of the physical properties. General adoption of the power press since the 1920's has revolutionized the manufacture of refractories, and greatly improved the product.

Hydraulic Pressing: In the hydraulic press the force on the material to be molded is applied through a ram actuated by a liquid under pressure. The hydraulic press is capable of exerting greater pressures than the mechanical power press, but operates more slowly.

Impact and Vibrating Presses: In impact and vibrating presses, relatively little pressure is exerted in the forming operation. Instead, rapid impact or vibration causes the particles to flow and to pack into a dense mass. This method of pressing is most successful with relatively non-plastic materials, such as basic, silica, and silicon carbide refractories.

The Extrusion Process: Application of the extrusion process is limited almost exclusively to clay materials of relatively high plasticity. The clays may be premixed wet or dry before being fed to a pug mill, where they are tempered and brought to the proper consistency. The prepared clay is fed to an extrusion machine, which forces a stiff column of the clay through a die of the approximate cross-section of the product desired. The force required in this operation is exerted by a spiral auger turning in a cylinder. Entrapped air is removed from the refractory mass by a deairing system within the machine chamber. The column extruded from the die is dense and strong, and of homogeneous texture. As the column is extruded, it is cut into proper lengths, generally with an automatic cutter. The shapes produced are of four general groups: (1) those which require no further forming, (2) those which are repressed to complete the forming, (3) those which are completely reformed in a vertical piercing-and-forming press known as a runner press, and (4) those which are reformed by manual methods.

Piercing-and-Forming: The piercing-and-forming press is used mainly to produce shapes of intricate pattern, especially those with openings which must be formed by piercing the blank shapes. In operation, the blank from the auger machine is inserted in the mold box of the press. The press mechanism moves the mold box upward against a top die or cap and forces piercing-pins through the blank to form the desired shape.

Air-Ramming: The air-ramming method is often used for forming refractory clay and high-alumina brick shapes which must be made from mixes containing high percentages of calcines. It produces brick of practically the same texture as that obtained from other processes of machine molding. Air-ramming is also

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used for forming various special shapes in basic refractory material.

Hand Molding: In the early days of the refractories industry, most brick were formed by hand molding. For the forming of most standard sizes, hand molding has been superseded by machine molding. Special shapes which are so large or so intricate that they cannot be formed by machine methods are still molded by hand. Less difficult shapes also are formed by hand when the number of brick required is not sufficient to justify the cost of steel press-outfits and accessories (die liners and pads, liner-holders, filler blocks, and plungers).

Slip-Casting: Some refractory shapes, especially if large and heavy, are made by slip-casting. The ground refractory materials are formed into a thin slip or slurry with water and an electrolyte, which increases the fluidity. By this method, clay suspensions of relatively low water content are made very fluid. To form the shapes, the slip is poured into a porous plaster mold, which absorbs most of the water. Drying of the shapes is completed after stripping off the molds.

Fusion-Casting: In this method of forming refractory shapes and blocks, finely pulverized refractory raw materials are carefully blended, melted in an electric-arc furnace, and cast into a mold. The molds are usually constructed of machined graphite; some are also made of highly refractory granular materials bonded with resin. The castings are annealed before cooling to atmospheric temperatures.

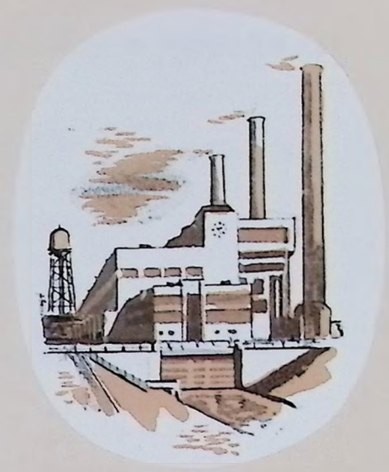
Firing: After drying, all refractory brick, except those which are bonded chemically or fused-cast, are fired to effect desirable chemical and physical changes, drive off volatile components, stabilize the volume, and develop a ceramic bond, which binds the material strongly together.

During the firing, the ware is heated and cooled down in accordance with predetermined burning schedules. For most types of refractories there are critical temperature ranges through which the temperatures must be carefully controlled. Extremely high temperatures are required for some products and the peak temperatures in some kilns are above 3100°F.

For firing refractories, both tunnel kilns and periodic kilns are used. In continuous tunnel kiln firing, the brick set on cars pass through the kiln, going successively through preheating, firing, and cooling zones. A definite temperature is maintained in each section at all times, and there is a continuous flow of ware through the kiln. Tunnel kilns vary considerably in area of cross-section, length, and details of design. They range in length from less than 200 feet to 600 feet and in width from 3 to 8 feet.

Prior to the introduction of continuous tunnel kilns, all refractories were fired in rectangular or circular periodic kilns, operating on an intermittent basis. Periodic kilns are still important in the industry, especially in smaller plants, and in plants making a variety of products, requiring different firing conditions. Even in plants designed primarily for tunnel kiln operation, it is not unusual to operate some periodic kilns for flexibility in production. The kilns are first loaded with green ware, closed, fired, and then allowed to cool, after which the fired product is withdrawn.

Coal, oil, and natural gas are the fuels used in burning refractory products. Of these, natural gas and fuel oil are preferred for firing tunnel kilns, although producer gas is still used to some extent. Gas-firing, with oil as a stand-by for emergencies, is a common arrangement.



FIRECLAY REFRACTORIES

HARBISON-WALKER REFRACTORIES COMPANY

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HARBISON-WALKER BRANDS OF FIRECLAY BRICK

SUPERDUTY FIRECLAY BRICK

Brand	Where Made	See Page
H-W Kala	Alabama	55
Zenith	California	58
Boone	Kentucky	61
Boone Bung	Kentucky	61
Kenmore	Kentucky	61
H-W Super Savage	Maryland	64
H-W Super Savage Bung	Maryland	64
Alamo	Missouri	66
Alamo Bung	Missouri	66
Alamo S	Missouri	66
Varnon	Missouri	66
Varnon BF	Missouri	68
Varnon S	Missouri	66
Varnon D	Missouri	66, 68
Dean	Pennsylvania	73
Dean S	Pennsylvania	73
Dean Bung	Pennsylvania	73

HIGH-DUTY FIRECLAY BRICK

Brand	Where Made	See Page
H-W Crown	Alabama	56
H-W Crown XB	Alabama	56
H-W	Alabama	56
Wylam A	Alabama	56
H-W Ala BF	Alabama	57
H-W 18 Ala	Alabama	57
Western	California	58
Western T	California	59
Western OHC	California	59
Royal Gorge	Colorado	60
H-W High Grade XX	Kentucky	62
H-W High Grade S	Kentucky	62
H-W High Grade T	Kentucky	62
H-W	Kentucky	62
H-W OHC	Kentucky	62
H-W Stove	Kentucky	62
H-W Ky BF	Kentucky	62
H-W 18 Ky	Kentucky	62
H-W Savage	Maryland	64
Walsh XX	Missouri	67
Walsh S	Missouri	67
Walsh T	Missouri	67
H-W	Missouri	68
H-W Mo BF	Missouri	68
H-W 18 Mo	Missouri	68
Franklin Crown	Ohio	70
H-W	Ohio	70
H-W OHC	Ohio	70
H-W Stove	Ohio	70
Benezet	Pennsylvania	73
Benezet OHC	Pennsylvania	73
H & B Woodland	Pennsylvania	73
H-W Special	Pennsylvania	73
H-W Stove	Pennsylvania	73
H-W	Pennsylvania	74
Woodland	Pennsylvania	74
Woodland X	Pennsylvania	74
Benezet BF	Pennsylvania	75
H-W 18 Pa	Pennsylvania	75
Coleman XX	Texas	77

HARBISON-WALKER BRANDS OF FIRECLAY BRICK

SEMI-SILICA FIRECLAY BRICK

Brand	Where Made	See Page
Kaosil	Pennsylvania	74

MEDIUM-DUTY FIRECLAY BRICK

Brand	Where Made	See Page
XX Southern	Alabama	56
Amador	California	59
Salamander	Missouri	68
Webster	Ohio	71
Widemire	Pennsylvania	75
Coleman	Texas	77

LOW-DUTY FIRECLAY BRICK

Brand	Where Made	See Page
Wylam	Alabama	57
Temple	Ohio	71
Temple	Pennsylvania	75

SPECIAL ABRASION-RESISTANT FIRECLAY BRICK

Brand	Where Made	See Page
Wylam A	Alabama	56
Duro Dot	Pennsylvania	75

BLAST-FURNACE BRICK

Brand	Where Made	See Page
H-W Ala BF	Alabama	57
H-W 18 Ala	Alabama	57
H-W Ky BF	Kentucky	62
H-W 18 Ky	Kentucky	62
Varnon BF	Missouri	68
Varnon B	Missouri	68
Varnon D	Missouri	66, 68
H-W Mo BF	Missouri	68
H-W 18 Mo	Missouri	68
Benezet BF	Pennsylvania	75
H-W 18 Pa	Pennsylvania	75

POURING-PIT REFRACTORIES

Brand	Where Made	See Page
H-W	Ohio	71
H-W	Pennsylvania	75

MORTAR MATERIALS

For every brand of brick there are H-W mortar materials of proved quality for laying. They are described on pages 138 to 146.

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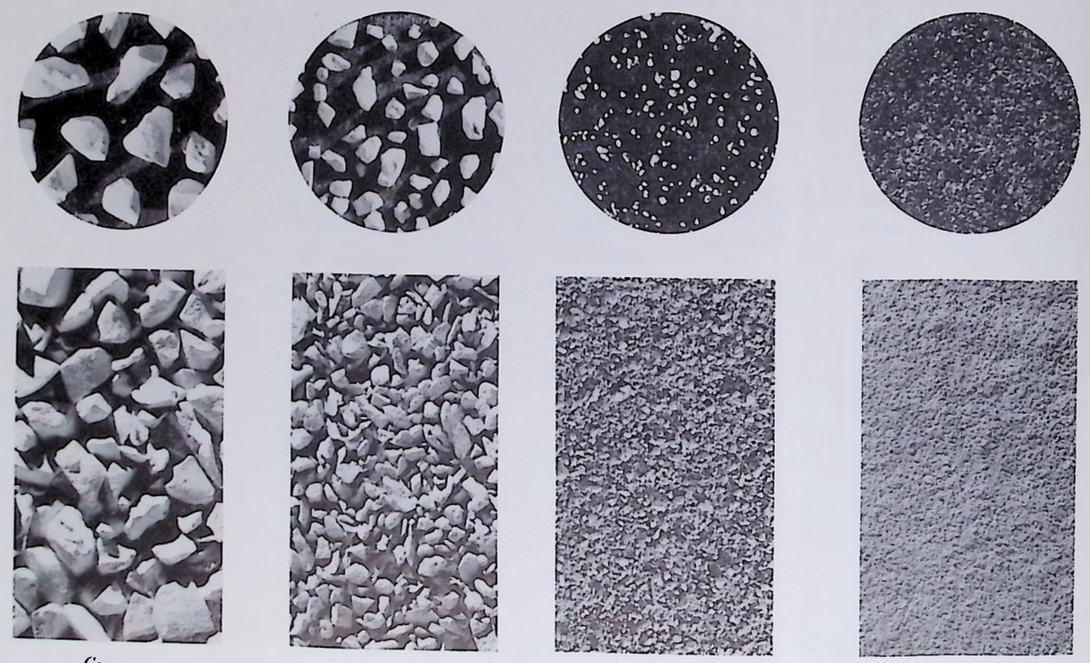
FIRECLAY REFRACTORIES

The plants at which Harbison-Walker Refractories Company manufactures fireclay brick are situated in Alabama, California, Colorado, Kentucky, Maryland, Missouri, Ohio, Pennsylvania, and Texas. The clays used include a wide variety of refractory flint, semi-flint, and plastic bond clays, and refractory kaolins. Subsidiary and affiliated companies also produce fireclay refractories in British Columbia, Mexico, and South America.

Clay Deposits: In all districts in which the company manufactures fireclay refractories, Harbison-Walker has extensive reserves of clays adapted to the manufacture of fireclay brick of the various classes. Blending of these clays in different proportions, and variations in the methods of processing make possible the production of brick having a wide range in properties, and in their utility for many different service requirements.

Proportioning: Most fireclay brick are made from blends of two or more clays; some brick, especially those of the low-duty class, are made of a single clay. The mixes for superduty and high-duty brick commonly contain raw flint and bond clays, with or without calcined clay. In making brick of kaolin and various other clays, a large proportion of the mix is precalcined to control the firing shrinkage, and to stabilize the volume and mineral composition of the product.

Grain Sizing: In making fireclay brick, it is necessary for the particles of ground clay to include a range of graded sizes, each in proper proportion. As illustrated below, these sizings vary from coarse, through coarse and fine intermediates, to extremely fine particles.



Coarse *Intermediates* *Fines*

A ground flint clay separated into its component sizes by screening.

Forming: The various sizes and shapes of brick are made by three principal methods, known as the power-press, the extrusion, and the hand-made processes. Certain shapes are formed by air-ramming, others by the impact process.

Most Harbison-Walker fireclay brick of the standard sizes and many special shapes are made by the power-press process. The clays are ground in a "dry pan," which is a rotating pan-shaped grinding mill, having slotted openings in the bottom. The batches are screened to the desired sizes, and thoroughly mixed with a small but definitely controlled amount of water. The moistened batch is then fed to a mechanically operated press in which the brick are formed under high pressure. One of the outstanding advances in the refractories art has been the development of the power-press process to its present state of perfection, with resultant improvement in the resistance of the brick to spalling, slag penetration and pressure.

In a modification of the power-press process, certain physical properties are enhanced by the application of a high vacuum during the forming of the brick. While blends of certain clays of optimum particle sizing are not benefited by vacuum pressing, many brick made in this way have a more homogeneous texture, and are harder, stronger, less porous, and denser than those made without vacuum. As a consequence they are more resistant to impregnation and corrosion by slags and to penetration by gases. For these reasons the vacuum method of manufacture is of particular value in the production of fireclay refractories for use in blast-furnace linings, in regenerator checkers, and in many other applications.

The extrusion process is used for making both standard sizes and special shapes. In making brick of the extruded type, the clays are ground in a dry pan, mixed wet or dry in a mixer, brought to the proper consistency in a pug mill, and extruded through the die of an auger machine in the form of a stiff column. The air is removed from the clay before extrusion by a deairing system within the auger machine chamber. The column is cut by means of wires into brick, which are usually repressed to give them sharp corners and edges and smooth surfaces. Most extruded brick are of high density. Many intricate special shapes are formed in vertical piercing-and-forming presses, in which blanks from the extrusion machine are completely reshaped.

Shapes which must be made from mixes containing high percentages of calcined clays, and other shapes which do not lend themselves to power pressing or extrusion, are sometimes formed by the impact method of power pressing, or by the air-ramming process. Very large or difficult special shapes may be molded by hand or air-ramming. Generally small lots of less difficult shapes are also formed by hand. The clays are ground and blended in proper proportion in a wet pan with sufficient water to give the most desirable consistency.

Shape molding requires a high degree of skill and experience on the part of the molders. The high quality and excellent workmanship of special shapes made by Harbison-Walker, both by machine and by hand, are well known throughout the industries.

Drying and Firing: The brick formed by any of the processes described above are dried either on hot floors or in tunnel or humidity driers, and fired in continuous car-type tunnel kilns, or in periodic downdraft kilns. The temperature of firing depends upon the maturing temperature of the clays, and often upon the service for which the brick are intended. In firing the brick, several necessary ends are accomplished. Free and combined water are driven

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Loading Fireclay Brick on Pallets for Shipment.

off. Iron and sulfur compounds and organic matter are oxidized, and the gases formed are eliminated. Mineral transformations and changes in volume are effected, and finally, the particles of clay are ceramically bonded together into mechanically strong brick.

Classification: In accordance with the A.S.T.M. standards, there are five general classes of fireclay brick, known as superduty, high-duty, semi-silica, medium-duty, and low-duty. Some special-service fireclay refractories are not included in this classification.

SUPERDUTY FIRECLAY BRICK

MINIMUM P.C.E. 33

The outstanding properties of superduty fireclay brick are high refractoriness, alumina content of 40 to 44 per cent, unusual strength and negligible shrinkage at high temperatures, low porosity, high temperature of vitrification, and resistance to spalling.

The superior properties of Harbison-Walker superduty brick result from the high quality and purity of the clays used, and from the technique followed in their manufacture. By scientific sizing of the grains, a texture is obtained which is relatively coarse, yet dense and highly impervious, and which imparts to the brick high resistance to thermal shock over the entire range of furnace operating temperatures. Because of their relatively high content of alumina and low percentage of basic oxides, Harbison-Walker superduty fireclay brick are highly resistant to the chemical action of various fluxes. By special manufacturing techniques, brand modifications are produced which are especially resistant to corrosion, frequently with somewhat less resistance to spalling.

For use as checkers, the high resistance of Harbison-Walker superduty fireclay brick to the destructive action of gases and fluxes is especially important. They are particularly suitable for use in malleable furnace bungs, where their ability to withstand high temperatures, rapid temperature changes, and the pressure to which they are subjected in the bung frames is excellent. Several other important applications are rotary kiln linings, roofs of electric steelmelting furnaces, and soaking pits.

HIGH-DUTY FIRECLAY BRICK

MINIMUM P.C.E. 31½

Before the introduction of superduty fireclay brick, those now classified as high-duty brick had to meet all the demands of industry for fireclay refractories for service under severe operating conditions. This they did with marked success. As furnace conditions in many industries became increasingly severe, a field developed which could be served adequately only by products of even higher quality. In their own field, however, high-duty fireclay brick still are used most economically, and some hundreds of millions annually continue to be used.

The use of high-duty brick within the temperature range for which medium- and low-duty brick are amply refractory is often an economy, since temperature of furnace operation is not the only factor which affects the life of the refractories. High-duty brick are more resistant to spalling influences than are fireclay products of lower refractoriness; and unlike medium- or low-duty brick they may be burned hard enough when desired to render them very resistant to disintegration by carbon monoxide gas. When costs of transportation and of handling and laying are considered, it is evident that structures built of high-duty brick cost little more than those built of less refractory materials.

SEMI-SILICA FIRECLAY BRICK

MINIMUM SILICA CONTENT 72 PER CENT

Among Harbison-Walker products are fireclay brick of the semi-silica class, containing approximately 75 per cent silica, with an extremely low content of basic oxides. The brand name is KAOSIL. Superior properties of KAOSIL are high temperature of incipient vitrification, stability of volume and rigidity under load at high temperatures, and excellent resistance to thermal shock. When exposed to alkaline fumes or dusts at moderately high temperatures KAOSIL brick acquire a surface glaze which retards absorption of the fluxes and protects them against corrosion. Up to their temperature limit, they expand slightly.

MEDIUM- AND LOW-DUTY FIRECLAY BRICK

MINIMUM P.C.E. OF MEDIUM-DUTY BRICK 29; OF LOW-DUTY BRICK 15

In some parts of many industrial furnaces, the refractory structure is subjected to temperatures which are relatively moderate or low. For such conditions, brick of the medium-duty or even of the low-duty class may give excellent service. In the low-temperature range, some of

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these brick are stronger and more resistant to abrasion than many high-duty brick.

Medium- and low-duty brick in general are dense, mechanically strong, tough, and resistant to abrasion and to slag action at moderate temperatures. For service in which temperatures fluctuate rapidly, power-pressed brick are to be preferred to those made by the extrusion process. Medium- and low-duty brick show little permanent change in volume when heated within the temperature ranges for which they are suited.

Harbison-Walker manufactures medium- and low-duty fireclay brick by the power-press and extrusion processes. Equal care in workmanship and maintenance of quality is exercised as in the making of more refractory products. The standard sizes are the same, hence in construction Harbison-Walker medium- or low-duty brick nicely lend themselves to use as backing for brick of higher refractoriness in the same furnace walls.

Among the applications for medium- and low-duty fireclay brick are included complete linings for furnaces or stacks where the temperatures are moderate or low; back-up linings for various types of furnaces; ash pit and ash hopper linings in boiler service; electrolytic cells in the chemical industry; patching in iron cupolas; the cold zones of tunnel kilns in the ceramic industry; and the housing of feed ends of rotary kilns.

MORTAR MATERIALS

It is important that fireclay brick be laid with mortar material of proper quality. For high-duty fireclay brick, this may be either a heat-setting mortar, such as H-W High-Duty Fire Clay, H-W Weathered Bond B Clay, or H-W Special Mortar, or it may be an air-setting high-temperature bonding mortar, such as Harwaco Bond, Penseal, Firebond, or Thermolith, as governed by service requirements.

Harbison-Walker superduty fireclay brick are usually laid with Harwaco Bond. For conditions requiring a heat-setting bonding mortar, H-W Superduty Mortar, H-W Special Mortar, H-W Sillimanite Bonding Mortar, or Ankorite 65 may be used, depending upon the service. For service in which an air-setting bonding mortar with a chrome base is desired, Thermolith is recommended.

STOCKS

At all Harbison-Walker plants where fireclay refractories are made, ample stocks are maintained of standard 9-inch straight brick and the corresponding series of sizes, as well as of other standard sizes and modified shapes for which there is a continuing demand for substantial quantities. The stocks also include the sizes normally required for the linings of boiler furnaces, cupolas, malleable iron furnaces, rotary lime and cement kilns, shaft lime kilns, ceramic kilns, and many other furnaces.

An adequate stock of suspended-arch tile and of rectangular checker brick facilitates prompt shipment. At the company's plants where blast-furnace refractories are manufactured, an endeavor is made to keep in stock complete furnace linings as well as refractories for the walls and domes of stoves. Shipments can be made of either straight or mixed carloads of all brands manufactured at any one plant.

BRANDS MADE IN ALABAMA

CLASS	BRAND	PROCESS*	TYPICAL SERVICE
Superduty	H-W Kala	P.P., H.M.	General superduty service; blast-furnace stoves; rotary kiln linings.
High-Duty	H-W Crown	P.P., Ext., I.P., H.M.	General high-duty service; blast-furnace stoves; rotary kiln linings.
	H-W Crown XB	P.P.	For high-duty service where resistance to pressure is important.
	H-W	P.P., H.M.	General high-duty service; open-hearth checkers.
High-Duty Abrasion-Resistant	Wylam A	P.P.	Abrasion resistant; intermediate and cold zones of shaft and rotary limestone kilns; chain sections of rotary kilns.
Medium-Duty	XX Southern	P.P.	Medium-duty service; backing for high-duty brick; stack linings.
Low-Duty	Wylam	P.P., Ext.	Used as backing for high-duty brick, as stack linings and for general low-duty service.
		BLAST-FURNACE BRICK	
High-Duty	H-W Ala BF	P.P.	Complete blast-furnace linings.
	H-W 18 Ala	P.P.	Complete blast-furnace linings.

** P.P. = Power Pressed Ext. = Extruded I.P. = Impact Pressed H.M. = Hand Molded*

Early in the present century, Harbison-Walker built a plant at Fairfield for the manufacture of fireclay and silica refractories. In more recent years a second works was built at Bessemer for the production of fireclay brick and the Fairfield Works was devoted to the manufacture of silica refractories only. Since World War II, both plants have been greatly enlarged and kept completely modernized, and are provided with the most modern and efficient manufacturing equipment, tunnel kilns and periodic kilns for highest quality production.

The raw material used at the Bessemer Works consists mainly of southern clays and kaolins. Because of the shrinkage characteristics of kaolin in drying and firing, it is rendered volume-stable before manufacture into brick, by calcination at very high temperatures.

Harbison-Walker manufactures in Alabama a complete line of aluminous fireclay refractories, including brick of all the various classes —superduty, high-duty, medium-duty, and low-duty—together with the only blast-furnace brick made in the South.

FOR SUPERDUTY SERVICE

H-W Kala brick are made entirely from southern clay and kaolin of the highest quality, and correspond in properties to the best of the superduty brick made in other manufacturing districts. Their density, high refractoriness (P.C.E. 33-34), volume stability, rigidity under load, and excellent resistance to spalling, all attest to the excellence of this product.

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FOR HIGH-DUTY SERVICE

H-W CROWN is a high-duty fireclay brick of exceptional merit. Its major constituent is highly refractory kaolin. The notable advance in preparation of the clays by high-temperature calcination in a rotary kiln has contributed greatly to the outstanding properties of H-W CROWN. The brick are formed mainly by the power press and by deaired extrusion.

The workmanship of H-W CROWN is equal to the best in the industry. Its desirable physical properties include excellent mechanical strength, stability of volume at high temperatures, and good resistance to thermal shock.

H-W CROWN brick are well adapted for service for which high-duty fireclay brick are required, as for example in boiler settings, glass-plant furnaces, rotary kiln linings, the checkers and sidewalls of blast-furnace stoves, and in many other metallurgical furnaces.

H-W CROWN XB is a high-duty fireclay brick made of essentially the same raw materials as H-W CROWN. By special high-temperature firing, the mineral composition is further stabilized, and some of the physical properties are substantially improved. Among the desirable properties of H-W CROWN XB are increased stability of volume, resistance to disintegration by carbon monoxide and other reducing gases, and superior resistance to pressure at high temperatures. It is designed especially for service under conditions of soaking heat.

H-W brand is a high-duty fireclay brick used mainly for the manufacture of special shapes and to a lesser extent of standard sizes. The mix is especially adapted to the hand molding of special shapes which are so large or intricate that they cannot be formed by machine methods. The brick are used both for checkers of open-hearth regenerators and for general high-duty service.

FOR HIGHEST RESISTANCE TO ABRASION

WYLAM A is a high-duty fireclay brick used for the linings of furnaces in which the brick are subjected to severe abrasion and impact. It renders outstanding service in the chain sections of rotary lime sludge kilns and rotary cement kilns, and in the feed ends of rotary lime and dolomite kilns. In shaft kilns for burning limestone, WYLAM A is used for lining the top sections. Another important application of WYLAM A is in coolers of rotary and other types. WYLAM A is also recommended for use in coke wharfs.

FOR MEDIUM-DUTY SERVICE

XX SOUTHERN is a medium-duty fireclay brick manufactured by the power-press process. It fills a need for brick of this class in the area served by the company's Alabama Works. XX SOUTHERN gives excellent service under furnace conditions not sufficiently severe to require brick of the high-duty class. It may be used to advantage in the upper portions of cupola linings, in flue linings, in boiler furnaces where the operating temperatures are only moderate, in stack linings, and as a backup for high-duty fireclay brick. XX SOUTHERN is supplied in standard sizes and other sizes which can be formed in the power press.

FOR LOW-DUTY SERVICE

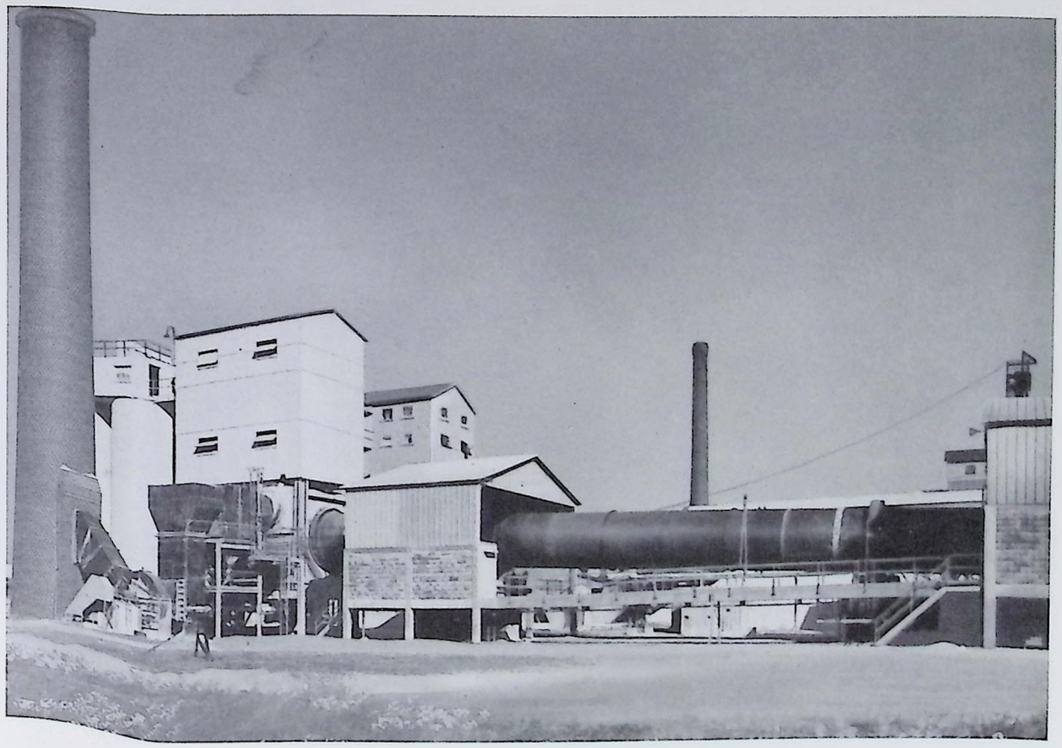
WYLAM fireclay brick are made from a blend of low-duty refractory clays with a proportion of precalcined material. They are formed by both the deaired extrusion process and the power-press process. WYLAM brick have a P.C.E. of Cone 26-27, corresponding to a softening temperature of 2965°F. Their porosity is low, and they are strong, dense, and uniform in size.

WYLAM brick are used for backing-up courses in boiler settings, for stack linings and for various other uses where low-duty brick may be employed to advantage. They serve with special benefit where resistance to abrasion and impact is necessary for good service.

FOR BLAST-FURNACE SERVICE

H-W ALA BF—of high-duty fireclay quality—was first produced in 1954 as the only blast-furnace brick made in the South. While low in impurities, it is dense and strong, and resistant to abrasion. Among its properties are excellent resistance to thermal shock, low subsidence under load at high temperatures, and exceptional resistance to the effects of carbon monoxide for a brick of its class. It is used in a number of blast furnaces in the southern part of the United States and overseas.

H-W 18 ALA is the same in composition as H-W ALA BF, but has the superior properties associated with a higher firing temperature.



Rotary Kiln Plant for Calcination of Kaolin at Bessemer Works, Alabama.

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BRANDS MADE IN CALIFORNIA

CLASS	BRAND	PROCESS*	TYPICAL SERVICE
Superduty	ZENITH	P.P.	General superduty service; boiler settings; heating furnaces.
High-Duty	WESTERN	P.P.	General high-duty service, especially where resistance to spalling is important.
	WESTERN T	Ext.	High-duty service, especially where resistance to abrasion or slag attack is important.
	WESTERN OHC	P.P.	Open-hearth and other regenerator checkers.
Medium-Duty	AMADOR	P.P.	General medium-duty service; backing for high-duty brick; stack linings.

* *P.P. = Power Pressed.* *Ext. = Extruded.*

Included in Harbison-Walker's mineral reserves are large deposits of high-quality fire clay near Ione, California. The company's plant at Ione produces superduty, high-duty, and medium-duty fireclay refractories. It is equipped for the manufacture of brick by both the power-press and the extrusion processes. The brick are fired in a modern continuous tunnel kiln and in periodic kilns.

The Ione clays are high in refractoriness and purity. They are mined by the open-pit method, which permits testing for control of blending long before the clays are taken from the ground. The first step in processing the clay consists of calcination at a high temperature in a rotary kiln, to stabilize its volume and to assure the manufacture of brick having close uniformity of size, and superior workmanship.

FOR SUPERDUTY SERVICE

ZENITH brand of superduty fireclay brick is made from superior California clays of high purity and refractoriness. Its P.C.E. value is 33-34 to 34, corresponding to a cone-softening temperature of nearly 3200°F. It has excellent resistance to thermal shock.

ZENITH brick are giving splendid service in boiler furnaces, under extremely severe operating conditions. They are used with economy in electric furnace roofs, billet- and slab-heating furnaces, aluminum reverberatory furnaces, glass tanks, carbon electrode baking furnaces, metallurgical furnaces, and furnaces used in the heavy minerals industries. Another service application is in the boiler furnaces of naval vessels, where avoidance of interruptions caused by failure of the refractories is of paramount importance.

FOR HIGH-DUTY SERVICE

WESTERN brand, a high-duty refractory, is made from a blend of select clays mined and processed under the direct supervision of Harbison-Walker's quality control personnel to produce a refractory of properly balanced properties. It is manufactured by the power-press process, assuring accuracy of size and uniformity of texture. WESTERN brick are outstanding in quality among high-duty fireclay refractories. For brick of this class, they excel in resistance to spalling.

Typical applications of WESTERN brand include lumber mill boiler furnaces, reheat furnaces, forge furnaces, oil heaters and similar furnaces in the oil refining industry, portland cement and lime kilns, gypsum kettles, ceramic kilns, and many other important furnaces typically used in West Coast industry.

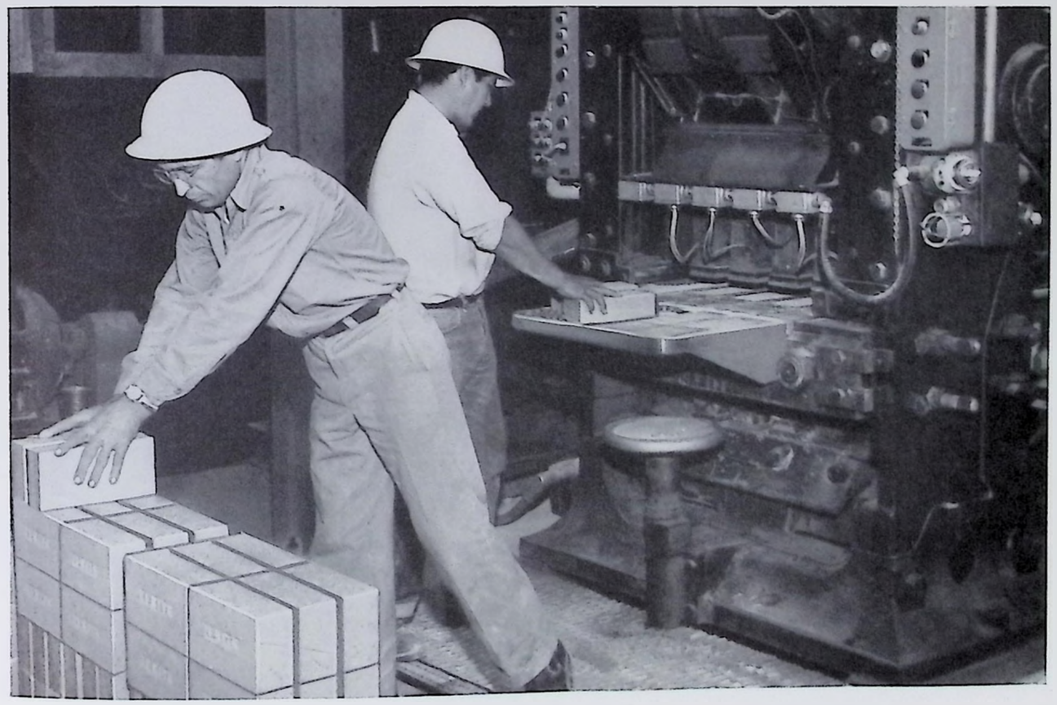
WESTERN T brick, manufactured by the extrusion process, are dense and strong, and have high resistance to abrasion and to penetration and corrosion by various industrial slags. They are used with marked success in the vertical lime kilns of the beet sugar industry. They have proved their superiority in foundry operations such as in cupolas, desulfurizing ladles, and pouring ladles of all sizes. They are also used with excellent results in regenerator checkers of open-hearth furnaces and glass-tank furnaces.

WESTERN OHC brick, made by the power-press process, are dense and strong. Their main application is in the regenerator checker settings of open-hearth and other furnaces.

FOR MEDIUM-DUTY SERVICE

AMADOR brick, made by the power-press method, are excellent refractories for use under conditions of moderate severity. In uniformity of size, AMADOR brick are excellent.

AMADOR brick give good service in such typical installations as annealing ovens, bake ovens, galvanizing pots, chimneys, and incinerators of various designs, and as backing.



Power Pressing Fireclay Brick at Ione Works, California.

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BRAND MADE IN COLORADO

CLASS	BRAND	PROCESS*	TYPICAL SERVICE
High-Duty	Royal Gorge	P.P., Ext., H.M.	General high-duty service.

** P.P. = Power Pressed Ext. = Extruded H.M. = Hand Molded*

Within recent years, Harbison-Walker has acquired substantial reserves of high-quality flint and bond clays in central Colorado, the only area between Missouri and the Pacific Coast in which commercial deposits of high-grade flint clay have been found. The high degree of purity of these clays accounts for the good balance of physical properties of the Royal Gorge brick. From the plant at Canon City, superior fireclay refractories are supplied to the industries of Colorado, the entire Rocky Mountain area, and the Southwest.

ROYAL GORGE brand of high-duty fireclay brick is made mainly by the power-press process from clays having a relatively low content of alkalies and other basic oxides. It has a P.C.E. of 32, exceptional stability of volume at high temperatures, excellent load-bearing characteristics, and good resistance to spalling. In service at high temperatures, the brick acquire a surface glaze, which protects them against corrosion and penetration by fluxes.

Royal Gorge brick give excellent service in the linings of boiler furnaces, blast-furnace stoves, various metallurgical furnaces, ceramic, lime, and cement kilns, roasters, and in furnaces used in oil refineries, petrochemical plants, and other industrial operations.



Sleeve Brick on Drying Floor Before Firing, at Canon City Plant, Colorado.

BRANDS MADE IN KENTUCKY

CLASS	BRAND	PROCESS*	TYPICAL SERVICE
Superduty	Boone	V.P., Ext., H.M.	General superduty service.
	Boone Bung	P.P.	Malleable and air furnace roof bungs.
	Kenmore	V.P., Ext., H.M.	For severe superduty services; glass-tank furnaces and open-hearth checkers.
High-Duty	H-W High Grade XX	V.P., Ext., H.M.	General high-duty service.
	H-W High Grade S	V.P.	Cupola linings, malleable furnace sidewalls and other similar service.
	H-W High Grade T	Ext.	General high-duty service, where low porosity or high resistance to erosion and abrasion is required.
	H-W	P.P., V.P., Ext., H.M.	General high-duty service; stove checkers.
	H-W OHC	V.P.	Open-hearth, glass furnace, and other regenerator checkers.
	H-W Stove	P.P., Ext., H.M.	Blast-furnace stove linings and checkers.
	BLAST-FURNACE BRICK		
High-Duty	H-W Ky BF	V.P.	Complete blast-furnace linings, including hearths.
	H-W 18 Ky	V.P.	Complete blast-furnace linings, including hearths.

** P.P. = Power Pressed V.P. = Vacuum Power Pressed Ext. = Extruded H.M. = Hand Molded*

For more than two generations, the products of Harbison-Walker's Olive Hill, Kentucky Works have met the highest standards of quality for refractories of fireclay material. The plant has been kept completely modernized, and includes both a continuous tunnel kiln for standard firing schedules, and several periodic kilns for special conditions of firing. A well-equipped control laboratory is operated for the maintenance of highest standards of quality.

FOR SUPERDUTY SERVICE

BOONE brick are dense and highly resistant to penetration by corrosive slags and destructive gases. As compared with high-duty fireclay brick, they have the advantages of higher refractoriness, lower porosity, greater constancy of volume and greater rigidity under load at high temperatures, and greater resistance to thermal spalling. They are adapted to service in which they are subjected to pressure, to high temperatures, or to corrosion and erosion by fuel ash and various furnace slags and fumes.

BOONE BUNG brick have the high refractoriness and resistance to spalling necessary for successfully withstanding the extremely severe service to which they are subjected in malleable furnace (air furnace) bungs.

KENMORE brick are made from the same clays as those used in making Boone brick and by the same process of molding. However, Ken-

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MORE brick are given an exceptionally hard burn which stabilizes the mineral structure, and imparts greater strength and rigidity under load at high temperatures. KENMORE has exceptionally good load-bearing capacity.

BOONE and KENMORE in service show superiority over high-duty fireclay refractories in applications where highly refractory dense brick of low spalling tendency are required, such as the bottoms of malleable iron furnaces, and the checkers of blast-furnace stoves, open-hearth furnaces, and glass furnace regenerators.

FOR HIGH-DUTY SERVICE

H-W HIGH GRADE XX brick embody a combination of high refractoriness, low porosity, low permeability, and superior resistance to spalling. They serve in many and varied applications. H-W HIGH GRADE XX is one of the best established brands in the glass industry for use in checkers, regenerator chambers and ports. Included among its many applications are linings for boiler furnaces, metallurgical furnaces, heating and annealing furnaces, incinerators, and ceramic kilns.

H-W HIGH GRADE S brick possess the desirable properties of high refractoriness and resistance to thermal spalling. They are exceptionally dense and are therefore more resistant to attack by slags than some other fireclay brick of equally high refractoriness. H-W HIGH GRADE S is a superior brick for furnace sidewall service, particularly in malleable iron furnaces.

H-W HIGH GRADE T brick, made by the extrusion process, find application in general high-duty service where high density and high resistance to abrasion and erosion are required. They are used for the linings of cupolas, for the sidewalls and bottoms of nonferrous metallurgical furnaces, for the sidewalls of silicate of soda furnaces, and for other important needs.

H-W brand is a high-duty fireclay brick, especially adapted to the manufacture of large and difficult shapes, but is made also to a smaller extent in standard sizes. These brick are used for linings and checkers of blast-furnace stoves, cupola linings, and general high-duty service.

H-W OHC brick are made in both Kentucky and Ohio. While developed specifically for open-hearth checker service, they are used in other regenerator service as well. They are manufactured by the vacuum power-press process, and possess to an unusually high degree the physical properties of high density, low porosity, and excellent load-bearing capacity.

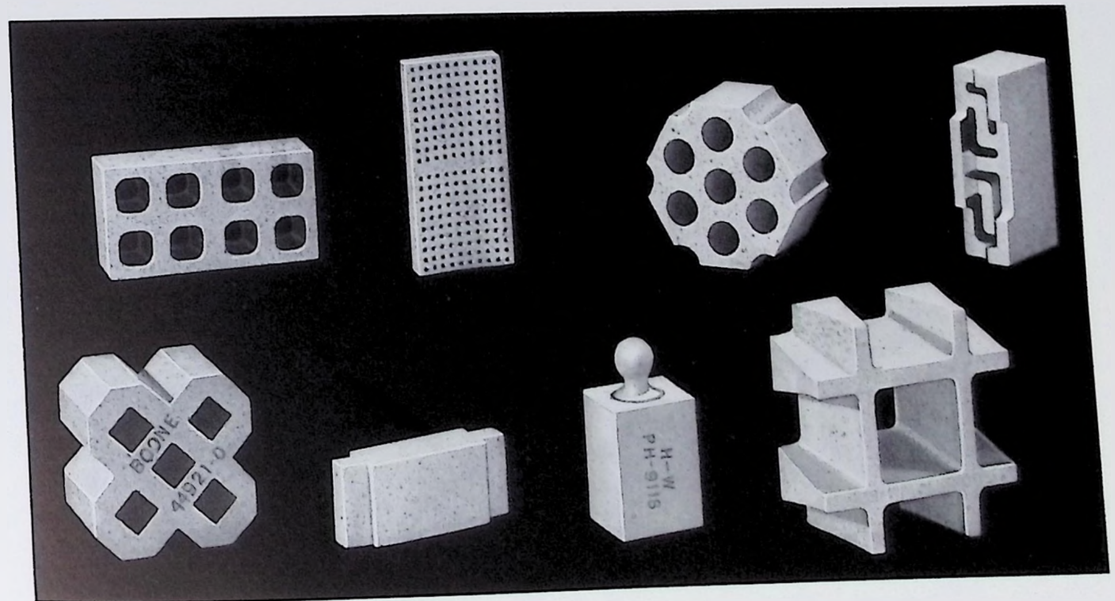
H-W STOVE brick have properties which fit them especially for service in the walls and checkers of blast-furnace stoves. They are dense and strong, volume-stable, and resistant to deformation by pressure at high temperature.

FOR BLAST-FURNACE SERVICE

Since early in the present century, Harbison-Walker has specialized in the manufacture of blast-furnace refractories at its Kentucky Works. During this period H-W KY BF linings have established many records and the scores of such linings now in service testify to the high reputation which they have throughout the industry. H-W 18 KY is similar in composition to H-W KY BF, but its volume and mineral constitution have been further stabilized, and its resistance to carbon disintegration has been enhanced, by a higher temperature of firing.



Tunnel Kiln With Kiln Cars at Olive Hill Works, Kentucky.



Typical Special Shapes Made at Olive Hill Works, Kentucky.

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BRANDS MADE IN MARYLAND

CLASS	BRAND	PROCESS*	TYPICAL SERVICE
Superduty	H-W Super Savage	P.P., Ext.	General superduty service; blast-furnace stoves; malleable furnace bottoms.
	H-W Super Savage Bung	P.P.	Malleable and air furnace roofs.
High-Duty	H-W Savage	P.P., Ext.	General high-duty service.

** P.P. = Power Pressed Ext. = Extruded*

Harbison-Walker's brands of Maryland superduty and high-duty fireclay brick were developed following the discovery of a large deposit of flint and bond clays having exceptional characteristics. The added margin of quality of these brands results from superior clays, the most modern manufacturing methods, and rigid laboratory control. The company's New Savage Works is a modern tunnel kiln plant, located at Grantsville in Western Maryland.

In manufacture, the most modern equipment is used. The optimum proportions of flint and bond clays, proper sizings of grains, best forming pressures and firing conditions, all contribute their important parts in the production of these unusual fireclay refractories. While the fullest advantage is taken of manufacture by the power-press method, the extrusion process is used also in making brick for certain particular requirements.

FOR SUPERDUTY SERVICE

H-W SUPER SAVAGE brick are used for service which is too severe for the advantageous use of high-duty fireclay brick, but not severe enough to require a brick of the high-alumina class. Among its important applications are electric furnace roofs, linings of soaking pits and heating furnaces, bottoms of malleable iron furnaces (air furnaces), and the walls and checkers of blast-furnace stoves.

H-W SUPER SAVAGE BUNG brick have established prominent records for service in the bung roofs of malleable iron furnaces.

FOR HIGH-DUTY SERVICE

H-W SAVAGE brick have an alumina content of 40 per cent or higher, with low content of basic oxides; low porosity; no shrinkage when reheated at 2910°F.; easily compressible secondary expansion at furnace temperatures, which assures tight impervious joints; and superior resistance to spalling. H-W Savage is made by the power-press process for best resistance to spalling, and by extrusion for greatest resistance to slag absorption and abrasion. The extruded brick are branded H-W Savage T.

Among the applications for which H-W Savage is especially suited are air furnaces, blast-furnace stoves and checkers, boiler furnaces, rotary kilns, continuous and periodic kilns, forge furnaces, glass-tank furnace regenerators including checkers, heating furnaces, incinerators, malleable furnaces, open-hearth furnace regenerators and checkers, soaking pits, and steel foundry ladle linings.

BRANDS MADE IN MISSOURI

CLASS	BRAND	PROCESS*	TYPICAL SERVICE
Superduty	Alamo	P.P., Ext., A.R., H.M.	General superduty service; blast-furnace stoves; electric steelmelting furnace roofs.
	Alamo Bung	P.P.	Malleable and air furnace roofs.
	Alamo S	V.P., A.R.	General superduty service requiring high density and strength.
	Varnon	P.P., Ext., A.R., H.M.	For severe superduty service; blast-furnace stoves; glass furnace regenerator checkers, walls and arches.
	Varnon S	V.P., A.R.	Malleable furnace sidewalls and bottoms; hot-metal transfer ladles; rotary kilns.
	Varnon D	V.P.	Furnace sidewalls and hearths, for severe slagging conditions; glass tanks; sodium silicate furnaces.
High-Duty	Walsh XX	P.P., H.M.	Lining of rotary kilns; general high-duty service, especially for resistance to thermal shock; blast-furnace stoves.
	Walsh S	Ext.	High-duty service, principally in malleable furnace sidewalls and cupola linings.
	Walsh T	Ext.	General high-duty service, where low porosity or high resistance to erosion or abrasion is required.
	H-W	P.P., H.M.	General high-duty service and stove checkers.
Medium-Duty	Salamander	P.P., Ext.	Medium-duty service.
	BLAST-FURNACE BRICK		
Superduty	Varnon BF	P.P.	Complete blast-furnace linings, including hearths.
	Varnon B	P.P.	Complete blast-furnace linings, including hearths.
	Varnon D	V.P.	Blast-furnace hearths.
High-Duty	H-W Mo BF	P.P.	Complete blast-furnace linings, including hearths.
	H-W 18 Mo	P.P.	Complete blast-furnace linings, including hearths.

** P.P. = Power Pressed V.P. = Vacuum Power Pressed Ext. = Extruded A.R. = Air-Rammed H.M. = Hand Molded*

Throughout the years, Harbison-Walker has developed in Missouri large reserves of high-grade refractory fire clays of various types adapted to the manufacture of superior fireclay refractories. The company's plants at Vandalia and Fulton are large manufacturing units capable of handling orders for any quantity of standard sizes and special shapes, made by the most modern manufacturing processes. Firing is done mainly in tunnel kilns; periodic kilns are used as conditions may require. Both plants embody developments based upon experience of almost a century in the manufacture of refractories. The geographical location offers definite advantages in transportation cost and delivery time for shipment over a large area.

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FOR SUPERDUTY SERVICE

ALAMO, as compared with the best high-duty fireclay brick, is more refractory—has a higher temperature of vitrification—is denser—has greater stability of volume at high temperatures—remains more rigid at high soaking heats—is more resistant to thermal shock. Because of its somewhat higher alumina content and lower content of basic oxides, ALAMO is also more resistant to the chemical action of many fluxes. For use as checkers, the high degree of immunity which this brick offers to the destructive influences of some gases, fumes, and fluxes is especially noteworthy. ALAMO is to be preferred for service in which highest resistance to spalling is important. Among its many applications are its extensive use in carbon-baking furnaces, walls and roofs of aluminum-melting furnaces, roofs of electric steelmelting furnaces, and linings of ceramic kilns. For best resistance to impact and abrasion, ALAMO is made by the extrusion process.

ALAMO BUNG brick possess the properties of high refractoriness and low spalling tendency so essential to service in the removable bungs of malleable iron furnaces. Excellence of workmanship and uniformity in size are important characteristics of ALAMO BUNG brick.

ALAMO S is similar to ALAMO in chemical composition and most physical properties, but is somewhat denser and stronger. It is recognized as a superior fireclay refractory in the superduty class, with its high degree of uniformity, low porosity, high strength, and resistance to abrasion. It is only slightly less resistant to spalling than ALAMO. ALAMO S is particularly suitable for malleable iron furnace sidewalls and bottoms, blast-furnace stove checkers, hot-metal transfer ladle linings, and rotary and shaft kiln linings.

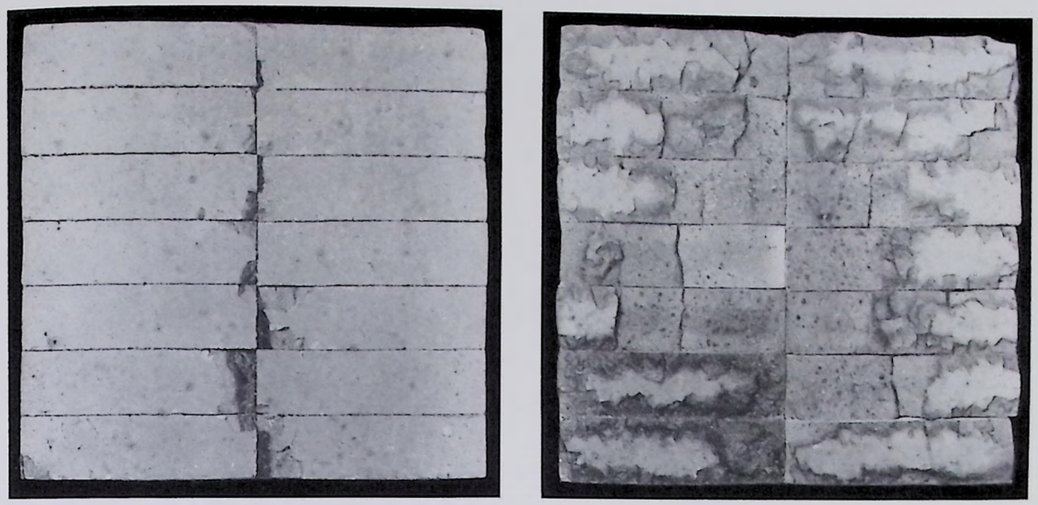
VARNON is similar in chemical composition to ALAMO, but the desirable physical properties are definitely enhanced by an especially hard burn with controlled kiln atmosphere which develops the most desirable mineral constitution. In all the several modifications of VARNON, this refractory excels in its degree of immunity to the destructive action of carbon monoxide and other reducing gases. VARNON is somewhat denser and stronger than ALAMO, has greater stability of volume at high temperatures, and greater rigidity under conditions of soaking heat. Noteworthy among the desirable properties of VARNON is its high resistance to thermal spalling.

The uses in which VARNON excels are many. They include the linings of metallurgical furnaces, the checkers of glass-tank regenerators, silicate of soda furnaces, the linings of rotary kilns, shaft lime kilns, ceramic kilns, carbon-baking furnaces, and incinerators.

VARNON S is an exceedingly dense and strong high-fired superduty fireclay brick. Among its important applications are sidewalls and bottoms of malleable iron furnaces (air furnaces), and the linings of hot-metal transfer ladles.

VARNON D is fired to a temperature even higher than that used for VARNON, with even further enhancement of such properties as density, high-temperature strength, resistance to slagging action, and stability of volume and mineral constitution. Its chief application is in furnace sidewalls and hearths, where subjected to severe erosive conditions and to corrosion by molten slags and metals, and by such other materials as sodium silicate, enamel frits, and mineral wool.

Other modifications of VARNON, including VARNON BF, are available for various special applications.



A Panel of ALAMO *Superduty Fireclay Brick after Spalling Test. Preheat 3000°F.*

A Panel of High-Duty Fireclay Brick after Spalling Test. Preheat 2910°F.

Typical Appearance of Fireclay Brick after Panel Spalling Test, Showing Contrast Between Superduty and High-Duty Brick.

FOR HIGH-DUTY SERVICE

WALSH XX brand for many years has been a leader among Missouri high-duty fireclay brick, possessing high refractoriness, superior resistance to spalling, unusual uniformity in quality and size, and exceptionally fine workmanship. Standard sizes and many rectangular shapes are made by the power-press method. Suspended arch shapes in this brand made by power pressing are unexcelled in many applications. They fulfill the requirements of close fit as assembled, high-temperature strength, and thermal shock resistance. Some special shapes are made by hand.

WALSH XX brick are used for the construction of boiler settings fired with all kinds of fuel; in the furnaces of oil refining, cracking and topping plants; in heat-treating and forge furnaces; in vertical and rotary lime kilns; in rotary cement kilns; in blast-furnace stoves; in metallurgical furnaces; and in other types of industrial furnaces in which the firebrick linings are exposed to severe service.

WALSH S and **WALSH T** are both manufactured by the extrusion process. They are very dense and of low porosity. These properties render them especially resistant to abrasion at high temperatures, to penetration by corrosive fumes, molten slags and fluxes, and to deformation due to load under conditions of soaking heat. Both brands possess the characteristic Harbison-Walker uniformity in quality and size and excellence of workmanship. In many applications they may be used interchangeably. However, service performance indicates that WALSH S brick are somewhat more resistant to spalling, and WALSH T withstand abrasion and impact somewhat better.

WALSH S brick are widely used in sidewalls of malleable iron and other metallurgical furnaces where severe slag action is a factor. They

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also give excellent results in cupola linings and in the combustion chambers of boiler settings.

WALSH T brick are widely favored as linings for both the feed-end and the discharge-end zones of rotary kilns used for burning cement, lime, and dolomite, and as linings for shaft kilns and cupolas. They are especially well adapted for service in the sidewalls and bottoms of furnaces used in nonferrous metallurgy, as for example, in brass and lead-melting furnaces. WALSH T gives excellent results in various parts of zinc distillation and refining furnaces.

WALSH S and WALSH T, as well as other Harbison-Walker brick made by the extrusion method, usually are repressed in steel dies to achieve the best workmanship and closest size tolerances.

H-W brand, a high-duty fireclay brick, is comparable in quality to the best brick of that class. The clay mix lends itself readily to the hand molding of special shapes of such intricate design that they cannot be formed by machine methods. Standard sizes and special shapes in H-W brand are used for general service.

FOR MEDIUM-DUTY SERVICE

SALAMANDER medium-duty fireclay brick are made from selected fire clays by the power-press process; **SALAMANDER T** is formed by extrusion. SALAMANDER and SALAMANDER T brick give excellent service where the prevailing furnace temperature and the operating conditions in general do not necessitate the use of high-duty fireclay brick. For example, they are used in the upper portion of cupola linings, in brick and tile kilns, in flue linings, in moderate temperature zones of boiler settings, in combustion chambers of boiler settings where the operating temperatures are relatively low, in stack linings, and as back-up brick.

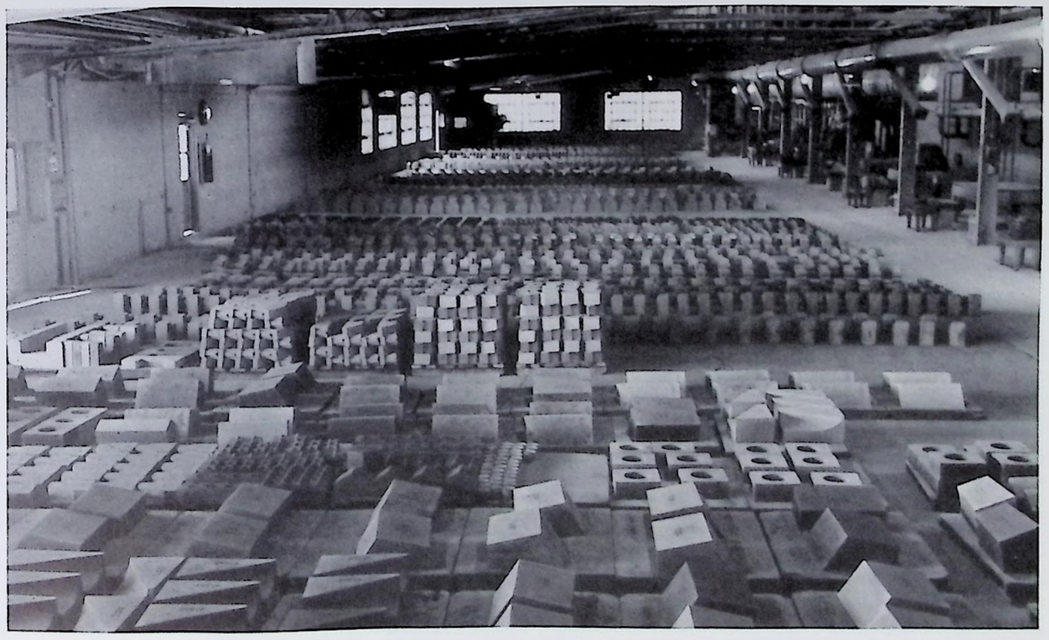
FOR BLAST-FURNACE SERVICE

Harbison-Walker is the leading producer of high-fired superduty fireclay refractories for use in blast-furnace linings, and today, the equivalent of nearly 50 complete linings of various modifications of the company's VARNON brand, including VARNON BF, VARNON B, and VARNON D, are in service throughout the country. These brick have the most complete development of the properties of high strength and density, low porosity and permeability, immunity to disintegration by carbon monoxide, a good margin of safety in refractoriness, and high resistance to spalling and slagging. They are used chiefly in the furnace bottom, lower inwall and upper inwall below the wearing plate, but in many cases have been specified also for the bottom and for the entire shaft lining above the mantle.

H-W Mo BF brand of high-duty blast-furnace brick is one of the more recent introductions to the Harbison-Walker family of blast-furnace brands. In this refractory, Harbison-Walker has made available a product with properties which render them especially suited for blast-furnace linings. Density, porosity, permeability and high resistance to disintegration by carbon monoxide, spalling and slagging are at levels comparable with those of the best high-duty blast-furnace brick made in the other producing states. H-W 18 Mo is the high-fired counterpart of H-W Mo BF, and is intermediate in characteristics between that brand and the VARNON blast-furnace brands.



Stockpile of Quality Controlled and Weathered Fire Clay at Fulton Works, Missouri.



Special Shapes on Hot Floor for Drying—Vandalia Works, Missouri.

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BRANDS MADE IN OHIO

CLASS	BRAND	PROCESS*	TYPICAL SERVICE
High-Duty	Franklin Crown	P.P., Ext., I.P., H.M.	General high-duty service.
	H-W	P.P., Ext., H.M.	General high-duty service.
	H-W OHC	V.P.	Open-hearth and other regenerator checkers.
	H-W Stove	P.P., Ext., I.P., H.M.	Blast-furnace stoves.
Medium-Duty	Webster	P.P., H.M.	Medium-duty service.
Low-Duty	Temple	P.P.	Low-duty service; backing for high-duty brick; stack linings; sodium cells.

POURING-PIT REFRACTORIES

** P.P. = Power Pressed V.P. = Vacuum Power Pressed Ext. = Extruded I.P. = Impact Pressed H.M. = Hand Molded*

Modern improved equipment and methods of manufacture have made Portsmouth Works a model unit for the production of fireclay refractories of excellent quality and workmanship. Both continuous car-type tunnel kilns and periodic kilns serve for firing. The Portsmouth plant is ideally balanced for the production of refractories for the various types of furnaces in numerous industries including steel, aluminum, power generation, glass manufacture, and other ceramic industries. It excels in the manufacture of special shapes.

FOR HIGH-DUTY SERVICE

FRANKLIN CROWN brick have been well established in industry for many years. They are widely used for general applications in the steel industry as mill brick and as open-hearth checkers, for rotary cement and lime kiln linings, and shaft lime kiln linings, ceramic kilns, and for the high-temperature sections of boiler settings. In the form of special shapes, Franklin Crown is a popular brand for the linings of domestic heating furnaces. The shapes are supplied in complete sets, for furnaces of various sizes and designs.

H-W brand is a superior fireclay refractory of the high-duty class, used mainly for the making of large or difficult shapes, and to a lesser extent for the manufacture of standard sizes. Among the many applications of this brand are included cupola linings, and the linings and checkers of hot-blast stoves.

H-W OHC is a high-duty brick of unusual density and strength, made by the vacuum-press process. It is used mainly for open-hearth and other regenerator checkers.

H-W STOVE is a strong dense high-duty fireclay refractory, made especially for service in the linings and checkers of blast-furnace stoves. It has marked stability of volume, and at stove temperatures sustains the load involved with minimum subsidence. In its use in stoves, the low permeability of this brand accounts for its excellent resistance to impregnation and corrosion by alkaline fluxes.

FOR MEDIUM-DUTY SERVICE

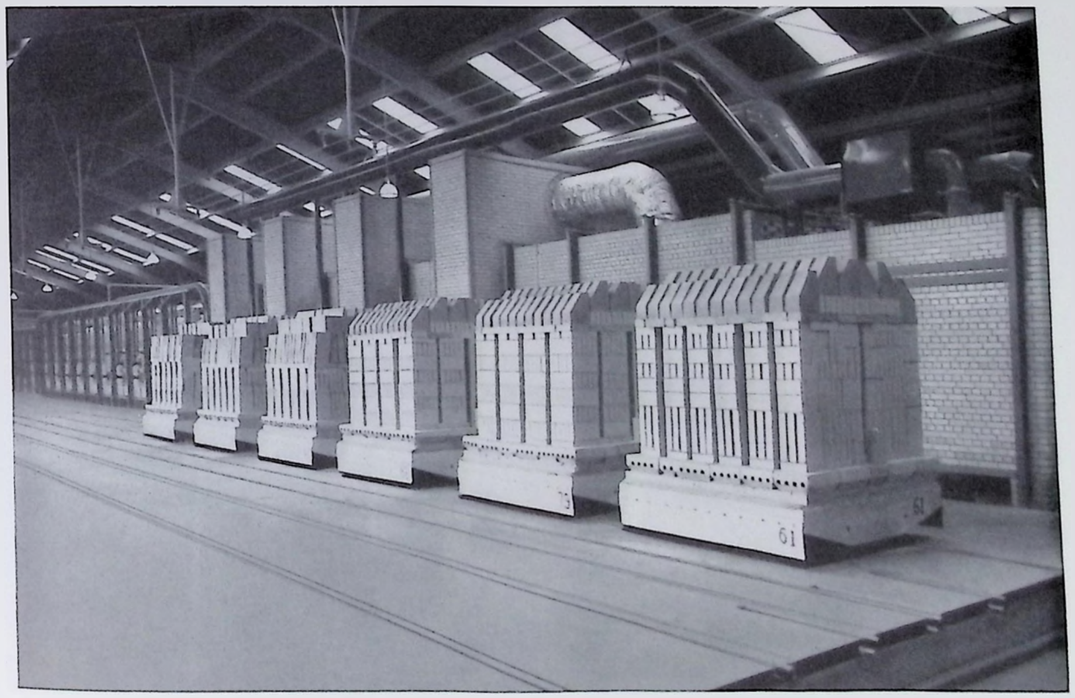
WEBSTER medium-duty brick are admirably adapted for service in which high refractoriness is not the most essential requirement but in which density and resistance to penetration by liquid slag are of paramount importance. Webster brick give excellent service in cupola linings. They are extensively used also in the intermediate and cold zones of lime kilns, heating furnaces, and in other applications for which medium-duty fireclay brick are suitable.

FOR LOW-DUTY SERVICE

TEMPLE brick, in the low-duty class, are used mainly in the back-up courses of furnace walls and in stack linings. They are of excellent workmanship. In many moderate temperature operations, this brand serves with splendid results as the working lining. Among its various applications are included linings of foundry ladles, annealing ovens, and sodium chloride cells.

POURING-PIT REFRACTORIES

Various pouring-pit refractories of excellent quality are made at this plant. These include stopper-rod sleeves for bottom-pour ladles and runner brick with accessory shapes for bottom-pouring ingot practice. Many sizes of gate and runner shapes for foundry molding assemblies are among the products made in Ohio. Some delivery benefits in many cases result from shipments of these various refractories of the highest standards from Portsmouth Works.



Brick on Tunnel Kiln Car Ready for Firing, Portsmouth Works, Ohio.

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BRANDS MADE IN PENNSYLVANIA

CLASS	BRAND	PROCESS*	TYPICAL SERVICE
Superduty	Dean	V.P., H.M.	General superduty service.
	Dean S	V.P.	Blast-furnace stove checkers.
	Dean Bung	V.P.	Malleable iron furnace bungs.
High-Duty	Benezet	P.P., V.P., H.M.	General high-duty service.
	Benezet OHC	V.P.	Open-hearth and other regenerator checkers.
	H & B Woodland	P.P., V.P., H.M.	High-duty service where high density and strength and low porosity are desired.
	H-W Special	P.P., H.M.	Linings of rotary kilns.
	H-W Stove	V.P., Ext., H.M.	Blast-furnace stoves.
	H-W	P.P., V.P., Ext., H.M.	General high-duty service; cupola linings.
	Woodland	P.P., V.P., H.M.	General high-duty service; open-hearth checkers.
	Woodland X	P.P., H.M.	Sprung and suspended roof arches and other high-duty service.
Semi-Silica	Kaosil	P.P., Ext., H.M.	Blast-furnace stoves, open-hearth regenerators, soaking pits, heating furnaces, ceramic kilns.
Medium-Duty	Widemire	P.P.	Medium-duty service. Also backing for high-duty brick; stack linings.
Low-Duty	Temple	P.P.	Low-duty service. Also backing for high-duty brick; stack linings.
Abrasion-Resistant	Duro Dot	P.P.	Cold and intermediate zones of rotary and shaft kiln linings.
BLAST-FURNACE BRICK			
High-Duty	Benezet BF	V.P.	Complete blast-furnace linings, including hearths.
	H-W 18 Pa	V.P.	Complete blast-furnace linings, including hearths.
POURING-PIT REFRACTORIES			

** P.P. = Power Pressed V.P. = Vacuum Power Pressed Ext. = Extruded H.M. = Hand Molded*

Harbison-Walker had its origin in Pennsylvania and built its early reputation on brick made from the high-quality flint and bond clays of that state. The company's Pennsylvania fireclay brick operations center about Clearfield, where the company has four plants.

Throughout the years, extensive reserves of superior clays of different types have been developed through a continuous program of prospecting. From these clays, fireclay refractories of all the standard classes are made, together with many special-purpose refractories. The modern manufacturing facilities include equipment for power pressing, vacuum pressing, extrusion with deairing, and hand molding. Firing is accomplished both in continuous tunnel kilns and in periodic kilns. At some of the plants, a considerable proportion of the output consists of large or intricate special shapes. The plant at Templeton is devoted largely to the production of blast-furnace and stove refractories.

FOR SUPERDUTY SERVICE

DEAN superduty fireclay brick, like other brick of their class, are made of clays of the highest quality. The alumina content is somewhat higher than usual for superduty brick. The temperature of firing is unusually high; this is the important factor which accounts for the stability in volume, and negligible shrinkage of Dean brick at high temperatures. Their resistance to thermal spalling is greatly superior to that of fireclay brick of the high-duty class.

Dean brick are used in boiler settings and rotary kiln linings in which the prevailing conditions are too severe for high-duty fireclay brick. Other applications correspond in general to those for which superduty fireclay refractories provide advantages.

DEAN S, a modification of Dean brick, is made by manufacturing techniques which increase density, high-temperature strength, and resistance to abrasion and slag attack. With but little sacrifice in spalling resistance, it fulfills various special severe requirements to best advantage. Dean S is used with superior results in checkers of blast-furnace stoves.

DEAN BUNG brick give excellent service in the bung arches of malleable iron furnaces.

FOR HIGH-DUTY SERVICE

BENEZET brand of fireclay brick was already serving the needs of industry when the great grandfathers of the present day were children. Throughout the years, the basic quality of this brand has been maintained, while improvements in processing and control have been introduced. It is manufactured by the power-press or vacuum-press process, depending upon the service in which the brick are to be used. Benezet brick are widely used for boiler settings, for the linings of metallurgical furnaces and enamel frit furnaces, and for many other refractory constructions.

BENEZET OHC brick are used primarily in open-hearth and glass furnace checker construction. They are formed by the vacuum power-press method, and are carefully processed to achieve maximum density and mechanical strength.

H&B WOODLAND brick are especially processed for service in which high density, high strength, and low porosity are important, as in the sidewalls of many furnaces. Standard sizes are formed by the power-press and vacuum-press processes. Many special shapes are hand molded.

H-W SPECIAL high-duty fireclay brick for many years have been the accepted standard for rotary kiln blocks to be used in the intermediate and cold zones of cement, lime, lime sludge, and dolomite kilns. They are well balanced in resistance to spalling and abrasion.

H-W STOVE brand is widely used for blast-furnace stove linings and checkers. These brick are made by the power-press, vacuum power-press, and extrusion processes. They have low

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porosity, high cold strength, and excellent resistance to deformation under load at high temperatures. The H-W STOVE composition is well adapted to the manufacture of the various patented stove checkers.

H-W brand corresponds in most of its physical properties to the best of high-duty fireclay brick. It is a special refractory in this general class, which lends itself to shape molding of brick necessarily made in intricate or unusual designs. It also is made in some standard sizes, cupola and rotary kiln blocks, and other shapes.

WOODLAND brick, for nearly three quarters of a century, have been regarded as the standard of highest quality. WOODLAND brick are used in many types of furnaces in metallurgical and other industries, in boiler settings, and in other constructions where the best high-duty fireclay brick are required.

WOODLAND X brick were developed especially for use in constructions where resistance to rapid changes in temperature is an essential requirement. Their composition and structure are designed to reduce spalling tendency. They are therefore particularly well suited for furnace roofs and arches of either the sprung or the suspended types. They are used successfully in incinerators, in boiler settings, in metallurgical furnaces of various types, in soaking-pit arches, and in other arch constructions.

SEMI-SILICA FIRECLAY BRICK

KAOSIL semi-silica fireclay brick—a truly unique refractory—is made from hard-fired siliceous kaolin of exceptional purity. It has a silica content of 75 to 76 per cent, and an extremely low alkali content—less than ½ per cent. KAOSIL, having a P.C.E. of Cone 29-31, is of superior quality in the class of semi-silica fireclay brick. It is formed mainly by the power-press method which is conducive to the most uniform texture and assures superior workmanship. Certain shapes are made by extrusion.

The outstanding properties of KAOSIL are high temperature of incipient fusion, stability of volume and rigidity under load at high temperature, and excellent resistance to thermal spalling. In furnace atmospheres high in alkaline fumes or dust, KAOSIL develops a surface glaze which retards penetration by fluxes.

In accordance with the A.S.T.M. classification of fireclay brick, semi-silica brick are tested for subsidence under the standard load of 25 psi at 2460°F.—the temperature commonly used in testing high-duty brick. However, because of its superior load-bearing characteristics, KAOSIL is tested by H-W at 2640°F., with subsidence equivalent to that of superduty brick.

Among the uses of KAOSIL and its modifications are the following:

Blast-Furnace Stoves
- Combustion wells, domes, and checkers.

Open-Hearth Furnaces
- Fantail roof, regenerator roof, regenerator sidewalls above checkers, checker arches.

Soaking Pits
- Sidewalls, regenerator arches, top courses of checker chamber walls, and covers.

Heating Furnaces
- Suspended or sprung-arch roofs, walls.

Hot-Metal Mixers
- Above the metal line.

Miscellaneous
- Piers under load in soaking heats.
- Heavily insulated walls and arches.
- Arches of unusually wide span.
- Ceramic tunnel kilns and accessories.

FOR MEDIUM-DUTY SERVICE

WIDEMIRE brand, made by the power-press method, is only slightly lower in refractoriness than the standard for high-duty brick. It has high strength and low porosity. The excellent properties of WIDEMIRE brick, made possible by the characteristics of the clays of which it is composed and by the method of manufacture, permit its satisfactory use for many applications, such as the linings of heating and annealing furnaces of various types, the upper linings of vertical shaft lime kilns, and certain sections of boiler settings.

FOR LOW-DUTY SERVICE

TEMPLE brick are made from selected Pennsylvania fire clay by the power-press process. They are uniform in quality, texture, size and workmanship.

TEMPLE brick are used for backing high-duty fireclay brick in boiler settings. They are used also in linings of second passes of boiler settings, in annealing ovens except fireboxes, in stacks, and in other furnace applications where moderate temperatures are employed.

FOR HIGHEST RESISTANCE TO ABRASION

DURO DOT brick are used advantageously for construction of furnace linings which must withstand severe abrasive action at moderate temperatures. Typical uses include the linings of the chain sections of rotary cement kilns, the linings of the moderate-temperature zones of lime kilns of both the rotary and shaft types, and the wharfs of by-product coke-oven plants.

FOR BLAST-FURNACE SERVICE

At its Pennsylvania Works, the company makes two brands of brick for blast-furnace linings—BENEZET BF and H-W 18 PA. BENEZET BF has a record of more than 75 years of continuous satisfactory service to the blast-furnace industry. Improvements in quality have kept pace with advancing technical knowledge, and with the more severe demands of industry. Throughout the years, BENEZET BF has maintained its high reputation as a leading brand.

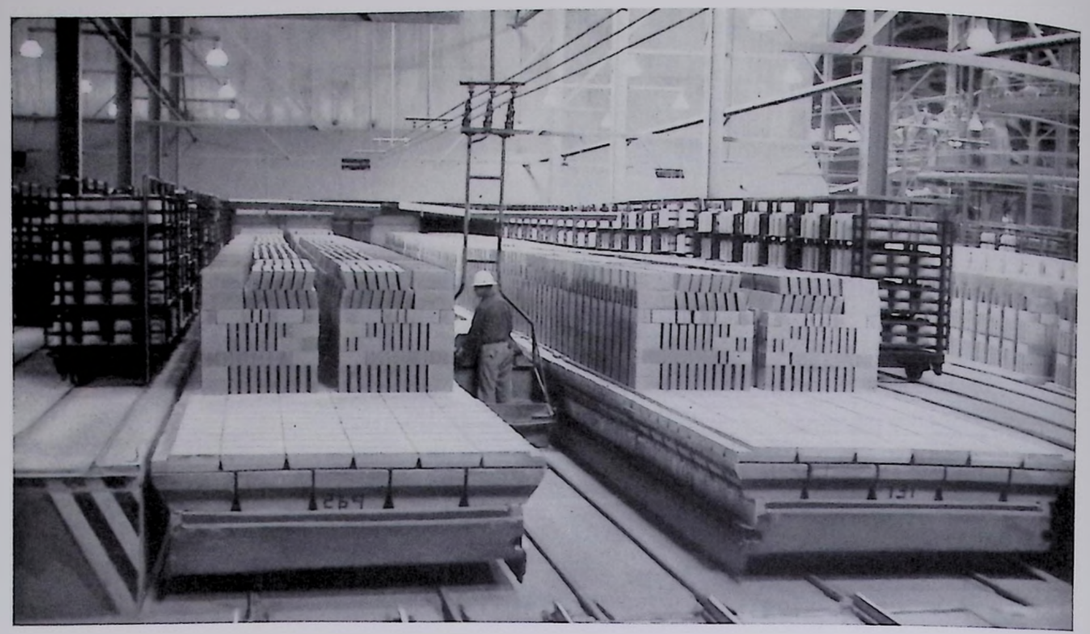
H-W 18 PA is similar in composition to BENEZET BF and possesses the advantages over that product which result from the higher temperature of firing. These advantages include further stabilization of mineral constitution, and increased resistance to disintegration by carbon monoxide gas.

BENEZET BF and H-W 18 PA are strong, tough, dense and of low permeability. They are highly resistant to both abrasion and corrosion, being hard-burned and fired under controlled conditions of kiln temperature and atmosphere.

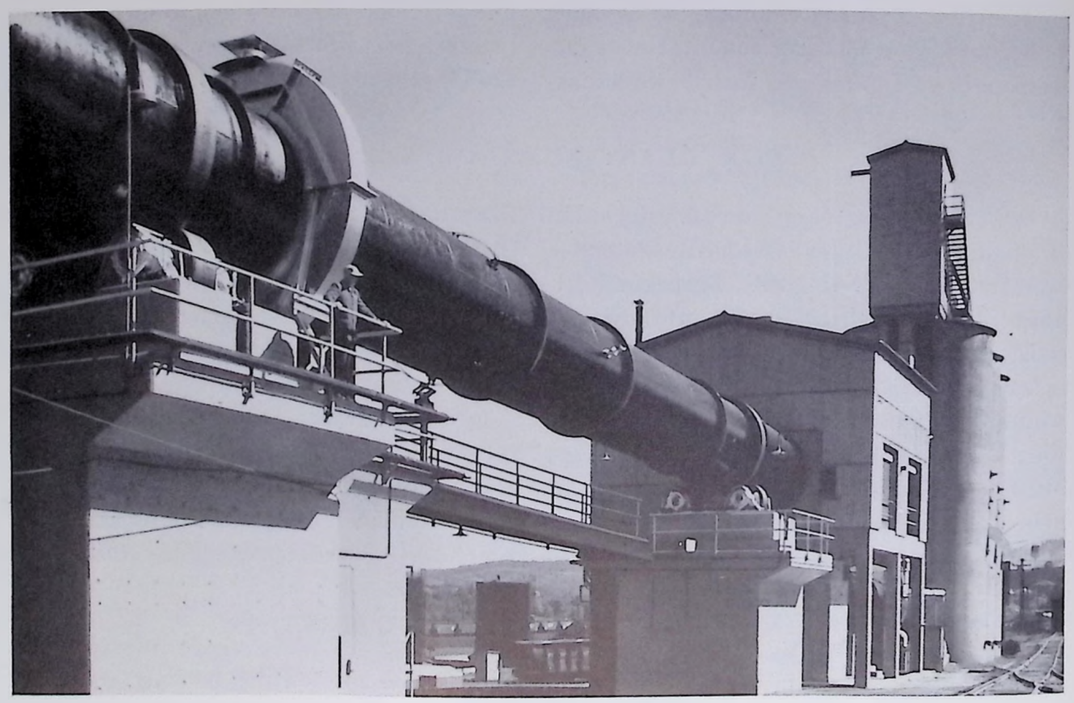
POURING-PIT REFRACTORIES

Pouring-pit refractories including nozzles, runner brick and sleeves, and gate and runner brick shapes for foundry molding assemblies are made in Pennsylvania. See also page 71.

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Kiln Cars Loaded With Shapes Ready for Firing—Clearfield, Pennsylvania.



Rotary Kiln Used for Calcining Fire Clay at Clearfield, Pennsylvania.

BRANDS MADE IN TEXAS

CLASS	BRAND	PROCESS*	TYPICAL SERVICE
High-Duty	COLEMAN XX	P.P., H.M.	General high-duty service; regenerator checkers.
Medium-Duty	COLEMAN	P.P., H.M.	Medium-duty service; boiler settings.

** P.P. = Power Pressed H.M. = Hand Molded*

For more than twenty years, Harbison-Walker has supplied high-quality fireclay refractories to meet the needs of industry throughout the area which can be served most advantageously from the company's plant at Athens, Texas. Adequate reserves of high-grade clays of proved quality will supply raw materials far into the future. At this thoroughly modern plant a large proportion of the clay used for making brick is hard fired in a rotary kiln to achieve maximum stability of volume and mineral composition. The products have earned the same high reputation as that of the Harbison-Walker refractories produced in other states.

FOR HIGH-DUTY SERVICE

COLEMAN XX brick are made by the power-press process in most of the standard sizes, from clays taken from the company's open-pit mines at Athens. Special shapes of simple or intricate design are formed by the most appropriate molding methods for securing the best physical properties.

The percentages of impurities—iron oxide, magnesia, lime, and alkalies—in COLEMAN XX brick are unusually low. This fact contributes to its distinction among high-duty brands—for its high refractoriness and particularly its unusual strength and stability of volume in soaking heat at high temperature. Its high resistance to spalling is above the average for many high-duty brands.

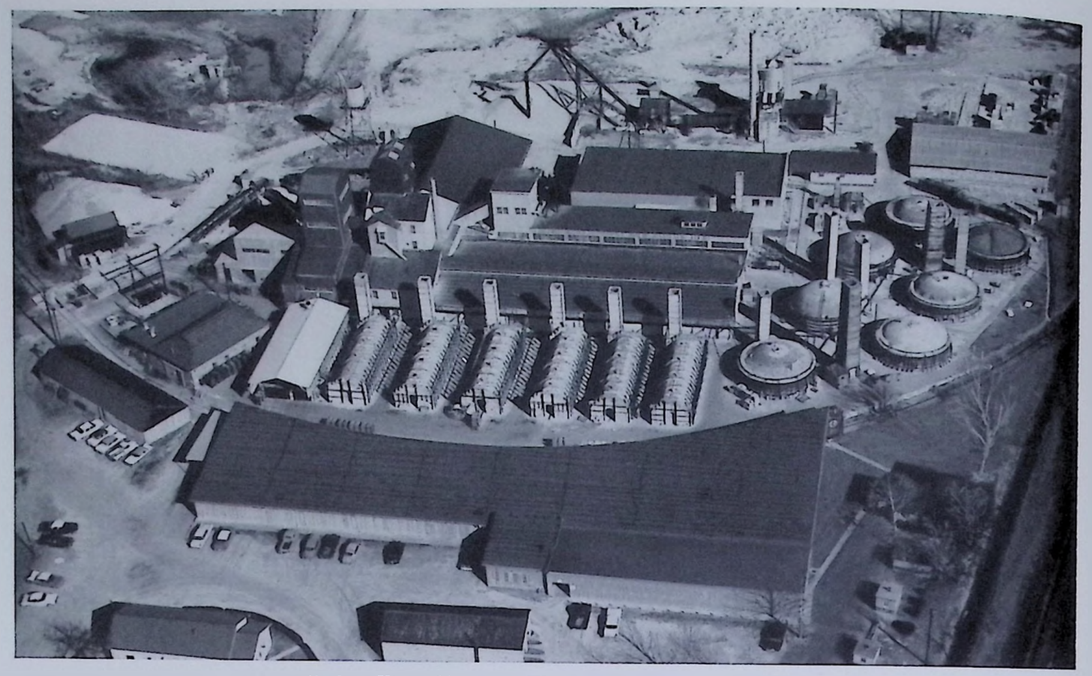
COLEMAN XX brick meet the requirements of high-duty service in a wide variety of applications including the settings of boilers, rotary kiln linings, and oil stills. Other important applications are linings of rotary kilns and checker settings of regenerators.

FOR MEDIUM-DUTY SERVICE

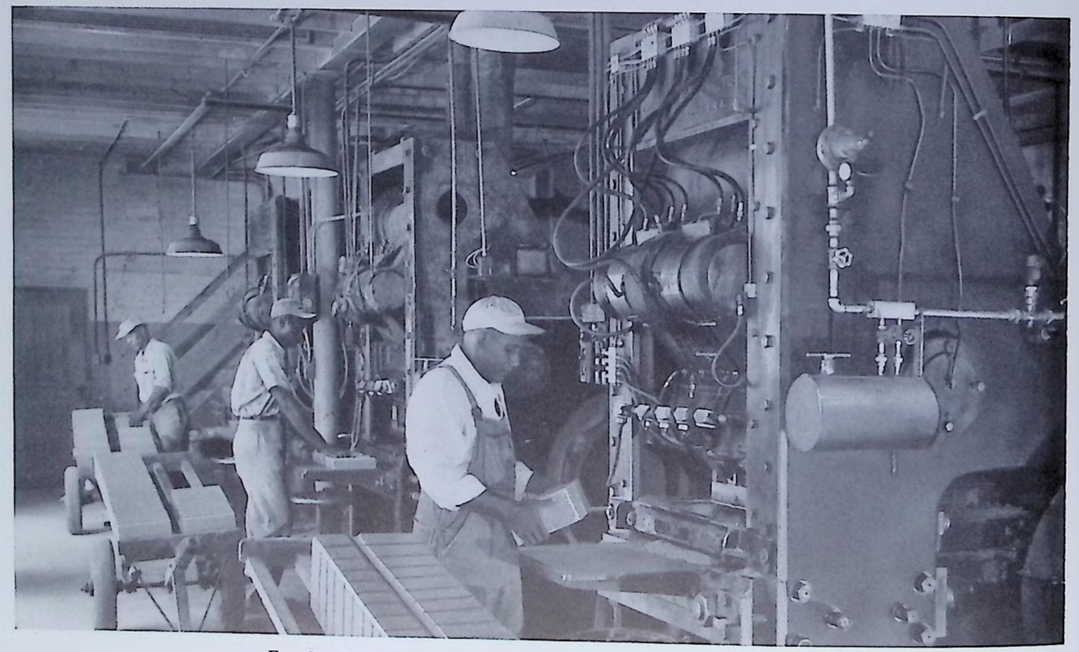
COLEMAN is a medium-duty fireclay brick of highest quality and workmanship, made by the power-press process. Its characteristics adapt it especially for service in which the conditions are not sufficiently severe to require the use of high-duty fireclay brick.

COLEMAN brick possess the properties of rigidity and resistance to load at high temperatures to a degree which is unusual for brick of the medium-duty class. They meet the same high standards of uniformity in quality and size as are met by COLEMAN XX high-duty fireclay brick. In furnace construction, COLEMAN brick are used advantageously in combination with COLEMAN XX and other brands of Harbison-Walker fireclay brick.

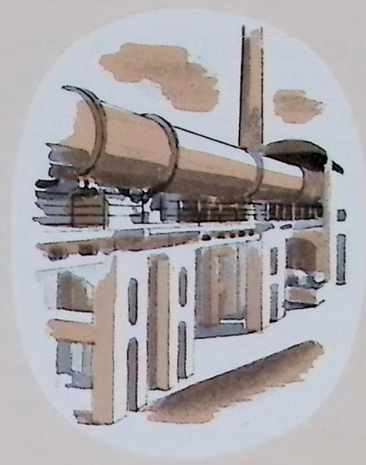
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Airplane View of Harbison-Walker Plant at Athens, Texas.



Forming Special Shapes on Power Press in Plant at Athens, Texas.



HIGH-ALUMINA REFRACTORIES

HARBISON-WALKER REFRACTORIES COMPANY

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HARBISON-WALKER BRANDS OF HIGH-ALUMINA REFRACTORIES

Class	Brand	Class	Brand
		BRICK	
45% Alumina	Dialite Dot	85% Alumina	Coralite D
50% Alumina	Dialite	85% Alumina	Coralite XD
50% Alumina	H-W Special HA	85% Alumina	Coral
60% Alumina	Anchor	85% Alumina	Coral P
60% Alumina	Anchor Dash	85% Alumina	Coral BP
60% Alumina	Alcor	90% Alumina	Korundal
60% Alumina	Alcor XX	90% Alumina	Korundal XD
70% Alumina	Alusite	Mullite (70% Al_2O_3)	H-W Mullite
80% Alumina	Coralite	Corundum (99+% Al_2O_3)	H-W Corundum

MORTAR MATERIALS

For all Harbison-Walker brands of high-alumina brick, there are corresponding brands of mortar materials of proved quality for laying. They are described on pages 138 to 146.

MONOLITHIC MATERIALS

For high-alumina plastic refractories, ramming mixes, and castables, see pages 152 to 168.

HIGH-ALUMINA REFRACTORIES

The trend to higher temperatures and greater production rates throughout industry necessarily brings most furnace operators to a consideration of high-alumina refractories. They constitute a group having great diversity of compositions and physical properties. While often chosen for their resistance to spalling, impact, abrasion, or load, their broadest appeal lies in their high refractoriness and their excellent ability to resist corrosion at high temperatures. For many applications, high-alumina brick have supplanted fireclay brick, silica brick, and even more costly refractories to decided advantage.

In seeking the most advantageous refractory for any particular service, the user will observe that high-alumina refractories cover a range in softening temperatures of more than 400°F., and that they offer the advantage of a stepwise progression from brick of 45 per cent alumina content to corundum brick, containing over 99 per cent alumina.

The great importance of high-alumina refractories becomes clear when it is realized that for service at temperatures above the range of fireclay and silica brick, high-alumina and basic refractories are the only two major groups used commercially in large quantities. High-alumina brick are multi-purpose refractories which may be used for service extending to a temperature of about 3600°F., in the absence of corrosive agents or destructive physical factors.

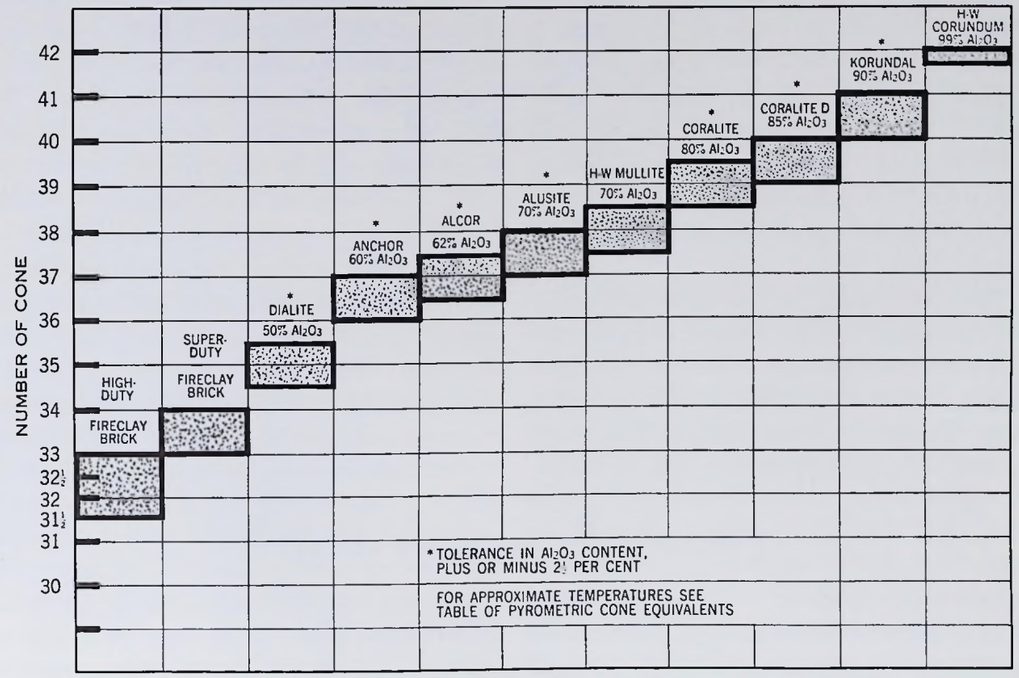
For one group of high-alumina brick, commercial classification is based upon alumina content. This group includes brick of the 45, 50, 60, 70, 80, 85, and 90 per cent alumina

classes. Brick of 99+ per cent alumina are included in a second group described below. In each class of the first group, the established industry tolerance in alumina content is plus or minus 2½ per cent. For example, the permissible range for brick of the 70 per cent alumina class is 67.5 per cent to 72.5 per cent alumina.

In the second group of high-alumina refractories—consisting of the two classes mullite and corundum—the brick are composed essentially of a single mineral species in well-developed crystalline form. The mineral mullite has the theoretical composition $3Al_2O_3 \cdot 2SiO_2$, corresponding to 71.8 per cent alumina, 28.2 per cent silica. Pure corundum consists of 100 per cent alumina.

High-alumina brick of all classes are more refractory than fireclay brick, approximately in proportion to their content of alumina. The chart below gives a graphic representation of the relation between their alumina content and their Pyrometric Cone Equivalent or P.C.E. The P.C.E. of high-duty fireclay brick may vary from Cone 31½ to 33, of superduty fireclay brick from Cone 33 to 34, while that of the different classes of high-alumina brick covers the entire range from Cone 34, with a softening temperature of 3205°F., to Cone 42, which has a softening temperature of 3660°F.

The high-temperature stability of high-alumina brick is indicated clearly by the temperatures used in testing them under load. While fireclay brick are tested at 2460° and 2640°F. in the standard load test at 25 pounds per square inch, high-alumina brick of some classes require much higher testing temperatures—even up to 3200°F.



Refractoriness of Fireclay and High-Alumina Brick Expressed in Pyrometric Cone Equivalents.

NOTE: The P.C.E. values of brick containing 80%, 85%, and 90% Al_2O_3 were estimated from the best available data.

HARBISON-WALKER REFRACTORIES COMPANY

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The chemical composition of a high-alumina brick indicates approximately its P.C.E. value, but does not reveal the mineral constitution, upon which many desirable properties depend, nor serve as a definite guide to all the physical properties. The properties of mechanical strength at high temperatures, shrinkage or expansion under heat, slag resistance, porosity, and permeability are dependent upon such factors as the character of the materials used, their proportions, the proportion of the batch which has been prefired, the method and temperature of prefiring, the sizing of the grains, the process of molding, and the firing temperature.

Harbison-Walker high-alumina brick include brands in all the various classes from 45 to 99+ per cent alumina, including mullite brick and corundum brick. They cover a wide range in refractoriness and other properties, and are designed to meet the requirements of a great variety of service conditions in many different types of furnaces. They are used with special benefit in vulnerable furnace parts. The high refractoriness of high-alumina brick permits insulation of furnace walls at higher temperatures than are practicable for walls built of fireclay brick.

Harbison-Walker high-alumina refractories are manufactured from diaspore clay, bauxite, and other materials high in alumina, which are used in both raw and calcined form. In making some brands, crystalline alumina (corundum) is used in various amounts. Some brick are made from synthetic mullite. The major proportions of the diaspore and bauxite used are precalcined to stabilize their volumes and promote desirable mineral transformations before forming into brick. During the firing of the brick, they are subjected to the particular heat treatment which will effect the necessary mineral changes, and give optimum density and maximum strength.

In the manufacture of high-alumina brick, certain important physical properties are developed to the highest degree when the brick are made under heavy pressure. Standard 9-inch sizes, rotary kiln blocks, and many other shapes of all Harbison-Walker high-alumina brands are made by the power-press process.

It is a decided advantage to use standard sizes, from the standpoint of physical properties as well as of cost. For service in which special shapes must be used in appreciable quantities, they should be so designed if possible that they can be power pressed. When this cannot be done, it is preferable to make them by the air-ramming method rather than by hand.

For illustration of brand selections which may be made for specialized service, there is ANCHOR DASH for highest spalling resistance, ALUSITE for rotary kiln and metallurgical furnaces, CORAL for resistance to attack by molten aluminum, CORALITE XD for lowest porosity, KORUNDAL XD for high-temperature resistance to pressure and corrosion, and H-W CORUNDUM for the very maximum in refractoriness.

45 PER CENT ALUMINA CLASS

DIALITE DOT brick have very low porosity, good stability of volume at high temperatures, and unusually high resistance to spalling. As examples of their uses, they serve with excellent results in various suspended constructions and in the caps of silicate of soda furnaces. DIALITE DOT brick are also used in the linings of rotary cement kilns beyond the high-temperature zones in sections where abrasion is only moderate, but spalling conditions are severe.

50 PER CENT ALUMINA CLASS

DIALITE brick, with a Pyrometric Cone Equivalent of 35, have a high temperature of incipient vitrification, excellent mechanical strength and constancy of volume at high operating temperatures, low porosity, and good resistance to thermal spalling. They are highly resistant to chemical attack by volatile alkalies and some slags, and to the effects of sulfur dioxide gas at high temperatures.

DIALITE brick typically are used in boiler furnace linings, regenerator checkers, fireboxes and understructures of pottery kilns, in settings of high-temperature oil stills, heating and forge furnaces, and roofs of sodium silicate furnaces. They are very well adapted to service in the burning zones of rotary kilns under certain operating conditions. In many of the rotary kilns used for burning cement, lime, or dolomite, the operating conditions are so severe that brick of higher alumina content than DIALITE are required for the burning zones. However, in such kilns DIALITE brick may be used to advantage in the intermediate zones.

H-W SPECIAL HA rotary kiln blocks are manufactured from Pennsylvania diaspore clays by the power-press process. They are strong and resistant to fluxing, and do not shrink at the high operating temperatures to which they are subjected in service. H-W SPECIAL HA has been one of the leading brands for lining the burning zone of rotary cement kilns operated at moderate temperatures. It provides a wide margin of safety over fireclay brick when so used, as it readily develops a protective coating of clinker, and retains the coating at the usual operating temperatures. Excellent economies result from the use of H-W SPECIAL HA rotary kiln blocks in cement kiln service which is too severe for fireclay brick, yet not so severe as to require brick of a higher alumina content or a basic refractory. H-W SPECIAL HA rotary kiln blocks serve admirably for use in the intermediate zone of some kilns which require brick of higher refractoriness in the burning zone.

60 PER CENT ALUMINA CLASS

ANCHOR and **ANCHOR DASH** brick have a P.C.E. value of 36 to 37, with the corresponding softening temperature of nearly 3300°F., about 50 degrees higher than that of brick of the 50 per cent alumina class.

ANCHOR and ANCHOR DASH brick are very resistant to attack by various fluxes, including ash from coal or fuel oil and some basic slags. They resist penetration by fluid slags, and have excellent stability of volume at high temperatures. They are well adapted to service in various types of oil-fired furnaces in which the temperatures are too high for refractories of the superduty fireclay class.

ANCHOR brick are used to advantage in the burning zones of shaft lime kilns, particularly those in which the operating conditions are severe. They serve well also in burning zones of some rotary kilns used for burning lime, lime sludge, and cement. They are recommended for use in slag line areas of various types of metallurgical furnaces. Coal ash of high iron content, and wood refuse ash high in alkalies, have appreciably less fluxing action upon ANCHOR than upon fireclay refractories. ANCHOR brick are used in the sidewalls of nickel anode furnaces, and bottoms and lower sidewalls of some aluminum-melting furnaces.

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ANCHOR DASH brick have a splendid reputation for resistance to corrosion by various fluxes and volatiles, and for service under severe spalling conditions, especially in the roofs of electric steelmelting furnaces. They are used in boiler furnaces fired with fuels having very corrosive ash, such as that of oil, wood refuse, and bagasse. Other applications include the bottoms and doors of air furnaces, the roofs of slab-heating furnaces, and the bag walls of oil- or gas-fired periodic kilns, as well as sulfur burners and suspended arches.

ALCOR brick are made with a considerable proportion of crystalline alumina, which accounts for their added margin of refractoriness, strength, and stability of volume at high working temperatures. Their P.C.E. value of 37 corresponds to a softening temperature of 3310°F. Their resistance to chemical attack by certain slags is excellent.

ALCOR brick give superior service in oil-fired furnaces using heavy residuum oil as fuel. Because of their exceptional ability to support loads under conditions of soaking heat, ALCOR brick are well suited for use in piers of various furnaces operated at high temperatures. Other important applications are in the construction of muffles of various types, roofs of small electric furnaces, and burner blocks. In walls and ports, and in other parts of glass-tank furnaces which are exposed to volatile alkalies and alkaline dust, ALCOR brick are more serviceable than brick of the same alumina content manufactured entirely from diaspore clay.

ALCOR XX contains a substantial percentage of crystalline alumina. Both ALCOR and ALCOR XX are made by the power-press or air-ramming processes. The porosity of ALCOR XX is very low for a refractory containing somewhat more than 60 per cent alumina. ALCOR XX brick are recommended for service in which the properties of importance are high refractoriness, low porosity, stability in volume and rigidity under long sustained loading at high temperatures, and excellent resistance to thermal spalling. Some of the uses of ALCOR XX include the construction of piers and muffles, electric furnace roofs, parts of the superstructure of glass-tank furnaces, and the linings of boiler furnaces operated under extremely severe conditions.

70 PER CENT ALUMINA CLASS

ALUSITE brick are made in Missouri, Pennsylvania, Alabama, and California. A substantial proportion of the raw material used in their manufacture is precalcined at high temperatures in modern rotary kilns.

The superiority of ALUSITE long ago established it as the leader in the class of 70 per cent alumina refractories. It has a P.C.E. of 37 to 38, with the corresponding high softening temperature of about 3325°F. Its porosity is much lower than that of most brick of its class, and its weight per cubic foot is correspondingly higher. While the texture of this brick is such that mechanical penetration by molten slags and softened clinker is relatively low, its resistance to rapid temperature changes is excellent.

ALUSITE is the standard refractory at many cement plants in the United States and other countries. Among high-alumina refractories, it has made a remarkable record over the years for use in the high-temperature zones of lime and cement kilns, particularly where the service conditions are difficult to meet. ALUSITE readily takes on and holds a satisfactory coating. It has shown excellent economies when used in the transition zones of cement, magnesite, and dolomite kilns in which the high-temperature zones are lined with basic brick.

The excellent economies resulting from the use of ALUSITE in the calcining zones of rotary lime, lime sludge, magnesite, and dolomite kilns have brought about its widespread adoption for such service. The steel industry uses ALUSITE for water-cooled ports, doors and top checker courses of open-hearth furnaces, for lower sidewalls of soaking pits, and for heating furnace bottoms. Excellent results are secured from ALUSITE in nonferrous metallurgical refining furnaces, in reverberatory and brass-melting furnaces, and in lead softening furnaces. ALUSITE brick have proved their excellence for service in the upper sidewalls and roofs of lead drossing, cupel, and by-product furnaces in which the furnace atmosphere is laden with litharge.

ALUSITE refractories are manufactured in all standard sizes of radial blocks, arches, and wedges which are used for the linings of rotary kilns. Other standard sizes and various special shapes are available also from stock.

80 PER CENT ALUMINA CLASS

CORALITE brick are considerably more refractory and more resistant to the fluxing action of various basic oxides than brick of lower alumina content. Their porosity is low and their rigidity under load at high temperatures is high. They have good resistance to spalling. Few refractories have a P.C.E. as high as that of CORALITE —approximately Cone 39—equivalent to a softening temperature of 3390°F.

Among the principal applications of CORALITE is its use in the high-temperature zones of rotary cement kilns. In rotary kilns employed for producing refractory dolomite and magnesite, CORALITE is used with economy in zones of the lining adjacent to the basic refractory burning zones. It serves the purpose well in the hottest parts of center-fired shaft lime kilns. CORALITE is used extensively in various nonferrous metallurgical furnaces for sidewalls, to withstand severe fluxing action of various slags.

85 PER CENT ALUMINA CLASS

CORALITE D is an 85 per cent alumina brick designed primarily for high-temperature rotary kiln service. It has high density, exceptional strength for brick of its class, and good stability of volume. Its resistance to thermal spalling is good.

CORALITE XD is an 85 per cent alumina brick of extremely high density. It has low porosity, high strength, good stability of volume at high temperatures, and excellent resistance to thermal spalling. This combination of desirable properties is achieved through an exclusive process of manufacture developed by Harbison-Walker. CORALITE XD brick are recommended for widely diversified industrial applications where high refractoriness and high density, exceptional strength, and good spalling resistance are the most important requirements.

CORAL, CORAL P, CORAL BP, and their modifications represent a special group of high-alumina refractories which were developed primarily for lining aluminum-melting furnaces. These refractories all have exceptional resistance to wetting, penetration, and reaction by molten aluminum and its many alloys. They also have properties which commend them for consideration in connection with the production and processing of some other nonferrous metals.

CORAL is a hard-burned brick containing approximately 85 per cent alumina. It is made with a special bond, developed by Harbison-Walker research, which contributes to its ex-

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cellent resistance to reaction with molten aluminum. CORAL P brick are chemically bonded with aluminum phosphate, and contain approximately 85 per cent alumina. They have high strength and withstand severe impact and abrasion. CORAL BP brick have the same composition as CORAL P, but are bonded by firing. They have exceedingly high strength.

90 PER CENT ALUMINA CLASS

KORUNDAL brick are made mainly from crystalline alumina, and contain approximately 91 per cent alumina and 8 per cent silica, with less than 1 per cent ferric oxide, lime, magnesia, and alkalies. The P.C.E. of KORUNDAL is estimated to be 40-41, equivalent to a softening temperature of nearly 3500°F.

The distinguishing characteristics of KORUNDAL brick are extremely high refractoriness, exceptional stability of volume and strength at high temperatures, and high resistance to thermal spalling and to corrosion by various industrial slags. They are also highly resistant to corrosion by the volatile alkalies and alkaline dusts present in the atmosphere of glass-tank and sodium silicate furnaces.

KORUNDAL XD, an important modification of KORUNDAL, is characterized by its extremely high density, appreciably higher than that of KORUNDAL, with corresponding lower porosity. These properties increase the resistance of the brick to corrosion and penetration by molten slags and other fluxes. KORUNDAL XD also has enhanced resistance to thermal shock and to load at temperatures up to 3000°F. and higher.

KORUNDAL and KORUNDAL XD brick are stable at very high temperatures because they consist mainly of the mineral corundum with a small percentage of mullite. Both of these minerals are highly resistant to corrosion by alkalies and some other fluxes at high temperatures.

KORUNDAL and KORUNDAL XD brick are suitable for service under conditions of soaking heat and severe fluxing action at very high temperatures. They satisfactorily withstand the severe corrosive action of oil ash having a high content of alkalies and vanadium oxide. KORUNDAL brick are used in piers, in supporting arches, and in other constructions where heavy loads at high temperatures prevail. They give outstanding service in the jambs, port floors, port arches, tongue arches, and, under the most severe conditions, in top checker courses of glass-tank furnaces. They are also used to advantage in roofs of some high-temperature electric furnaces producing ferroalloys, and in sidewalls and bottoms of aluminum and aluminum alloy melting furnaces.

MULLITE CLASS

Pure mullite ($3Al_2O_3 \cdot 2SiO_2$) has a composition of 71.8 per cent alumina and 28.2 per cent silica. The natural minerals kyanite, sillimanite, and andalusite of theoretical purity contain only 62.9 per cent alumina as compared with 71.8 for mullite, and when fired either alone or bonded with refractory clays can only partially approach the mullite composition.

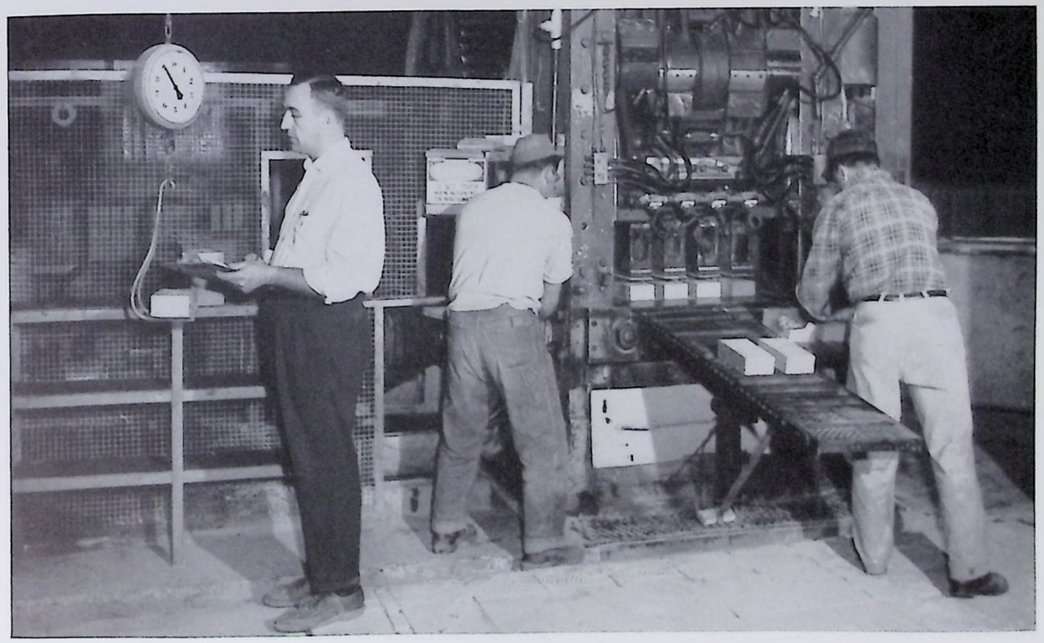
H-W MULLITE brick are made from the synthetic mineral mullite prepared by Harbison-Walker from raw materials of an unusually high degree of purity, which are prepared and sintered at high temperatures in a rotary kiln. The brick consist essentially of interlacing crystals of the mineral mullite, and are virtually free from alkalies and other impurities.

H-W MULLITE has a P.C.E. value of about 38, corresponding to a softening temperature of 3335°F. In volume stability at temperatures up to 3140°F. it is far superior to some brick of the usual 70 per cent and higher alumina classes. It has excellent load-bearing properties, together with marked resistance to fluxing by corrosive dusts and volatile alkalies. It is used to advantage in glass-melting furnaces, electric steelmelting furnace roofs, in various other metallurgical furnaces, and diversified applications where severe service conditions prevail.

CORUNDUM CLASS

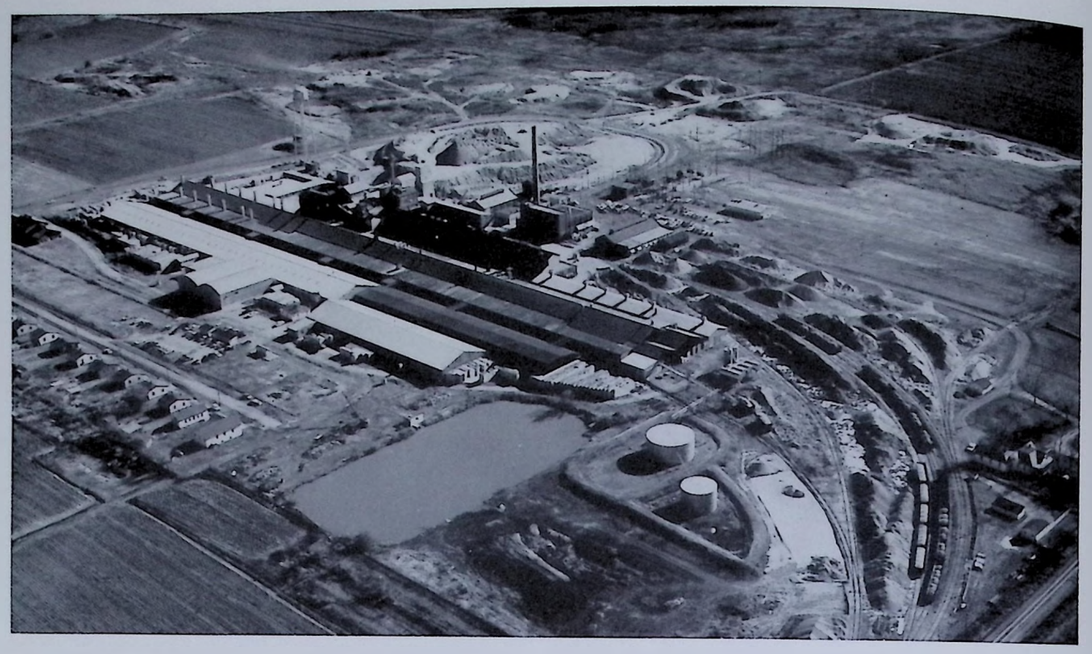
H-W CORUNDUM is an extremely hard-fired refractory, consisting entirely of corundum (crystalline alumina) in the purest form commercially available. The content of alumina (Al_2O_3) is above 99 per cent, and that of the basic fluxes lime, magnesia, and alkalies totals less than 0.5 per cent. Because of this high degree of purity the melting point is almost as high as that of pure corundum, which is approximately 3720° F. (2050°C). H-W CORUNDUM brick are very strong, and at high temperatures they are outstanding in resistance to deformation under load. They are exceptionally stable in volume at high temperatures, since in the process of manufacture, they are fired to temperatures in excess of 3000°F. in a kiln designed especially for the purpose.

H-W CORUNDUM brick are well adapted to service at very high temperatures. They are highly resistant to attack by strongly alkaline and other basic fluxes. They may be used advantageously for operating conditions similar to those for which KORUNDAL XD is adapted, under such conditions that longest service life can be secured only from brick of the highest possible content of alumina.

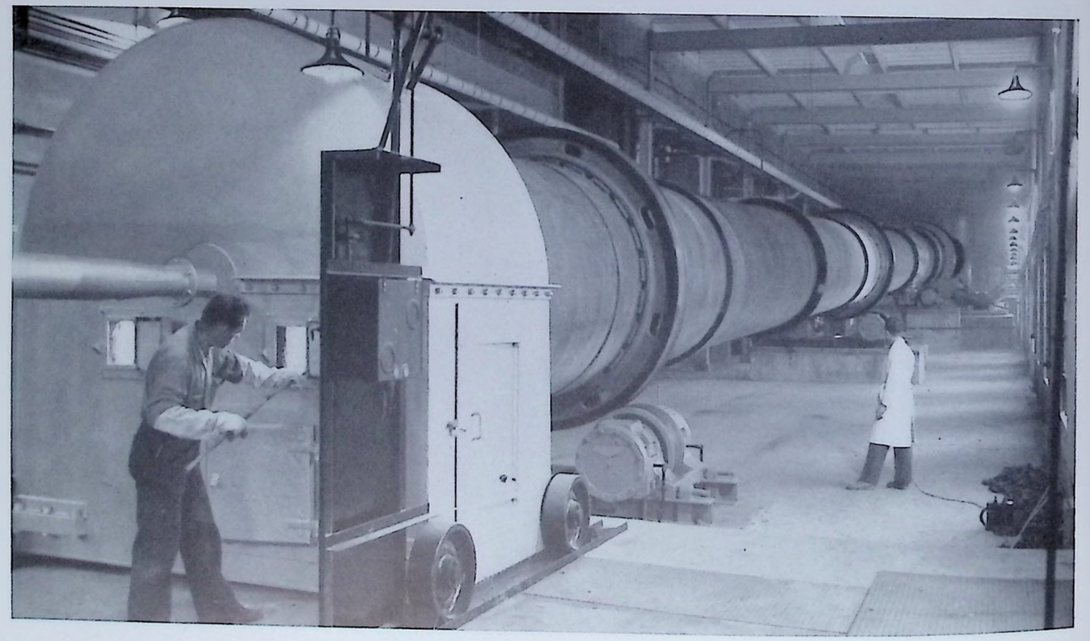


Power-Pressing High-Alumina Brick at Clearfield, Pennsylvania.

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Airplane View of Vandalia, Missouri, Plant where High-Alumina Refractories are Made.



Rotary Kiln at Vandalia Works Used for Calcination of High-Alumina Clays and Other Clays.



SILICA REFRACTORIES

HARBISON-WALKER REFRACTORIES COMPANY

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HARBISON-WALKER BRANDS OF SILICA REFRACTORIES

Brand	Quality	Typical Service
		BRICK
VEGA	Superduty	General superduty service. Open-hearth roofs; glass furnace crowns, walls, and other parts; copper smelting and refining furnaces.
VEGA HP	Superduty	Hot repairs for open-hearth roofs; other superduty service where high resistance to spalling is important.
STAR	Conventional	General high-duty service. Electric furnace roofs and sidewalls. Glass furnace walls, crowns, and other parts. Copper smelting and refining furnaces. Chemical recovery coke ovens. Beehive coke ovens.
VEGALITE	Insulating	Insulation of silica brick, especially roofs of glass tanks. Construction of tunnel kiln crowns.

Both VEGA and STAR are supplied in several different modifications, to serve various particular needs.

		QUARTZITE GANISTER
H-W GROUND QUARTZITE		Bonded with refractory clays used for monolithic furnace and ladle linings.

MORTAR MATERIALS

For all applications of silica brick, there are H-W brands of mortar materials of proved quality for laying them. They are discussed on pages 138 to 146.

SILICA REFRACTORIES

THE plants of Harbison-Walker at which silica brick are manufactured are situated in Alabama, California, Indiana, Maryland, Ohio, Pennsylvania, and Texas, in close proximity to the consuming industries. The advantageous geographic distribution of these plants facilitates delivery to all points.

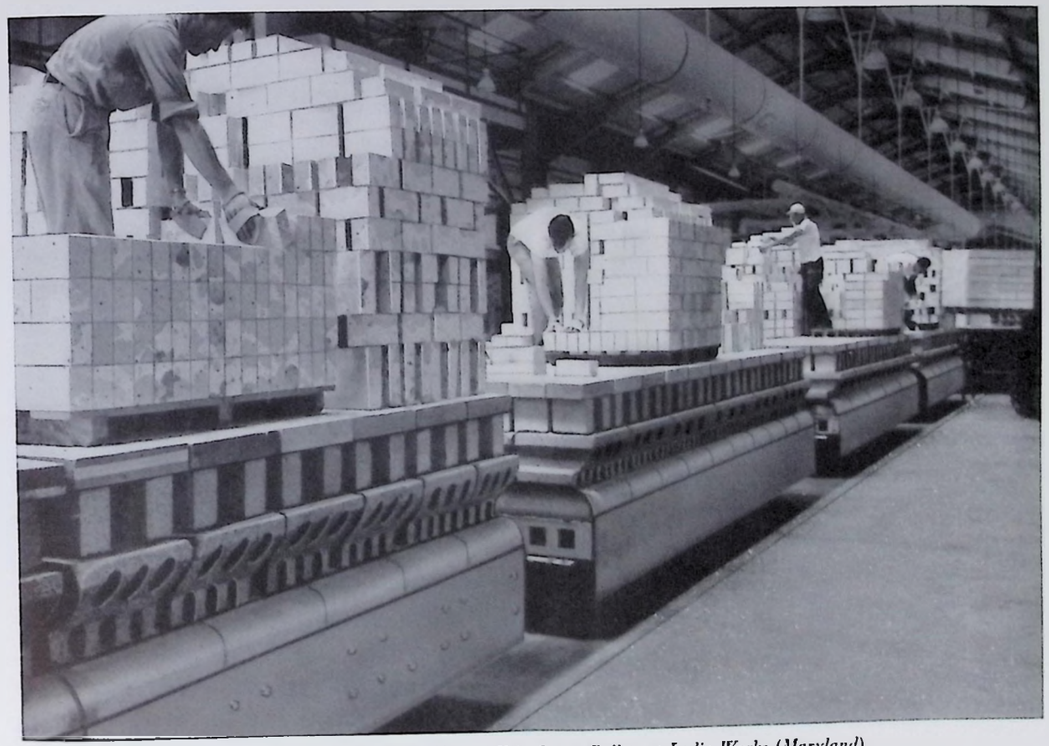
Raw Materials: The raw material used in the manufacture of silica refractories consists essentially of the mineral quartz in finely crystalline form, having the proper characteristics of conversion to the high-temperature crystal modifications of silica. Washing of the rock is practiced to remove natural impurities and thus to insure the highest commercial quality.

Manufacture: The crushed raw material is ground in enclosed dry pans, and a proportion of the material from the dry pans is fed to ball mills for fine grinding. The ground material is separated into several sizings by screening. These are blended in definite proportions, usually in pan-type mixers, where water, 2.0 to 3.5 per cent of lime, and organic binders are added. The lime is necessary for the formation of a strong ceramic bond.

Standard sizes and many special shapes are formed by power pressing. The gravity-machine method of forming is used to a relatively slight extent for certain established requirements. Some special shapes are formed by impact pressing; those which cannot be molded mechanically are formed by hand.

Immediately after being molded, the "green" or unfired brick are placed on steel pallets and loaded upon drier cars or directly upon tunnel kiln cars. They are dried in tunnel driers and fired at high temperatures in continuous tunnel kilns or in periodic kilns. The tunnel kilns range from 500 to 600 feet in length, and are the longest used in the refractories industry. The firing temperature must be high enough to convert the quartz into the forms of silica which are stable at high temperatures. In the firing and cooling of silica refractories there are critical temperature ranges through which the brick must pass; consequently, it is necessary to maintain a carefully planned time-temperature schedule. This insures the production of strong well-bonded brick, which during firing attain their normal permanent expansion of 12 to 15 per cent by volume.

Effects of Alumina and Alkalies: Silica brick after firing contain a small proportion of silicates in a body which is otherwise crystalline silica. Upon being reheated to high temperatures, the silicates melt to form a liquid; as the temperature rises, the amount of liquid increases through solution of silica, at first very slowly and then more rapidly, especially above 2900°F. When relatively small amounts of liquid are present, the solid crystalline portion of a brick forms a rigid skeleton, with liquid merely between the solid particles, and the brick as a whole retains its rigidity even under load. With the larger amounts of liquid developed at higher temperatures, the bond is weak-



Transfer of Silica Brick from Tunnel Kiln Car to Pallets at Leslie Works (Maryland).

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ened, and the brick may lose its rigidity.

The percentage of liquid formed at high temperatures in brick containing the usual 2.0 to 3.5 per cent of lime increases almost in direct proportion to any increase in the total amount of alumina, titania, and alkalies. The temperature of failure under load decreases correspondingly. Individually, the effects of these oxides vary appreciably. In silica brick, when the sum of the alumina, titania, and alkalies is less than 0.50 per cent, the temperature of failure under a load of 25 pounds per square inch, is 50° to 90°F. higher than for brick containing a total of 1.0 per cent of these oxides. It is for this reason that the brick classified as "superduty silica brick" may contain no more than 0.50 per cent total alumina, titania, and alkalies.

Characteristic Properties: Among the important properties of silica brick are their relatively high melting temperatures of about 3080° to 3110°F.; their ability to withstand a pressure of 25 to 50 pounds per square inch at temperatures within 50° to 100°F. of their ultimate melting points; high resistance to many basic dusts and fumes and to acid slags; constancy of volume at temperatures above 1200°F.; and virtual freedom from thermal spalling above 1200°F. At high temperatures, the thermal conductivity of most silica brick is somewhat higher than that of the usual fireclay brick.

At temperatures below 1200°F., silica brick have less resistance to thermal shock than fireclay refractories. They are readily attacked by basic slags, and by iron oxide at high temperatures in a reducing atmosphere.

The refractoriness, strength, resistance to thermal shock, and other properties of silica brick differ appreciably among the several modifications of VEGA and STAR brands, depending upon the service for which the brick are intended.

SILICA BRICK

VEGA: The superduty silica brick VEGA was developed to meet the demand for a silica refractory that would permit higher furnace temperatures, give longer life, and reduce maintenance costs. The purity of the raw materials used for the manufacture of VEGA brick is maintained by a rigorous program of quality control testing. Its content of alumina plus alkalies and titania does not exceed 0.35 per cent maximum, and its refractoriness in the load test at 25 pounds per square inch is approximately 75°F. higher than that of STAR. In the roofs of open-hearth steel furnaces, VEGA brick outlast conventional silica brick by a considerable margin.

VEGA superduty silica brick are used with equally satisfactory results in the superstructure of glass-tank furnaces, in the roofs of copper reverberatory furnaces, nickel and copper anode furnaces, and copper wirebar furnaces.

VEGA HP: Included in Harbison-Walker's line of silica refractories is a modification of VEGA known as VEGA HP. Its primary application is the hot-patching of open-hearth roofs and other furnace structures.

VEGA HP is similar in strength and porosity to VEGA, and it has the same low content of alumina plus alkalies. In its temperature of failure in the load test at 25 pounds per square inch, it comes within 10° to 20°F. of VEGA and is 50° to 60°F. higher than silica brick of conventional quality. The distinguishing property of VEGA HP is its outstanding resistance to thermal shock. It can be heated safely at a rate two or three times as rapid as is safe for most other superduty silica brick of comparable alumina content. This property is attained by the addition of catalysts to the brick batch, and by certain changes in manufacturing.

VEGA HP is recommended for hot-patching open-hearth roofs, for complete open-hearth or electric furnace roofs, or other structures built of silica brick where resistance to thermal shock is highly important.

STAR: For more than sixty years, STAR silica brick of conventional quality have been regarded as the standard of quality for this type of refractory. The properties responsible for the excellent service of this brick are rigidity under load at high temperatures, high resistance to spalling above 1200°F., high mechanical strength and resistance to abrasion, resistance to corrosion by acid slags, uniformity of size and excellence of workmanship.

STAR silica brick are used extensively in a wide variety of industrial furnaces. They are employed in the construction and maintenance of open-hearth and electric steel furnaces, by-product and beehive coke ovens, glass tanks, copper matte reverberatory furnaces, copper and nickel refining furnaces, copper wirebar and anode furnaces, zinc furnaces, tunnel kilns, vertical shaft lime kilns, and various other furnaces. They are widely favored for the construction of roof arches and piers. Modern manufacturing equipment and the large capacity of Harbison-Walker's silica brick plants make possible the most satisfactory handling of orders of any size.

A modification of STAR silica brick, branded STAR DASH, developed especially for electric furnace roofs and sidewalls, is supplied for use under severe spalling conditions. It can be heated safely nearly twice as rapidly as most other silica brick of conventional quality.

STAR Silica for Coke Ovens: For more than half a century, Harbison-Walker STAR silica brick have been widely accepted as the standard of quality for the construction of chemical-recovery or by-product coke ovens. The company has supplied the refractories for the greater percentage of the thousands of ovens in the United States and Canada.

The extremely rigid requirements for the silica brick for this service are fully met by a modification of STAR made especially for by-product coke ovens. Adequate refractoriness is paramount. The brick must be properly fired, to render them volume-stable in service. They must have as nearly perfect workmanship as is commercially practicable in order to secure strong gas-tight construction. The oven wall brick must be very strong for resistance to abrasion and load at operating temperatures. They must withstand rapid temperature changes, and they must be of texture and density conducive to the greatest possible flow of heat through the walls. Harbison-Walker, with its experience in making of silica brick for by-product coke ovens, is particularly qualified to produce superior products for this service.

STAR silica brick, of a modification especially adapted to service in the crowns of beehive coke ovens, are strong and resistant to thermal shock such as is common to the operation of these ovens.

VEGALITE is a lightweight silica brick, with a bulk density of only 60 pounds per cubic foot. It is suitable for use up to 3000°F. At a mean temperature of 1200°F., its insulating value is more than twice that of STAR. VEGALITE is used largely for the insulation of silica brick construction, especially the crowns of glass tanks. It serves also for the construction of tunnel kiln crowns, and its properties commend it for arches of wide span.

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H-W GROUND QUARTZITE

The term "ganister" is commonly applied to the dense high-silica rock (quartzite), which is suitable for use in the manufacture of silica refractories. Ganister rock is ground to various sizings, and supplied for many important uses. **H-W GROUND QUARTZITE**, in various mixtures with H-W WEATHERED BOND B CLAY, is used for making rammed linings and for daubing and patching. The mixtures may be rammed into place or they may be applied by means of any of the several available commercial types of air guns. KUPLOMIX, which is described on page 161, is a prepared mixture of this kind.

H-W GROUND QUARTZITE, of the sizings especially suited for the various purposes, has been adopted as standard at many plants for building the monolithic bottoms of acid open-hearth and acid electric steelmelting furnaces. It is widely used also for the preparation of monolithic ladle linings in steel foundries. Usually a percentage of highly refractory plastic bond clay furnished by Harbison-Walker is mixed with the ground ganister. When desired, the ground ganister is supplied mixed with the clay, ready for use. It serves well in various mixtures for forming the linings of electric induction furnaces.

While many side-blow converters in steel foundries are lined entirely with STAR silica brick, others are lined wholly or in part with a mixture of H-W GROUND QUARTZITE and refractory bond clay. A special blend of this ganister with H-W WEATHERED BOND B CLAY is used extensively.

MORTAR MATERIALS

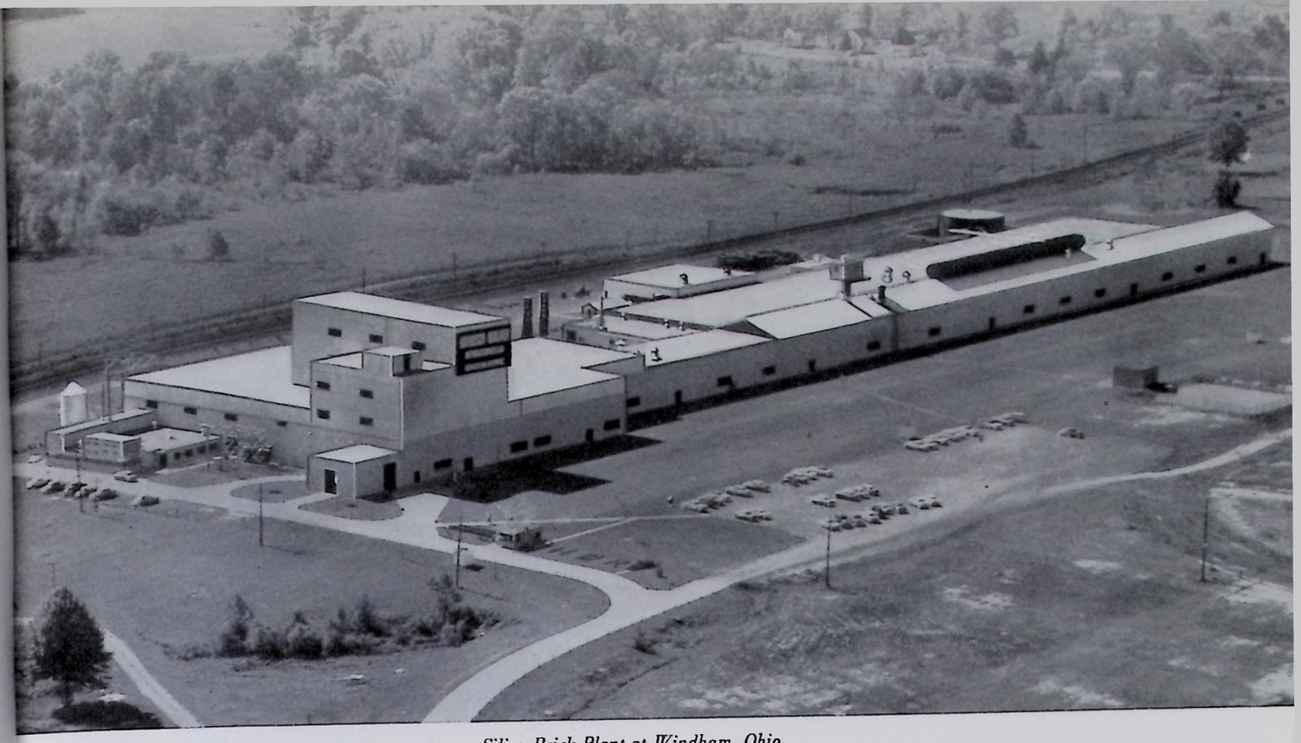
Most mortar materials commonly used for laying silica brick have a silica base; some have a chrome ore base. Among mortars with a silica base are FIREBOND, which is air-setting, and H-W STAR SILICA FIRE CLAY, H-W COKE OVEN SILICA FIRE CLAY, STARBOND, and VEGA BOND which are heat-setting. VEGA BOND, which was developed especially for use with superduty silica brick, represents the ultimate in refractoriness of silica mortar materials. For applications requiring a bonding mortar with a chrome ore base, Harbison-Walker supplies THERMOLITH, which is air-setting, and H-W SPECIAL FURNACE CHROME, which is heat-setting.

SUGGESTIONS CONCERNING THE USE OF SILICA REFRACTORIES

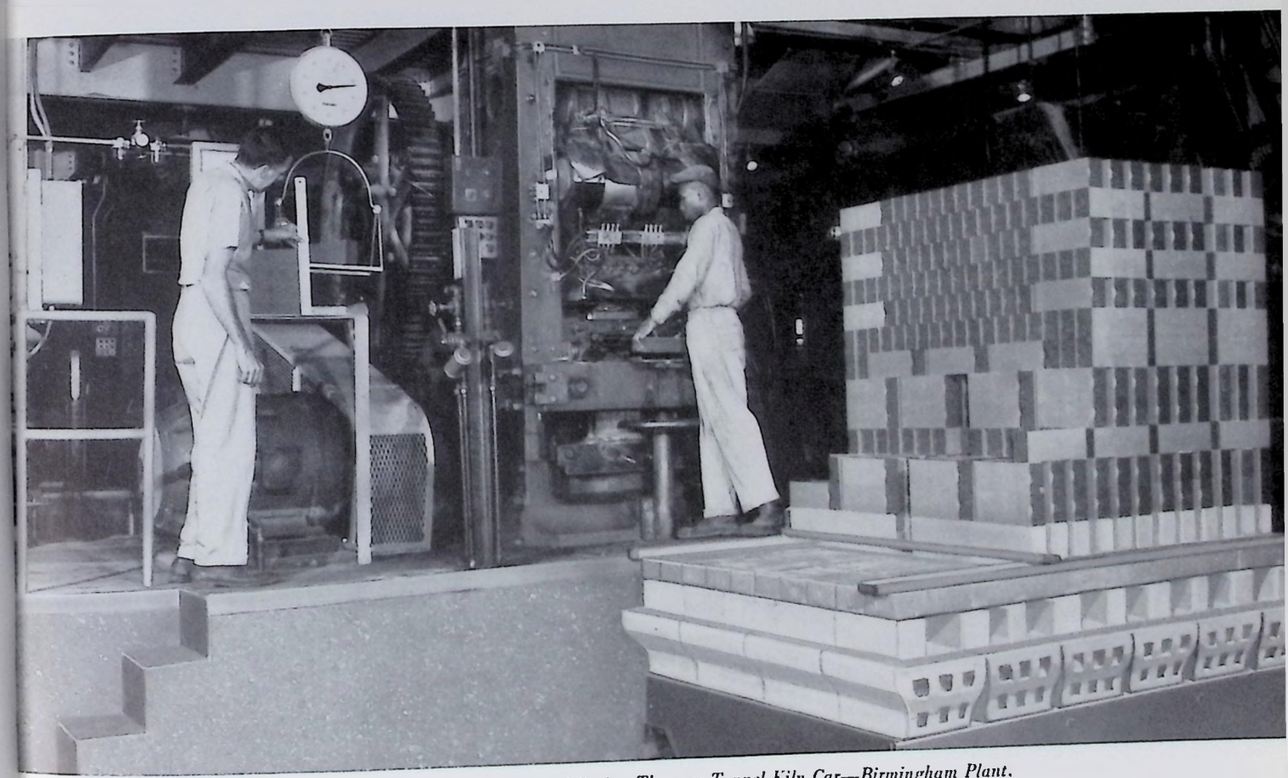
Silica brick should be kept dry during storage.

Bonding mortar used for silica brick should be mixed with sufficient water to permit laying with dipped joints. Heating of the brickwork to a dull red heat should be done slowly, to expel the moisture gradually, and to avoid spalling. To avoid too rapid heating of wall and arch surfaces, flame should not be allowed to come in contact with the brick during the early stages of heating. VEGA HP and STAR DASH can safely be heated more rapidly than the usual silica brick. Both heating and cooling should be uniformly progressive, with a minimum of fluctuation. Provision for expansion of the brick is made at the rate of ⅛ to 3/16 inch per foot, depending upon the construction.

Cooling of silica brick to a red heat of about 1200°F. may be accomplished rather rapidly if cold air is not allowed to impinge upon the brick at any time. Further cooling from a dull red heat to atmospheric temperatures should be done slowly and carefully to avoid spalling.

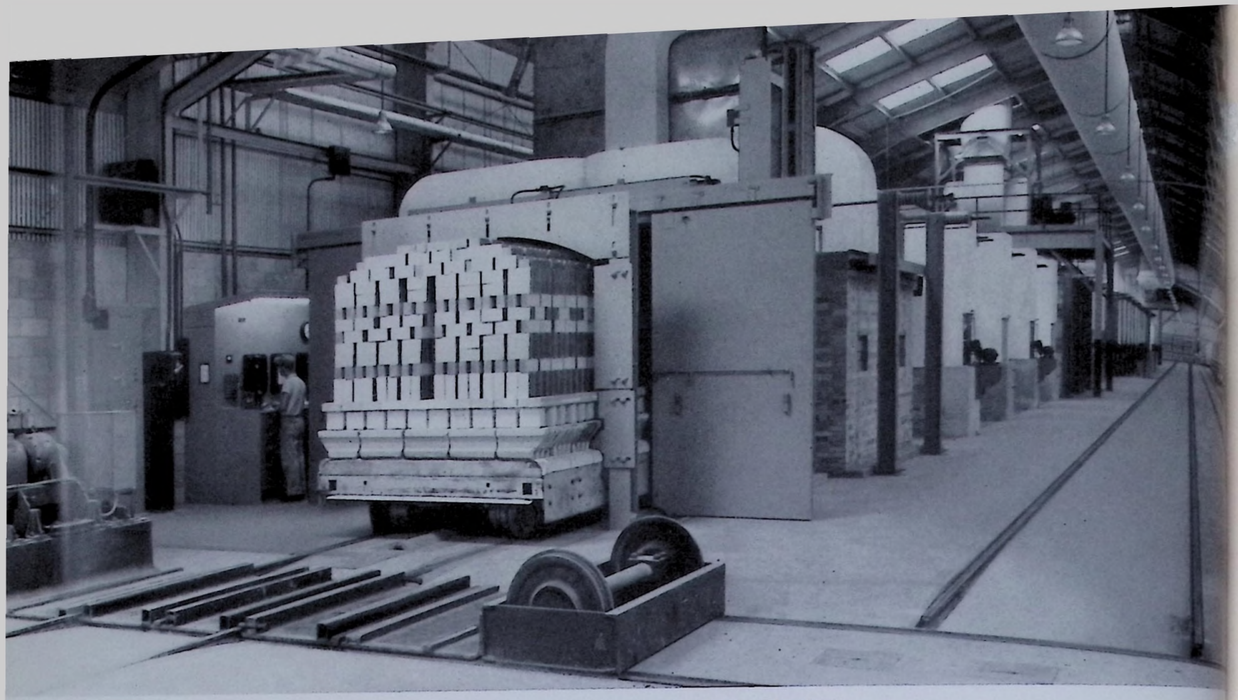


Silica Brick Plant at Windham, Ohio.

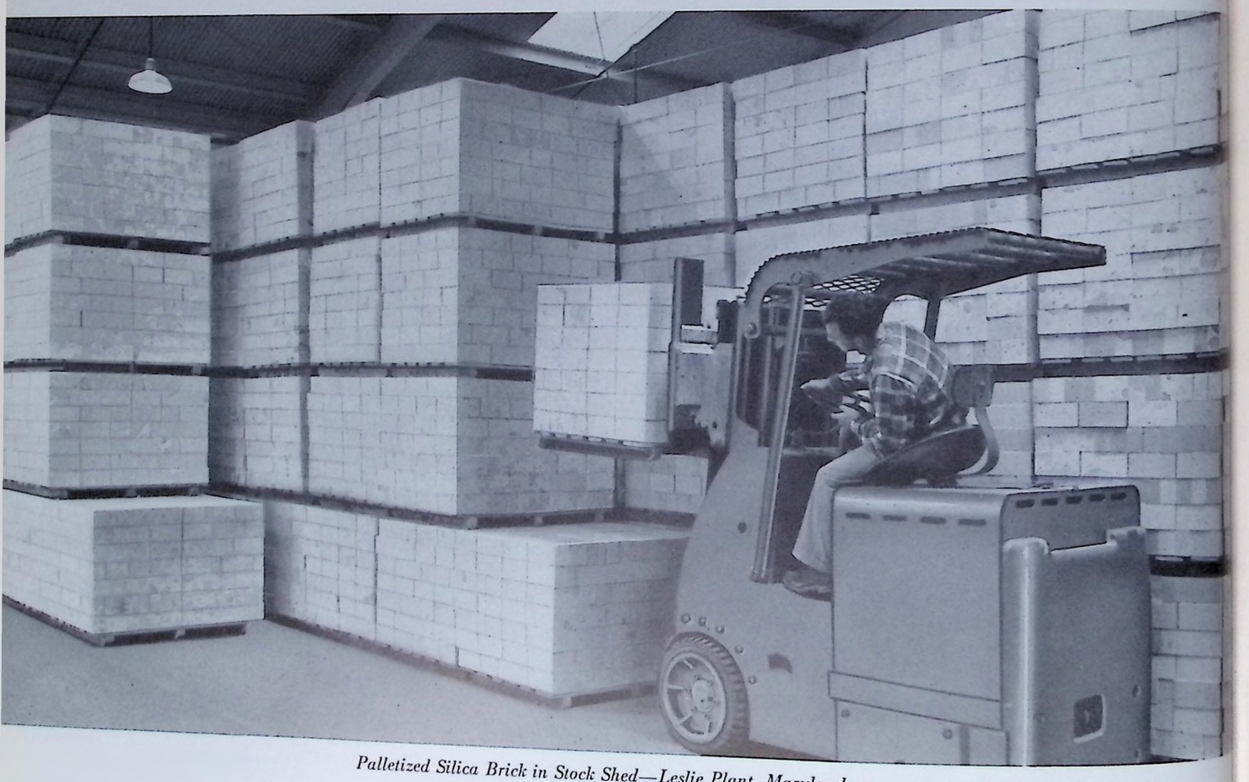


Power Pressing of Silica Brick and Setting Them on Tunnel-Kiln Car—Birmingham Plant.

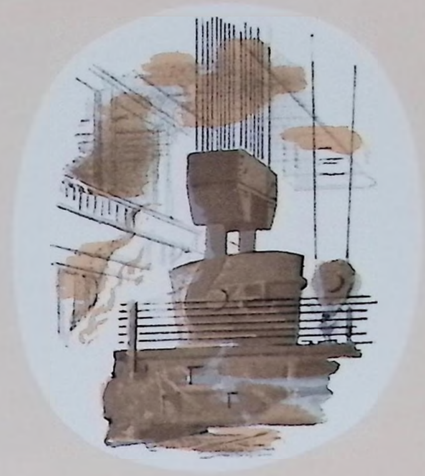
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Kiln Car Entering Tunnel Kiln in Plant at Leslie, Maryland.



Palletized Silica Brick in Stock Shed—Leslie Plant, Maryland.



BASIC

REFRACTORIES

HARBISON-WALKER REFRACTORIES COMPANY

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HARBISON-WALKER BRANDS OF BASIC BRICK

Brand	Class	Type of Bond	Page
H-W Periklase	Magnesite (High-Periclase)	Fired	104
Harklase	Magnesite (High-Periclase)	Fired	104
H-W Magnesite	Magnesite	Fired	104
Oxibak	Magnesite	Fired	104
Magnex CF	Magnesite	Chemical	104
Magnecon	Magnesite	Fired	104
Magnel	Magnesite (High-Periclase) plus Spinel	Fired	106
Magnelex	Magnesite (High-Periclase) plus Spinel	Chemical	106
Magnex	Magnesite-Chrome	Chemical	106
Magnex B	Magnesite-Chrome	Fired	106
Magnex H	Magnesite-Chrome	Chemical	106
Metalkase Magnex H	Magnesite-Chrome	Chemical	106
Magnex OHR	Magnesite-Chrome	Chemical	108
Metalkase Magnex	Magnesite-Chrome	Chemical	108
Thermag	Magnesite-Chrome plus Spinel	Fired	108
Thermag H	Magnesite-Chrome plus Spinel	Fired	108
Chromex	Chrome-Magnesite	Chemical	108
Chromex B	Chrome-Magnesite	Fired	109
H-W Chrome	Chrome	Fired	109
Chromex S	Chrome	Chemical	110
Forsterite	Forsterite	Fired	110
Forsterite L	Forsterite plus Spinel	Fired	110
Oxiline H	Magnesite-Dolomite	Bitumen	110
Oxiline CL	Magnesite	Bitumen	110

NOTE: Any brand of H-W basic brick may be metal encased on three or four sides. Many basic brick brands are metal encased and internally plated; or metal encased, internally plated and fitted with a steel suspension member, known as a Tabkase (see page 102). Certain sizes are provided with a creased metal casing to provide expansion allowance (Exkase). The word "Metalkase," preceding a brand name, shows that the brick are metal encased; "Tabkase," that the brick are metal encased and provided with a suspension member; "Exkase," that the casing has an expansion crease. The suffix XP indicates that the brick has a single internal steel plate; XXP, two internal plates. Thus the brand "Metalkase Magnex" designates a metal-encased Magnex brick; "Metalkase Magnex XXP" a metal-encased Magnex brick provided with two internal steel plates. Similarly, the term "Tabkase Magnex XXP" signifies brick of Magnex composition, provided with a Tabkase and two internal plates; and "Exkase Magnex OHR" a metal-encased Magnex brick having a creased metal casing to provide for thermal expansion, and intended for use in open-hearth roofs. Metalkase brick are used extensively in suspended installations of various designs.

HARBISON-WALKER BRANDS OF MORTAR AND MONOLITHIC BASIC REFRACTORIES

Brand	Composition or Base	Type of Bond or Set	Page
Grain Materials			
H-W Washington Dead-Burned Magnesite Grains	D.B. Magnesite*	Heat	111
H-W Periklase Grains	D.B. Magnesite (High-Periclase)	Heat	111
Mortar Materials			
H-W Washington Furnace Magnesite	D.B. Magnesite	Heat	112, 138, 142
H-W Special Furnace Chrome	Chrome Ore	Heat	112, 138, 143
H-W Periklase Bonding Mortar	D.B. Magnesite (High-Periclase)	Air	112, 138, 145
Forsterite Bonding Mortar	Forsterite	Air	112, 138, 146
Thermolith	Chrome Ore	Air	112, 138, 146
Hot-Patching Mixes			
H-W Magnaset	D.B. Magnesite	Heat	112
QX Magnifrit	D.B. Magnesite	Heat	112
Ramming Mixes			
H-W C-Mix	D.B. Magnesite (High-Periclase)	Air	112, 152, 160
H-W Magnamix	D.B. Magnesite	Air	113, 152, 160
H-W Magnamix 85	D.B. Magnesite	Air	113, 152, 160
H-W Magnamix F	D.B. Magnesite	Air	113
H-W Periklase Batch	D.B. Magnesite (High-Periclase)	Air	152, 160
Thermolith Batch	Chrome Ore	Air	152, 160
Plastic Thermolith Batch	Chrome Ore	Air	152, 158
H-W Oximix	D.B. Magnesite-Dolomite	Bitumen	113, 152, 160
Gun Mixes			
H-W Magnamix S	D.B. Magnesite	Air	114, 152, 162
H-W Special Furnace Chrome GG	Chrome Ore	Heat	114, 152, 162
H-W Gunshot	Chrome Ore	Air	114, 152, 162
Castables			
H-W Perimix	D.B. Magnesite	Hydraulic	153, 166
H-W Chrome Castable	Chrome Ore	Hydraulic	153, 165
H-W Harchrome Castable	Chrome Ore	Hydraulic	153, 165
H-W Chromepak	Chrome Ore-D.B. Magnesite	Air	153, 166
H-W Chrome Fill	Chrome Ore	Hydraulic	153, 165
Molding Materials			
H-W Forsterite Grains	Olivine	Heat	170, 172
H-W Forsterite Flour	Olivine	Heat	170, 172
H-W Magnamold	D.B. Magnesite	Heat	170, 172

* *D.B. Magnesite = Dead-Burned Magnesite.*

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BASIC REFRACTORIES

The properties and uses of magnesia, chrome, and forsterite are such that these materials are grouped together as "basic refractories." At high temperatures, they are all highly resistant to the corrosive action of chemically basic slags, solid or liquid oxides, dusts, and fumes.

Nomenclature: Originally, the term "magnesite" referred solely to the naturally occurring mineral or rock composed essentially of magnesium carbonate. However, ever since the industrial usage of the natural mineral began, the term "magnesite" with a modifying word has been applied to most manufactured magnesia refractory products. Thus dead-burned magnesia is known commercially as "dead-burned magnesite," and refractory brick consisting essentially of magnesia are called "magnesite" brick, and to some extent "periclase" brick. The terms "magnesite-chrome" and "chrome-magnesite" refer to blends of dead-burned magnesite and chrome ore; the component which predominates is named first.

The mineral periclase is the stable crystalline form of magnesium oxide. Hence it follows that all refractories manufactured of magnesia are mineralogically periclase, regardless of their origin, whether from natural magnesite or brucite, or from sea water or other brine.

Dead-Burned Magnesite: The strongly basic chemical character of magnesia, together with its extremely high temperature of fusion, renders it invaluable for use as a refractory in contact with basic slags and other basic fluxes. Almost from the time the basic open-hearth process for making steel was introduced down to the present, dead-burned magnesite has been employed as a hearth material for the furnace. Refractory brick made wholly or partly of dead-burned magnesite have filled important metallurgical and other needs. From its various sources, Harbison-Walker is in position to supply magnesia-containing refractories of any type, class, or amount which may be desired.

The largest producer of dead-burned magnesite in the United States is the Northwest Magnesite Company in which Harbison-Walker has a controlling interest. The company has two large operations, one at Chewelah, Washington and the other at Cape May, New Jersey. Near Chewelah, large deposits of naturally occurring magnesite are mined by the open-pit method. All of the crude rock is beneficiated by the sink-float method, and a substantial proportion by oil flotation. The concentrates are further processed in the rotary kiln plant at Chewelah, producing dead-burned grain magnesite of excellent quality.

In its large operation at Cape May, New Jersey, Northwest Magnesite Company produces high-purity dead-burned magnesite from magnesium hydrate produced by treatment of sea water with high-quality calcined dolomite in proper proportions. The magnesium hydrate formed is thickened and washed in huge concrete tanks 200 feet and 300 feet in diameter, after which it is filtered for further removal of water. The final step in processing the magnesium hydrate is firing in rotary kilns at very high temperatures to produce dense granular dead-burned magnesite, consisting essentially of the mineral periclase.

In 1957, Harbison-Walker completed building and started operating a plant at Ludington, Michigan, for the production of extremely pure dead-burned magnesite—periclase—from deep-well brine. At this plant, the company produces high-purity dead-burned magnesia of a high density formerly unobtainable commercially.

Chrome Ore: The refractoriness and unique chemical character of chrome ore and chrome brick give them an important role as materials for furnace linings. Of all basic refractory materials, chrome ore is the least basic. Practically all of the chrome ore used in this country for the manufacture of refractories is imported from the Philippine Islands, Turkey, Rhodesia, and South Africa. The ores of greatest utility as refractories contain 31 to 45 per cent Cr_2O_3, 24 to 35 per cent Al_2O_3, and 14 to 20 per cent MgO. The company's Research Department has made thorough studies of the properties of all the ores which are commercially available, and has developed methods of processing them for the production of superior refractory products.

Magnesite-Chrome Compositions: Great impetus to the use of basic refractories occurred during the early 1930's, when important discoveries were made regarding combinations of chrome ore and dead-burned magnesite. The accessory minerals in chrome ore are siliceous and in general not of high refractoriness. It was learned that the addition of finely ground dead-burned magnesite would convert the silicates to the refractory mineral forsterite, and also improve important high-temperature properties of the brick, including load-bearing ability, stability of volume, and resistance to spalling. Today most basic brick contain both dead-burned magnesite and chrome ore.

Forsterite: The development of a commercial refractory material consisting mainly of the mineral forsterite ($2MgO \cdot SiO_2$) is an achievement of Harbison-Walker research. Prior to this development, magnesium silicates had not been used as high-temperature refractories except on a small scale in Europe. Forsterite refractories are made essentially from the mineral olivine, with the addition of magnesia and generally of alumina. Because of their characteristic properties, forsterite refractories have become widely used for various important furnace applications.

Manufacture: Basic brick in general are formed at high pressure in mechanical presses from ground, sized and blended raw materials—dead-burned magnesite, chrome ore, olivine, and other minerals—with or without minor amounts of bonding agents. Some basic brick are bonded by firing; others are bonded chemically. Chemically-bonded basic brick were first introduced by Harbison-Walker in the early 1920's, and since then have become a type of basic refractory of major industrial importance.

The brick to be bonded by firing are first dried in controlled-humidity driers, then placed in continuous tunnel kilns and subjected to a soaking heat at a sufficiently high temperature to cause the grains to bond strongly together. For some types of basic refractories, the firing temperatures are 3000°F. or even higher.

In manufacturing chemically-bonded brick, the bonding constituents are blended with the ground materials before pressing, and the bond is developed by curing in special tunnel driers. Later, after having been placed in service, chemically-bonded brick undergo changes at high temperatures, and their desirable characteristics approach and in some properties even surpass those of brick which have been fired at high temperatures.

The various Harbison-Walker basic refractories are manufactured in large modern plants at Baltimore, Maryland and Hammond, Indiana. Many basic brands are produced also at the company's plants at Pittsburgh, Pennsylvania, Fairfield, Alabama, and Warm Springs, California. At all plants, uniformity and high quality of products are assured by quality control tests throughout all stages of manufacture.

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THE PRACTICE OF METAL-ENCASING BASIC BRICK

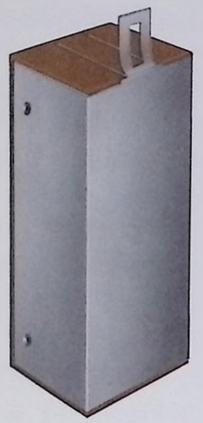
The practice of using steel casings or plates around and between basic refractories, for the purpose of increasing their life in service, was introduced by Harbison-Walker in 1916, and proved to be one of the truly great discoveries of the refractories industry. The practice was so successful that it grew rapidly, and today a large proportion of all basic brick used are metal encased. During the years, there have been changes and improvements in the manner of applying the metal to the brick. The most advanced practice is that now used by Harbison-Walker Refractories Company.

Metal encasing of the various brands of basic brick has accounted for improved practice and service in open-hearth and electric steelmelting furnaces, in copper and nickel reverberatory and copper refining furnaces, in rotary kilns, and various other industrial furnaces. It has made practicable the use of basic brick in many roof constructions.

Most metal-encased brick are of chemically-bonded magnesite-chrome compositions. However, basic brick of any class, either chemically bonded or fired, may be metal encased when service conditions require it.

TYPES OF METALKASE BRICK

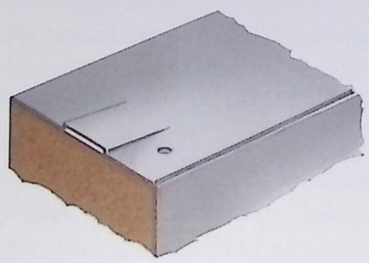
A.



A. Tabkase

H-W Tabkase brick, in addition to the metal casing and the internal plates, have a stainless steel tab by which the brick are given additional vertical support. They are used for basic roof and wall construction. Tabkase brick are also conveniently used for patching existing basic roofs to prolong the furnace campaigns. The word Tabkase is always used in association with a specific brand name, as for example Tabkase Magnex brick.

B.

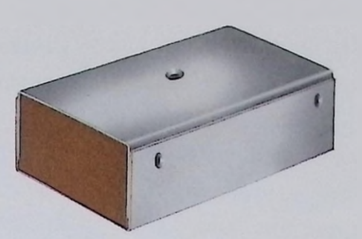


B. Exkase

H-W Exkase brick are Metalkase brick having a crease in the metal casing to provide expansion allowance. The word Exkase is used as a prefix with specific brand names, as for example Exkase Magnex OHR.

TYPES OF METALKASE BRICK—Continued

C.

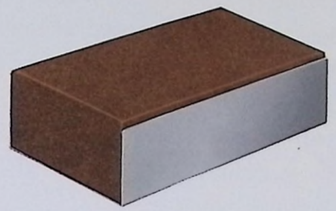


C. Metalkase Brick

Enclosed on all four sides in sheet steel.

The brick are fully preformed under high pressure before they are encased. Firm adherence of the patented welded steel casing to the refractory is assured by the tight grip of the indentation.

D.

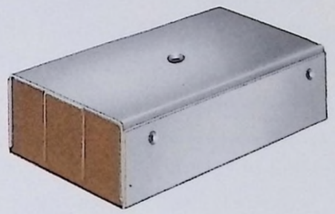


D. Metalkase Brick

Firmly encased in sheet steel on three sides.

These brick are especially suited for electric furnace sidewalls and other specific applications.

E.

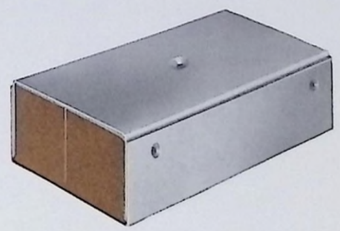


E. Metalkase XXP

Metalkase XXP brick are chemically-bonded basic brick with two internal plates, formed under high pressure, and are furnished in standard sizes, and suspended arch and other shapes. They are available in various compositions. In the illustration the Metalkase XXP brick is cut to show the plated construction. These plates extend throughout the entire length of the brick.

Extensive use in service has clearly demonstrated the superior resistance of the internally-plated brick to spalling and peeling.

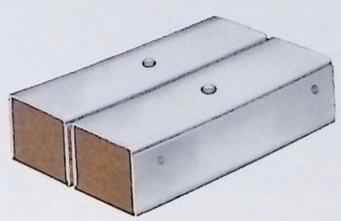
F.



F. Metalkase XP

Metalkase XP brick, having a single internal plate, are made in both chemically-bonded and hard-fired basic brick of various classes. They are available in standard sizes and many special shapes. These brick are used in various particular applications with great benefit.

G.



G. Metalkase 9 x 2¼ x 2½-inch Brick

Each brick is enclosed on all four sides in sheet steel. As laid in a furnace wall, the metal is spaced substantially the same as in Metalkase XP, and provides the advantages of hard-fired metal-encased basic brick, where desirable. Chemically-bonded brick also are furnished in this size.

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MAGNESITE BRICK

H-W PERIKLASE brick contain about 93 to 94 per cent magnesia, mainly as crystalline periclase, with less than 1 per cent iron oxide. Their superior properties result from the most desirable chemical composition, optimum grain sizing, high pressure of molding, and the very high temperature at which they are fired. They are very resistant to hydration on initial heating. They have good strength both cold and hot, and possess the very desirable property of excellent stability of volume at furnace temperatures under soaking heats.

H-W PERIKLASE brick give outstanding service in the subhearths of open-hearth and electric furnaces. They are also used in front and back walls of open-hearth furnaces; in some copper converters; in the lower sidewalls and invert-arch bottoms of copper refining furnaces; in the linings of lead softening, drossing, and by-product furnaces; in bottoms of heating furnaces; and in the high-temperature zone linings of some rotary kilns. In various types of high-temperature furnaces, H-W PERIKLASE brick meet a need for refractories usable at temperatures considerably above 3000°F.

HARKLASE brick, consisting almost entirely of pure periclase, have a magnesia content of over 97 per cent. The melting point of pure periclase is over 5000°F.—a temperature far higher than the melting points of other widely used refractories. With their exceptionally high refractoriness and ability to resist corrosion by various destructive basic slags, HARKLASE brick are used with special benefit in a variety of metallurgical and other industrial furnaces.

H-W MAGNESITE brick are made from dead-burned magnesite containing over 90 per cent magnesia and carefully controlled proportions of minor components. The brick are molded under heavy pressure, fired at high temperatures, and have great mechanical strength.

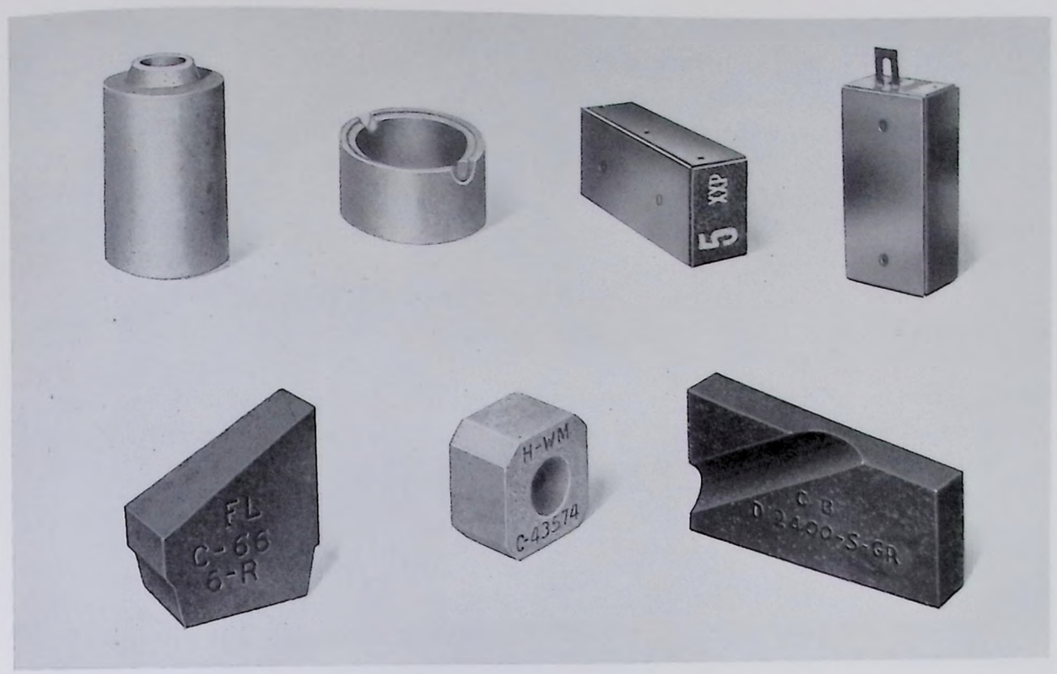
H-W MAGNESITE brick are highly resistant to erosion by molten metals and basic slags. Some of their most important applications are in the bottoms, the lower front and back walls of basic open-hearth furnaces; in the bottoms and lower sidewalls of basic electric steelmelting furnaces; in heating furnace bottoms; in copper and nickel converters, reverberatories, refining, and melting furnaces; in the lower sidewalls of lead softening and refining furnaces; and in parts of various other furnaces used in the metallurgical industries.

OXIBAK is a fired magnesite brick developed to meet the special service conditions which prevail in basic oxygen steelmaking vessels. It has a higher iron oxide content than other magnesite brick, is hard and dense and is highly resistant to erosion and to spalling. In addition to its main application as the back-up lining in oxygen steelmaking furnaces, it may also be used advantageously in the linings of some copper converters.

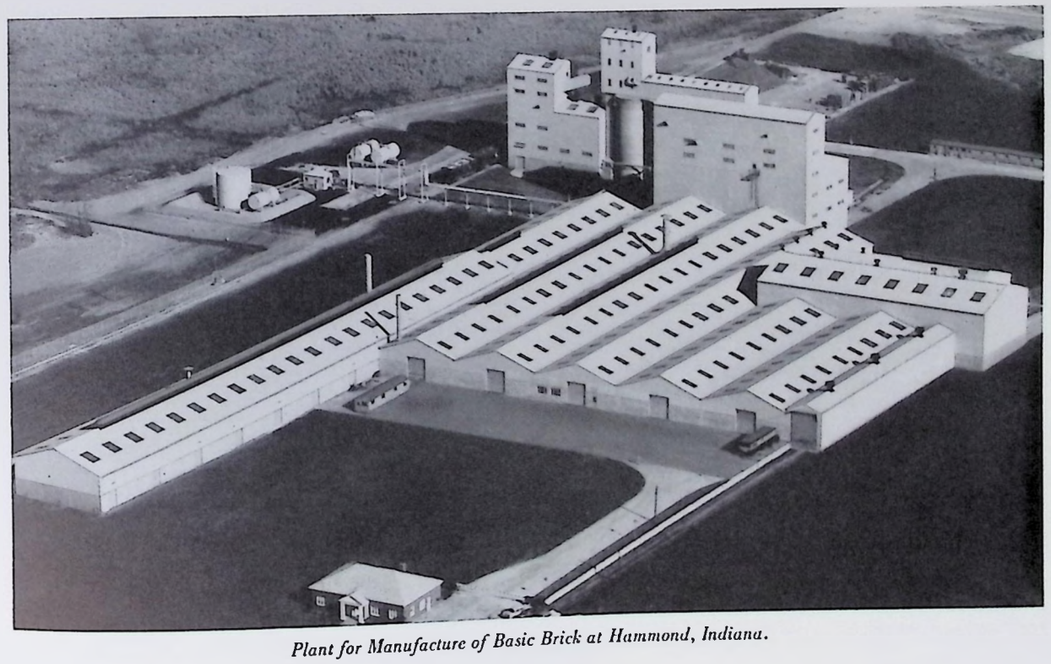
MAGNEX CF (chrome-free), a modification of the magnesite-chrome brick MAGNEX, is a chemically-bonded magnesite brick. It possesses in large degree the desirable physical properties of MAGNEX, and is particularly adapted for use in applications where the presence of chrome is objectionable, as in some basic cupola and electric furnace operations.

MAGNECON brick are made in Canada, from Canadian natural magnesite. They are manufactured by the company's Canadian subsidiary, Canadian Refractories Limited. They give excellent service in many special applications.

MAGNECON brick are unusually resistant to chemical attack by portland cement clinker.



Typical Basic Brick Shapes.



Plant for Manufacture of Basic Brick at Hammond, Indiana.

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They have achieved wide success in many countries for lining the burning zone of rotary cement kilns. Their outstanding ability to take a coating quickly, and to hold the coating when the kiln is cooled, is conducive to long service life and the maximum output of clinker at low cost for the refractories per barrel of cement.

MAGNECON brick serve advantageously for the linings of furnaces in which the slag is high in lime, or in which basic dusts come in contact with the refractories. At moderate temperatures, MAGNECON brick are resistant to iron scale and to slags high in iron oxide. They give excellent service in furnace operations where the brick are exposed to contact with lime, dolomite, or alkaline dust.

MAGNEL is a fired magnesite brick consisting essentially of crystalline magnesia or periclase with a bond of magnesium-aluminate spinel. It is used in open-hearth furnaces in the main roofs, front walls, back walls, and suspended uptake walls.

MAGNELEX is a chemically-bonded brick consisting of periclase with a spinel bond and having practically the same composition as MAGNEL. It is, however, superior in resistance to spalling, and is used in open-hearth front walls and end walls.

MAGNESITE-CHROME BRICK

MAGNEX is a chemically-bonded magnesite-chrome brick which, throughout the years, has acquired a wide reputation for quality and service. The sizing of the grains, the nature of the bond, and the high pressure of forming impart strength, rigidity, and good resistance to spalling. MAGNEX and METALKASE MAGNEX brick are well suited for back walls of basic open-hearth furnaces and for basic electric furnace walls above the metal and slag line.

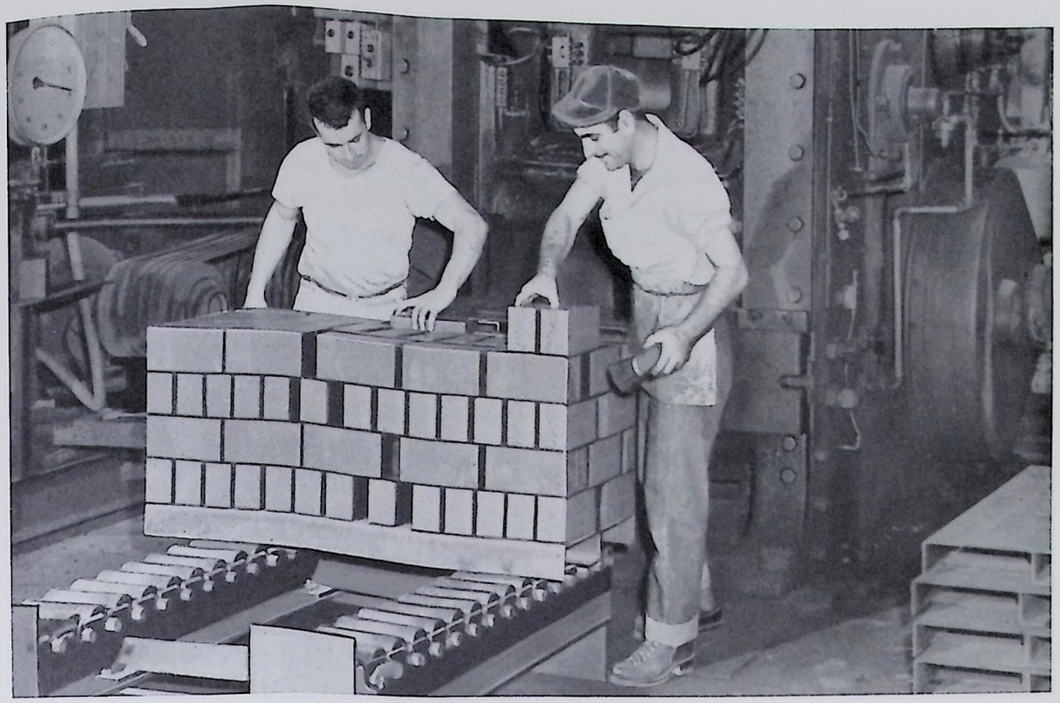
MAGNEX brick, installed with steel plates, are used advantageously in the burning zones of rotary kilns used for making portland cement clinker and various other products which are fired at high temperatures.

MAGNEX B is a fired magnesite-chrome brick of essentially the same composition as MAGNEX. Among its applications are linings of the burning zone in rotary kilns used for dead-burning magnesite and dolomite.

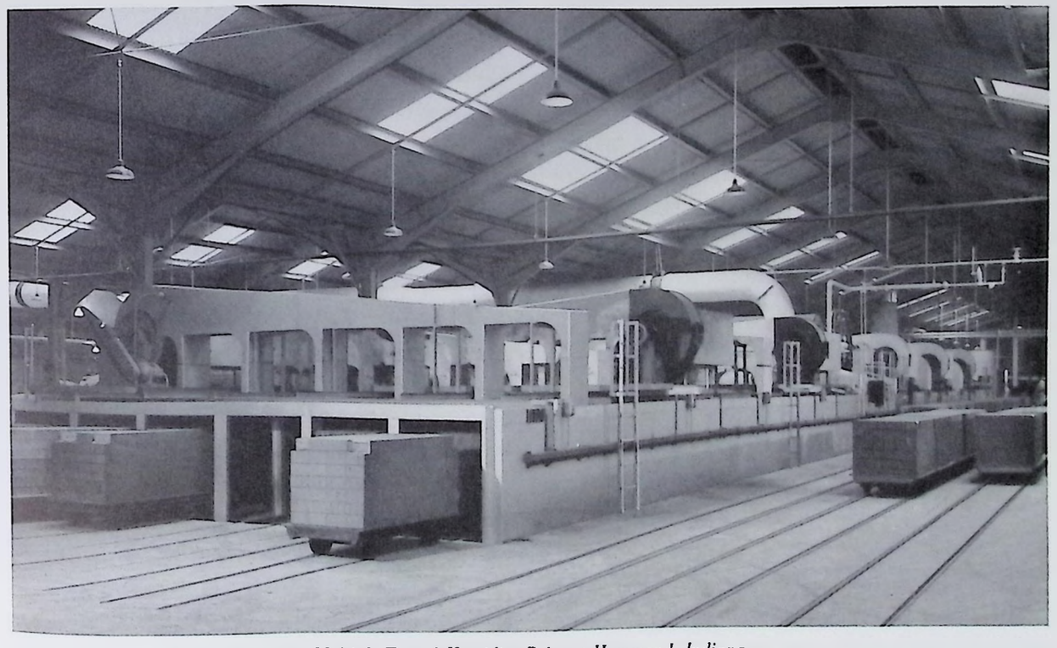
MAGNEX H is a chemically-bonded magnesite-chrome brick similar to MAGNEX, but of appreciably higher magnesia content. It is used for severe service applications in the steel industry, such as front and end walls of basic open-hearth furnaces, and the upper walls of electric steelmelting furnaces.

METALKASE MAGNEX H is the brand name for basic brick of MAGNEX H composition, suitably encased in sheet steel. METALKASE MAGNEX H has the high refractoriness and slag-resisting qualities of other magnesite-chrome brick, with improved resistance to spalling. In service, the metal at the hot ends oxidizes and combines with the magnesia of the brick to form a magnesioferrite bond, producing a monolithic surface. Farther back in the wall the steel remains rigid and reinforces the brickwork.

In the front and back walls of open-hearth furnaces, METALKASE MAGNEX H brick give several times the life of silica brick and have repeatedly demonstrated their superiority over various other basic refractories. In the end walls of furnaces having silica brick roofs, METALKASE MAGNEX H often lasts for as much as two or even three furnace campaigns. Its use in skewbacks and in roof shoulders or panels increases the life of the silica roof and



Power Pressing Basic Brick at Warm Springs, California.



Multiple-Tunnel Humidity Drier at Hammond, Indiana.

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results in longer life of front and back walls.

In the upper sidewalls of some basic electric steelmelting furnaces, METALKASE MAGNEX H has given double the life secured from other basic brick because of its superior resistance to spalling. It is also used advantageously for the lower sidewalls of soaking pits.

METALKASE MAGNEX H brick are manufactured in standard 9, 13½, and 18-inch straights and sizes, as well as in a wide variety of special shapes, including various designs of suspended shapes.

Throughout the years, METALKASE MAGNEX H brick without internal plates have given outstanding service, largely because of their resistance to spalling. Extensive use in service has shown that the internally-plated brick have even greater resistance to spalling, and as a result of improved stress relief, appreciably reduced tendency to peel.

MAGNEX OHR is a chemically-bonded magnesite-chrome brick developed especially for open-hearth roof service. Important contributors to the excellence of this refractory are the high purity of the dead-burned magnesite used in its manufacture, the relative sizings of the magnesite and the chrome ore, and the high density of the brick. The magnesia is fully stabilized as periclase of high density. MAGNEX OHR is volume-stable at high temperatures and has superior resistance to spalling.

To obtain maximum advantage of the composition and other superior properties of MAGNEX OHR, the brick are metal encased and internally plated, and in this form are known as METALKASE MAGNEX OHR XXP. These brick are used in open-hearth roofs in both sprung and suspended construction of all designs, with unmatched service records.

METALKASE MAGNEX brick in several other modifications are used as suspended roofs of copper-matte reverberatory furnaces and of copper refining furnaces. They serve also to advantage as shoulders in the roofs of copper-matte reverberatory furnaces, extending 4 to 5 feet from the skews at each side, with silica brick in the central section. They serve equally well in the upper sidewalls of copper reverberatory and refining furnaces.

THERMAG is a spinel-bonded magnesite-chrome refractory in which a complex spinel bond is developed during the firing at high temperature. Prior to the development of THERMAG, no magnesite-chrome brick were available which possessed not only the usual desirable properties of this type of refractory, but also the strength needed in service where resistance to abrasion and erosion are very important.

THERMAG is well adapted for the linings of high-temperature zones of rotary cement kilns. Its high strength is maintained throughout the temperature gradient extending through the lining. Protective coatings are readily developed and firmly retained. Of special importance is the excellent service given by THERMAG and THERMAG H in roofs of copper electric furnaces.

THERMAG H is a fired magnesite-chrome brick, with a duo-spinel bond, developed especially for use in glass regenerator checkers. It is also recommended for use in rotary kiln linings. In its thermal spalling characteristics, it is greatly superior to nearly all other basic brick.

CHROME-MAGNESITE BRICK

CHROMEX is a chemically-bonded chrome-magnesite brick characterized by high mechanical strength, and constancy of volume at high temperatures. Due to a texture imparted by the mix and the sizing of the grains, it has excellent resistance to the spalling effects of rapid changes in temperature, as compared with many other basic brick.

In the copper industry, CHROMEX brick are used to advantage in the upper walls of refining furnaces. Various vulnerable parts of the brick structure in secondary melting furnaces give longer service when built of CHROMEX brick.

CHROMEX is widely used in the linings of recovery boiler furnaces, and parts of other furnaces in kraft and soda paper mills.

CHROMEX B is a chrome-magnesite brick fired at an extremely high temperature. In its manufacture, application is made of all that has been learned through extensive research on means of securing the utmost stability in volume of chrome-magnesite brick at high temperatures and under heavy loads. Its change in volume in the reheat test at 3140°F. is almost negligible. It is remarkably strong at high temperatures, and has good resistance to thermal shock. Because of its relatively moderate basicity, CHROMEX B can be used in contact with various other types of refractories at high temperature.

The chemical character of CHROMEX B, and its combination of desirable physical properties, account for its successful application in back walls, front-wall piers, and walls and subbottoms of basic open-hearth furnaces, as well as in the suspended roofs and supported walls employed in the construction of basic ends of open-hearth furnaces. CHROMEX B is used to advantage also in the linings of basic electric steelmelting furnaces, in soaking pits, and in the bottoms of forge furnaces.

CHROMEX B serves with excellent results in the linings of copper and nickel converters. It is also used with good advantage in complete sidewalls of copper refining furnaces; in the bottoms of copper electric furnaces; in aluminum holding furnaces, brassmelting furnaces, and in parts of glass furnaces.

Several modifications of CHROMEX B, including CHROMEX BH of higher magnesia content, are used in vulnerable furnace positions.

CHROME BRICK

H-W CHROME brick are manufactured from chrome ores of the qualities which experience has shown to be the most suitable, and are fired at high temperatures in tunnel kilns. The properties of chrome brick upon which their utility mainly depends are their refractoriness and high resistance to the corrosive action of the usual metallurgical slags except those high in ferrous silicate. The thermal conductivity of chrome brick is considerably lower than that of magnesite brick.

H-W CHROME brick are occasionally used in basic open-hearth furnaces for facing the port blocks, and as subhearths. In certain types of furnaces, such as soaking pits, heat-treating, forge, and welding furnaces, the iron oxide scale formed has a strongly corrosive action upon both fireclay brick and silica brick. H-W CHROME brick serve to advantage in the portion of the furnace where this scale collects. Six or eight courses of chrome brick are often used with economy in the lower sidewalls of soaking pits.

In the paper industry, the refractory linings of furnaces employed for the recovery of sodium salts are subjected to severe chemical attack. In many paper mills H-W CHROME brick laid with THERMOLITH have proved highly resistant to the destructive influences which prevail in these recovery furnaces.

Other applications of H-W CHROME brick

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include bottoms of aluminum-holding furnaces, carbon bisulfide retorts, and parts of lead-melting and other metallurgical furnaces.

CHROMEX S, a chemically-bonded chrome brick, is used with increased benefit in various specific applications. It is used in the bottoms of kraft mill recovery boilers of the paper industry, and in parts of glass furnace regenerators.

FORSTERITE BRICK

FORSTERITE refractories are strongly established for use as furnace lining materials in many industries. Outstanding characteristics are their stability of volume and strength at high temperatures. They show negligible shrinkage when heated to 3000°F. Their strength at high temperatures has led to their use in furnace roofs.

FORSTERITE brick are used to some extent in the high-temperature zone of rotary and shaft lime kilns, and of rotary lime sludge and refractory dolomite kilns, and as checkers of glass furnace regenerators. In sprung-arch roofs of various metallurgical furnaces, FORSTERITE brick give excellent service.

FORSTERITE L Brick: This high-fired spinel-stabilized modification of FORSTERITE has greatly broadened the scope of utility for this class of basic refractory. Extensive research has resulted in the enhancement of certain chemical and physical properties, which especially adapts it for several particular applications.

FORSTERITE L is extremely resistant to wetting and to the fluxing action of volatile alkalies and batch dust, which accounts for its widespread use in glass furnace ports, regenerators, and checkers. By its use in checker settings, clogging is largely avoided. It withstands exposure to alternate oxidizing and moderately reducing atmospheres to better advantage than most other basic refractories. However, it is not used in gas checker settings.

FORSTERITE L brick give splendid service as checkers in regenerators of basic open-hearth furnaces. In addition to the properties mentioned above, the high-temperature strength, stability of volume and good spalling resistance of FORSTERITE L especially commend it for use as checkers in settings which are exposed to severe conditions.

SPECIAL BRICK FOR OXYGEN VESSELS

OXILINE basic brick, in their modifications OXILINE H and OXILINE CL, were developed by Harbison-Walker research for use in the working linings of the basic oxygen vessels of the steel industry. They are made of magnesite-dolomite and magnesite compositions with a bitumen bond.

OXILINE brick have the ability to withstand severe mechanical and thermal shock, and are adequately refractory to withstand the high temperatures involved in the oxygen process. At the hot face of the brickwork, the bonding material loses its volatile constituents and is converted into carbon, resulting in lower permeability and increased corrosion resistance.

These brick are available in several modifications. OXILINE H brick are magnesite-dolomite refractories. OXILINE CL brick are high-lime magnesite refractories, and are exceptionally resistant to atmospheric hydration—a property of considerable importance during periods of temporary furnace shutdown.

BRICK MODIFICATIONS FOR SPECIAL SERVICE CONDITIONS

For superior resistance to some special or unusual conditions of furnace operation, a series of basic brick of modifications having special compositions and properties has been developed. Most of these refractories have a base of dense, extremely pure periclase grains, and their distinguishing features depend mainly on the character of their fine-grained bonding groundmass. In some brands, the bond consists mainly of forsterite; in others, of magnesium-aluminate spinel, or of several spinels with magnesium-aluminate predominating.

In these brick, embracing different combinations of physical and chemical properties, the range of compositions provides for resistance to a wide diversity of corrosive conditions and other destructive factors, including cyclic atmospheric or temperature effects. The brick may be extremely hard fired for maximum stability of mineral constitution, or chemically bonded for the benefit of maximum spalling resistance. For certain wall and arch constructions, they are provided with metal casings. The best composition for any particular furnace operation will be best determined by consultation with a Harbison-Walker sales engineer.

DEAD-BURNED MAGNESITE

H-W WASHINGTON DEAD-BURNED MAGNESITE GRAINS: Dead-burned Washington grain magnesite for use in furnace bottoms is prepared by heating the raw magnesium carbonate in rotary kilns at a sufficiently high temperature to expel the carbon dioxide, and to bring about complete shrinkage and sintering together of the resulting particles of magnesia. As shipped, the dead-burned magnesite consists of hard dense nodules which are composed mainly of the mineral periclase (crystalline magnesia). These nodules or grains are practically inert to atmospheric moisture and carbon dioxide, but will slake in contact with steam up to about 700°F. at normal pressure and up to about 900°F. at high pressure.

H-W WASHINGTON DEAD-BURNED MAGNESITE GRAINS contain a minor proportion of fluxing constituents, which help the material to sinter or set at the service temperature in the bottoms of open-hearth and electric steelmelting furnaces. The high content of periclase and relatively low content of lime account for their freedom from air-slaking in dry storage.

H-W WASHINGTON DEAD-BURNED MAGNESITE GRAINS may be mixed with 10 per cent to 20 per cent of basic open-hearth slag for use in making furnace bottoms, and for patching in open-hearth and electric steelmelting furnaces.

H-W WASHINGTON DEAD-BURNED MAGNESITE GRAINS are supplied in the form of a mixture of grains ranging in size from a maximum of either ½ or ⅜ of an inch in diameter, as desired, to very fine particles, with enough of the finer sizes to fill the interstices between the larger grains and thus to give very dense packing.

H-W PERIKLASE GRAINS are prepared from high-purity dead-burned magnesite (periclase), obtained by processing sea water and other magnesium-bearing brines. They have a magnesia content of 92 per cent or higher. The grains are dead-burned at high temperatures to render them volume-stable and inert to slaking by atmospheric moisture.

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BASIC MORTAR MATERIALS

H-W WASHINGTON FURNACE MAGNESITE is a finely ground dead-burned magnesite product used dry or with a suitable bonding agent for laying basic brick, for patching and for building up steep banks such as those at the back wall of the open-hearth furnace, and for maintaining the bottoms and sidewalls of ferroalloy furnaces.

H-W SPECIAL FURNACE CHROME, finely ground refractory chrome ore, has a wide field of usefulness. It serves not only for laying chrome brick, but also, under certain conditions, for laying other basic brick or silica brick. It is employed for ramming around the flush-holes of open-hearth furnaces; as a daubing and grouting material for the protection of the brickwork in back walls, front walls, ports, block and door jambs of open-hearth furnaces; as a daubing material in furnaces of other types; and also for sealing basic brick construction against excessive air infiltration or gas leakage under positive pressure.

H-W PERIKLASE BONDING MORTAR is an extremely refractory air-setting mortar of exceptionally high magnesia content. It is ideally suited for laying H-W Periklase brick and some other basic brick.

FORSTERITE BONDING MORTAR is used primarily with Forsterite brick, and its composition corresponds closely to that of the brick. It is air-setting, and at furnace temperatures develops a strong ceramic bond.

THERMOLITH is an air-setting high-temperature cement of chrome ore base. Because of its nearly neutral chemical character and other desirable properties, it serves as a bonding material in a wide range of applications. Thermolith forms joints which are extremely resistant to chemical corrosion by a wide variety of industrial slags.

Complete information concerning the various H-W Bonding Mortars is given in another chapter, on pages 138 to 146.

HOT-PATCHING MIXES

H-W MAGNASET is a quick-setting basic grain material especially adapted to hot-patching and maintenance of bottoms and banks of open-hearth and electric furnaces. It is prepared from selected Washington magnesite of high refractoriness. The carefully controlled grain-sizing of H-W Magnaset contributes to high density after installation in the furnace hearths.

QX MAGNIFRIT is a quick-setting basic magnesite-base refractory, especially designed for patching deep holes in basic open-hearth and electric steelmelting furnace bottoms. This superior fettling and patching refractory is described in more detail on page 187.

BASIC RAMMING MIXES

H-W C-MIX is a magnesite ramming mix made from high-purity dead-burned magnesite (periclase), with a magnesia content over 92 per cent. It is unusual in its high degree of resistance to hydration. It has excellent volume stability with negligible shrinkage at highest operating temperatures, together with best resistance to the corrosive action of highly basic slags. Its high strength over the entire range of steel furnace operating temperatures accounts for the unusual resistance to erosion. A properly rammed H-W C-Mix bottom contains the maximum content of periclase per cubic foot. Its high density and low permeability retard penetration by molten metal and corrosive slags.

H-W C-Mix used for contour-ramming of the permanent bottoms of basic open-hearth and electric steelmelting furnaces greatly reduces down-time, saves labor, and avoids burning-in sacrifice of refractory superstructure. With its measurable margin of superior properties, it reduces over-all costs of refractories and increases furnace availability. Special modifications of H-W C-Mix are used for patching in the cone section and taphole area of oxygen-process steelmaking vessels.

H-W C-Mix hearths are rapidly installed without special skill. Complete open-hearth furnace bottoms have been placed at the rate of over four tons of H-W C-Mix per hour, with less than five man-hours of labor per ton of material. The installation of an open-hearth bottom with H-W C-Mix may begin immediately upon completion of the subbottom, front wall, back wall, and roof, and proceed simultaneously with construction of ports and end walls, and repairs to regenerators.

H-W C-Mix is shipped dry in sacks of 100 pounds net weight. It is prepared for use by mixing with water to the proper consistency.

H-W MAGNAMIX is an air-setting magnesite ramming mix which permits the installation of new basic open-hearth and electric furnace bottoms complete to their finished contours before the application of heat. Steel can be made within a very few days after construction of the hearth is begun.

H-W Magnamix contains more than 80 per cent magnesia, largely as periclase, the durable component of magnesite furnace bottoms. H-W Magnamix is installed without the addition of slag and the high magnesia content is therefore not diluted. When properly rammed into place, an H-W Magnamix bottom contains about 130 pounds of periclase per cubic foot. This is an appreciably higher concentration than can be secured with dolomite mixtures, or with mixtures of dead-burned magnesite grains and furnace slag.

H-W Magnamix is used with excellent results for maintaining and repairing the tapholes, flats, and banks of basic hearths. In hot-patching, the dampened H-W Magnamix clings to the steepest banks and sinters rapidly to form a dense, durable patch of any required area and depth. The high refractoriness, the excellent working properties, and the uniformity in quality of H-W Magnamix are maintained through constant supervision and control.

H-W Magnamix is shipped dry in sacks of 100 pounds each. It is prepared for use by mixing with the proper amount of water.

H-W MAGNAMIX 85 is a magnesite ramming mix containing about 85 per cent magnesia, mainly in the form of volume-stable periclase. It is a modification of H-W Magnamix having increased strength at intermediate temperatures. Its uses are described on page 160.

H-W MAGNAMIX F is a magnesite ramming mix of special finer grind for best workability and ease of installation by manual methods, for maintenance of banks and spouts in the basic open-hearth furnace.

H-W OXIMIX is a basic ramming mix developed especially for use in oxygen-process vessels. It forms both the monolithic hearth of the furnace and the intermediate monolith between the working lining of Oxiline brick and the protective lining of hard-burned Oxibak brick against the steel shell.

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BASIC GUN MIXES

H-W MAGNAMIX S and **H-W SPECIAL FURNACE CHROME GG** are applied by means of air-placement guns. H-W MAGNAMIX S has the proper grind and the proper quick-acting bonds to allow the material to be air-emplaced on furnace walls through a suitable gun with water added at the gun nozzle. H-W MAGNAMIX S can be applied to a thickness of several inches and provides a high-magnesia maintenance material best suited to the high operating temperatures of open-hearth and electric steelmelting furnaces. Its good resistance to basic slags makes it especially adapted for gun maintenance of banks and hearths.

H-W SPECIAL FURNACE CHROME GG for gunning has the proper grind for air-emplacement and can be used wherever the high refractoriness and neutral chemical characteristics of a heat-setting chrome-base gunning mix are desired. It is used extensively for maintenance and hot repairs of open-hearth back walls, skewbacks, bridge walls, ports, and jambs.

H-W GUNSHOT is an air-setting chrome-base material of fine grind, blended with binders to insure good adhesion to the surfaces of hot refractory linings. It is used primarily in open-hearth furnaces for maintenance of front and back walls, for maintenance of the skews of basic roofs, and for sealing the uptakes and end walls. (See pages 152 and 162 also.)

BASIC CASTABLES

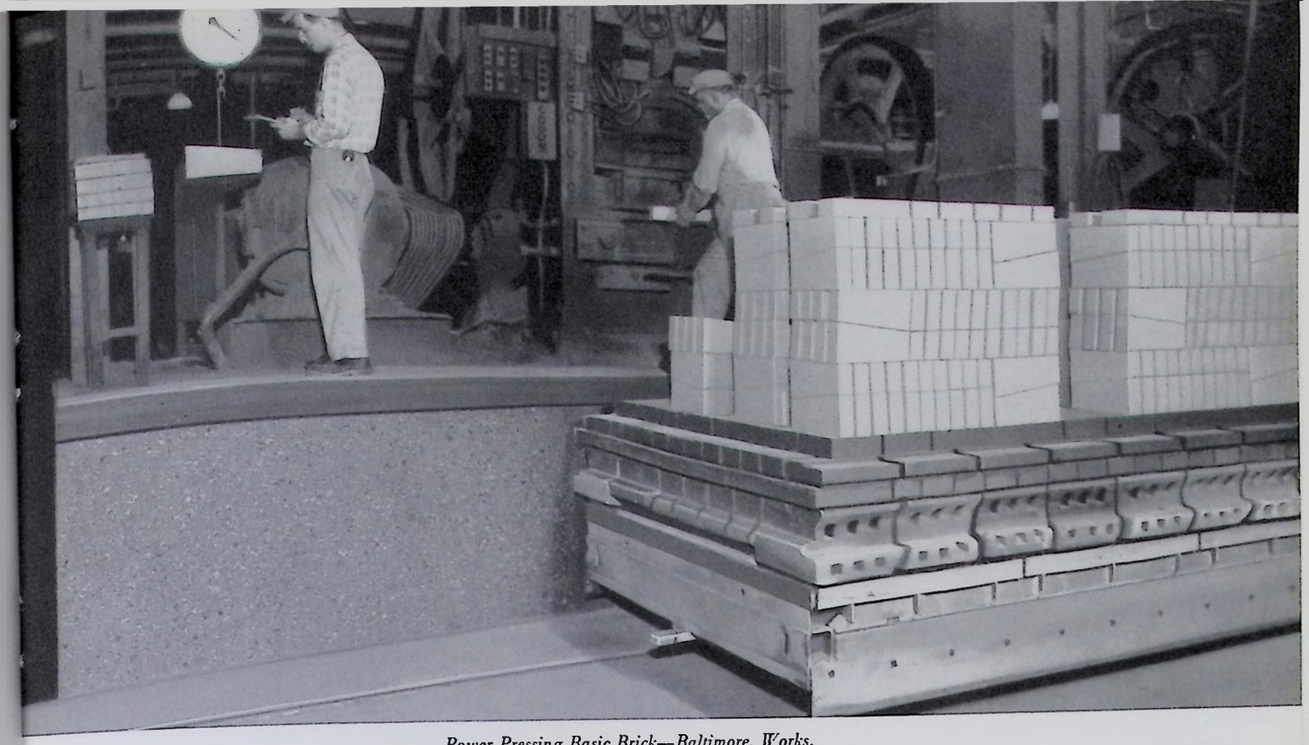
The various brands of basic castables manufactured by Harbison-Walker are discussed in the chapter on "Monolithic Refractories." See page 153, and also pages 165 and 166.

SUGGESTIONS CONCERNING THE USE OF BASIC REFRACTORIES

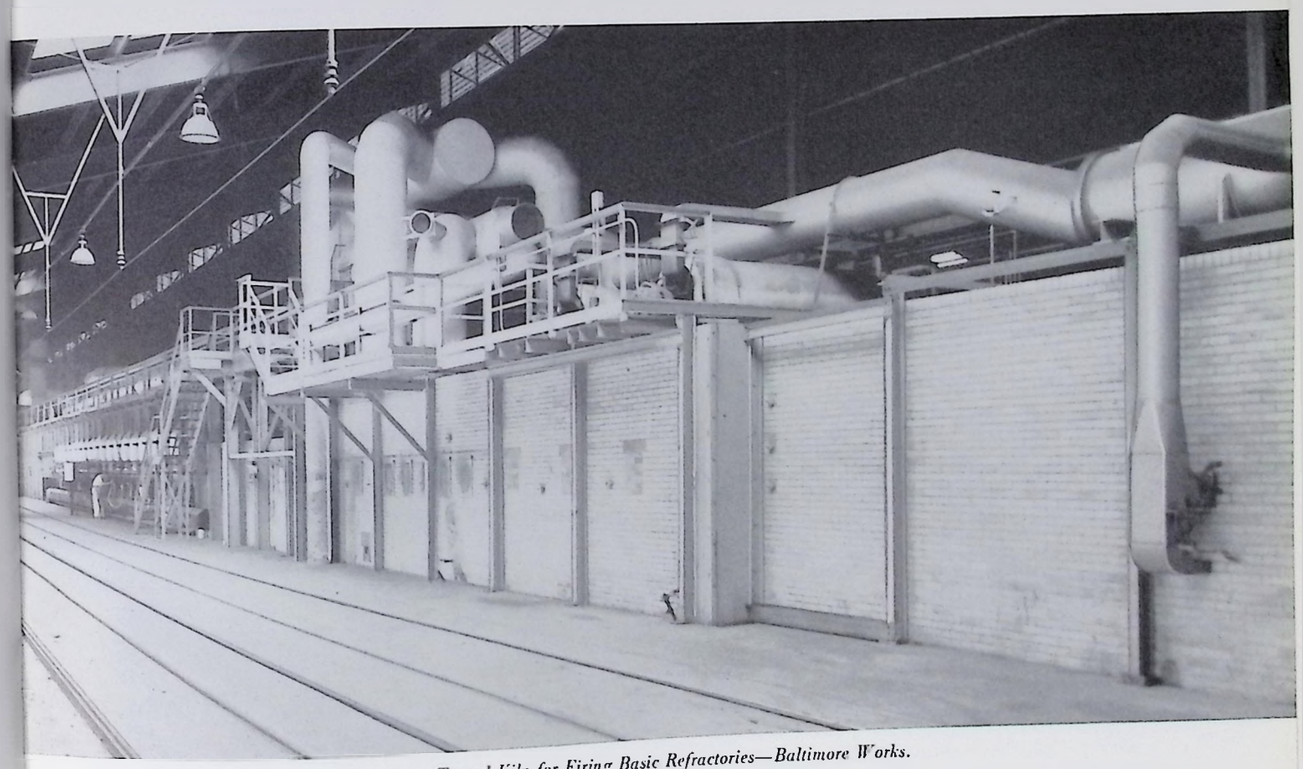
Harbison-Walker makes a multiplicity of basic refractory products, differing widely in composition as well as in chemical and physical properties. Many of these were developed for specific furnace applications. Selection of the most serviceable basic refractories for any particular application depends upon the operating conditions, and frequently requires analysis by a competent engineer of wide experience. Studies of this kind are included in the service which Harbison-Walker renders to users.

Magnesite brick and fireclay brick should not be used in contact with each other above 2375°F. At 2600° to 2700°F. they react strongly with each other, forming a liquid slag. At 2800° to 2900°F. magnesite and silica brick react, with effects which are somewhat damaging to both. In high-temperature service, it is therefore good practice to separate magnesite refractories from fireclay brick, and frequently from silica brick, by a neutral course such as chrome brick or by a heavy joint of THERMOLITH.

Refractories containing free magnesia may hydrate and slake at relatively low temperatures in the presence of water or steam. To prevent possible deterioration in storage, or when placed in service in furnace constructions, basic materials should be kept dry. This is especially important in the case of some chemically-bonded brick, since the bonding agents are somewhat soluble in water. It is good practice to avoid rapid heating or cooling of basic brick.



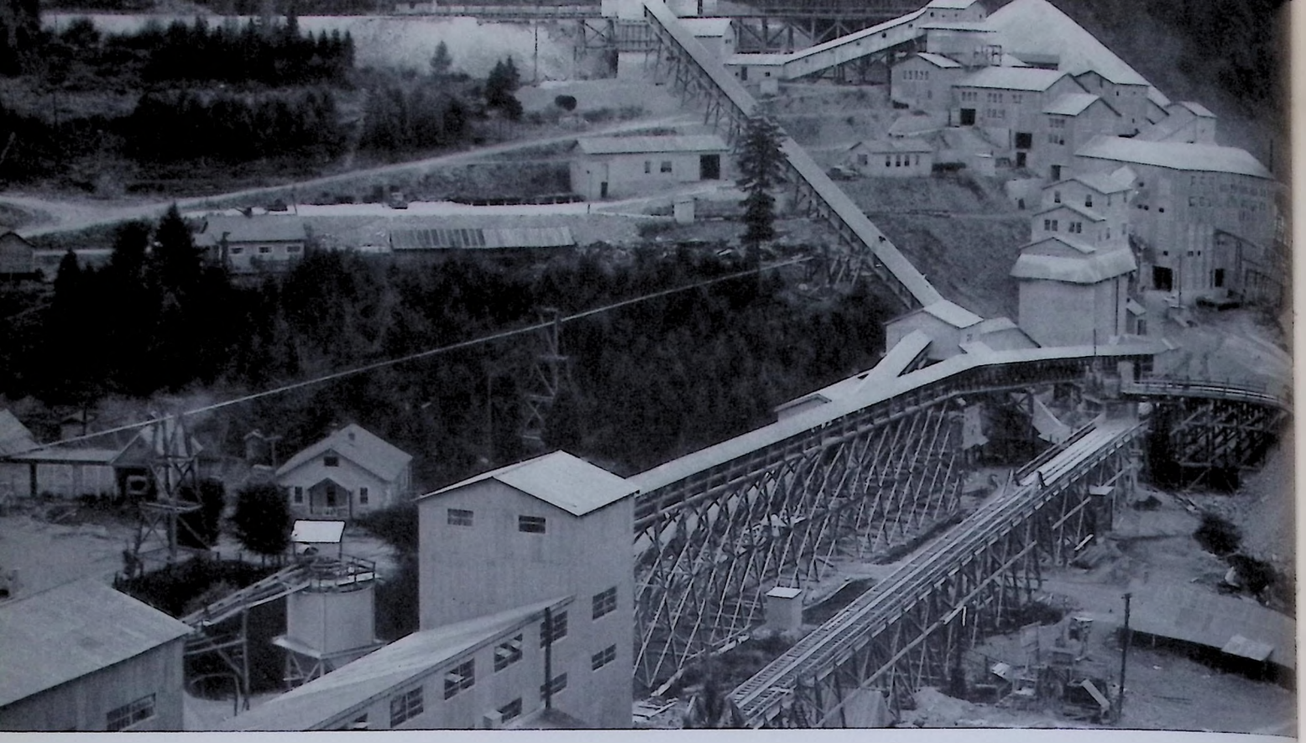
Power Pressing Basic Brick—Baltimore, Works.



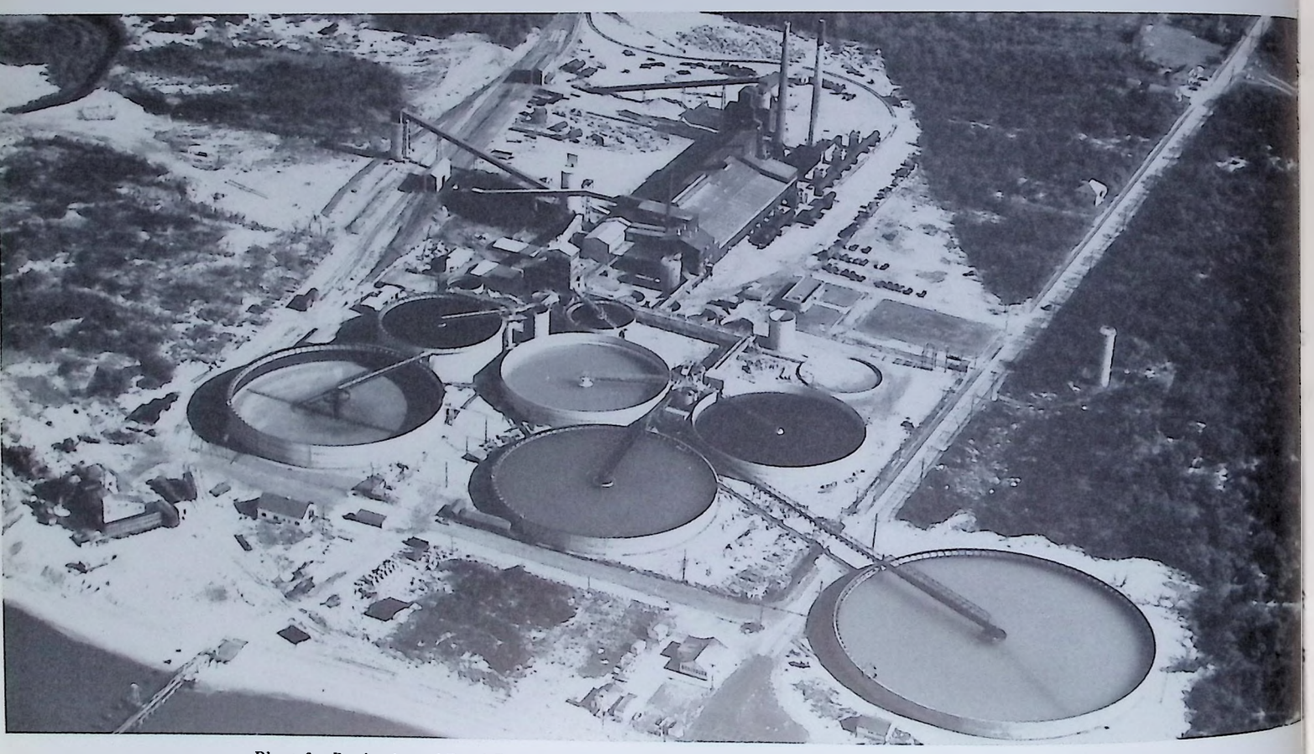
Continuous Tunnel Kiln for Firing Basic Refractories—Baltimore Works.

HARBISON-WALKER REFRACTORIES COMPANY

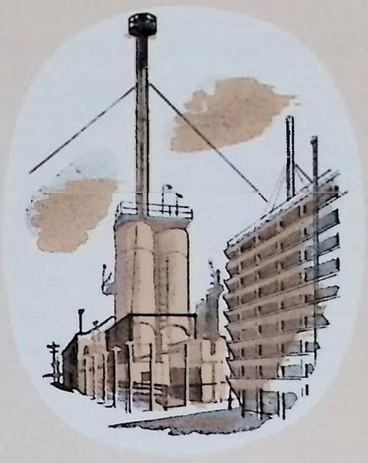
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Plant for Benefication of Crude Magnesite—Northwest Magnesite Co., Chewelah, Washington.



Plant for Production of Dead-Burned Seawater Magnesite—Northwest Magnesite Co., Cape May, New Jersey.



ACID-PROOF BRICK AND TILE

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HARBISON-WALKER BRANDS OF ACID-PROOF PRODUCTS
FOR CHEMICAL-RESISTANT CONSTRUCTIONS

Brand	*Material*	*Shipping Point*
DURO	Standard Sizes and Shapes	Clearfield, Pennsylvania
DURO DOT	Standard Sizes and Shapes	Clearfield, Pennsylvania
W-ACID	Standard Sizes and Shapes	Bessemer, Alabama
H-W ALKAMORTAR	Mortar for Moderate Alkalinity	Same As Brick

ACID-PROOF BRICK AND TILE

DURO acid-proof brick and tile are dense, vitreous, nonabsorbent, and strongly resistant to the action of many solvents. Unlike ordinary vitrified brick and chemical stoneware, DURO is manufactured from materials of extremely low flux content. The very low porosity and the nonabsorbent quality of DURO are imparted by the method of manufacture and by the high temperature of firing. Standard shapes which can be formed by machine methods are rendered highly impervious by being molded at high pressure with a high vacuum.

During the firing of DURO, the material of which it is composed is converted very largely into stable minerals which are insoluble in various acids and corrosive acidic chemical solutions, and are very resistant to the action of moderately concentrated alkaline solutions. The mineral constitution of DURO, and its close vitreous texture, render it highly insoluble in mineral acids (except hydrofluoric acid), and organic acids of any degree of concentration at practically all working temperatures.

DURO standard brick sizes are supplied with any of the faces scored as desired to form stronger joints with certain types of cements. Faces of the brick which will be exposed to the corrosive influences of acids are not scored.

DURO shapes of many designs are made to order by highly skilled hand molding. Among a large variety of shapes are those for domes and dished bottoms of cylindrical tanks, capping tile and separators for electrolytic tanks, girders and supports for acid tower packing, and assemblies for openings through linings.

DURO DOT is appreciably more resistant to rapid fluctuations in temperature than DURO, although slightly less dense. The refractoriness of DURO DOT is unusually high for acid-resisting material. It is well adapted for service in processes employing temperatures as high as 2300°F. in conjunction with nascent gases and acid fumes. It has exceptionally high mechanical strength.

W-ACID brick, made in Alabama, are the counterpart of DURO in their physical and chemical properties and are used for the same purposes as DURO. At many points, especially throughout the South, their delivered cost is lower than that of DURO because of lower transportation costs.

A complete list of the brick sizes which are standard in acid-proof brick is given on pages 498 and 499.

Cements: The type of cement used for laying DURO brick is dependent upon the kind of service for which the brick are intended. For relatively low-temperature service, DURO brick in many cases are bonded with sulfur compound or resinous cements. DURO brick used in contact with concentrated acids, and at higher operating temperatures, preferably are laid with an acid-proof cement which sets hard upon drying. When DURO brick are used at comparatively high temperatures and must resist the action of acid or other corrosive fumes, they are sometimes laid with HARWACO BOND.

H-W ALKAMORTAR, which is highly resistant to the action of moderately concentrated alkaline solutions, gives excellent results when used for laying DURO and W-ACID brick in storage and dissolving tanks of the paper industry.

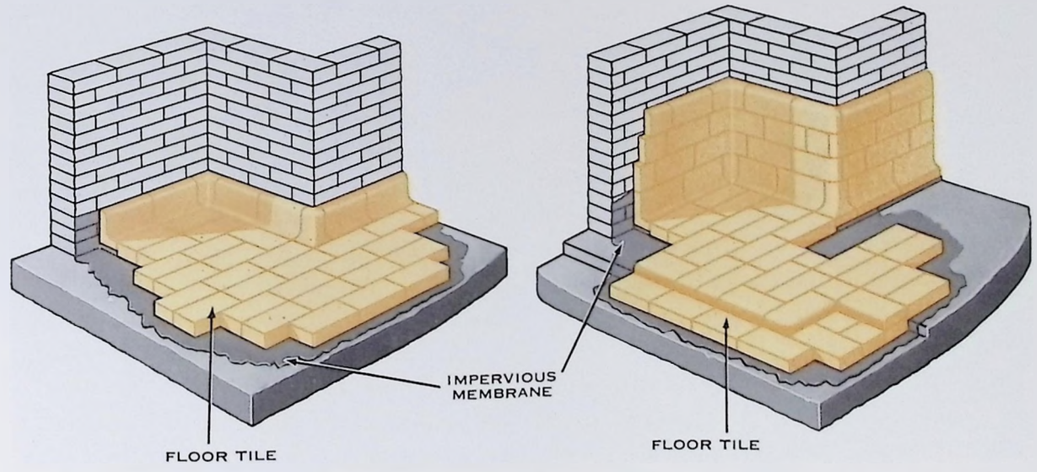
ACID-PROOF FLOOR CONSTRUCTION

In many plants acid solutions come in contact with the floors. In others, the floors are subject to hard wear, continual dampness, and exposure to corrosive liquids. For these conditions DURO and W-ACID floor construction is widely preferred.

The smooth, nonglassy surface of DURO is good for traction and the avoidance of slippage. Surfaces can be textured if desired. DURO is vitreous to the most desirable degree for high strength to withstand impact and abrasion and for maximum impermeability and resistance to chemical action.

The light buff color of DURO, with freedom from the glare caused by glazed surfaces, contributes to the clean, sanitary appearance of the floors. The excellent workmanship of DURO tile and the variety of cove base shapes makes readily feasible a neat close fitting construction that is easy to keep clean.

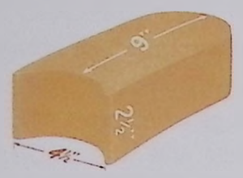
The floors are usually laid with standard rectangular tile of the 9″ x 4½″ x 2½″ and 9″ x 4½″ x 3″ series. The sizes used include those of 1¼, 1½, 2, 2½, and 3-inch thickness. Standard 9″ x 4½″ x 2½″ or 3″ straights are preferable for floors subjected to heavy moving loads. Standard 12″ x 6″ x 1½″ tile are especially suited for some floor constructions.



Typical Designs of DURO *Tile Floor Construction.*

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UNIVERSAL CIRCLE BRICK AND BOOK TILE



Universal Circle Brick



Book Tile

DURO and W-ACID Universal Circle Brick, made in two sizes, are used to build 4½-inch linings in vertical tanks or stacks having any diameter from 2′-0″ to 30′-0″. This is possible because of the unique design of the ends of the brick, which provides both flexibility and tightness of joints. Use of the Universal Circle Brick is especially advantageous in plants having tanks of different diameters, since the one size will fit all tanks. A typical assembly and table of quantities required are shown on page 499.

DURO Book Tile are furnished for linings 2 inches, 2½ inches, or 3 inches thick. DURO Book Tile are extremely dense and have superior workmanship. The brick are scored as desired for best adhesion of certain cements.

PACKING RINGS AND TILE FOR ACID TOWERS

DURO and W-ACID tower packing tile are made from exactly the same materials as those used in the manufacture of the corresponding acid-proof brick. They are dense and vitreous throughout, have superior resistance to chemical attack, and provide maximum surface area per cubic foot of packing.

Packing rings are manufactured in various sizes, such as 3″ x 3″, 4″ x 4″, and 6″ x 6″. The 6-inch rings are made with or without cross recesses at one end as shown in the illustrations on page 122. This feature brings about equalization of gas pressure, prevents channeling of the gas, and permits uniform distribution of the washing liquid. Thus, maximum contact between gas and liquid are maintained throughout the tower or scrubber.

Packing rings of greater length than 6 inches are manufactured for certain purposes. For some applications, straight cylinders without partitions are used.

The surfaces of DURO packing rings may be either smooth or corrugated as desired. The corrugations increase the exposed area, and thus render more effective the contact between the gas and the liquid.

Packing rings are easily and rapidly laid in either circular or rectangular towers. When they are nested together, the areas of the openings between rings are approximately equal to that of the openings within the rings themselves. In placing successive rows of the larger rings, no effort need be made to line them up vertically, because the equalizing cross recesses greatly reduce gas channeling, and also retard clogging of the openings.

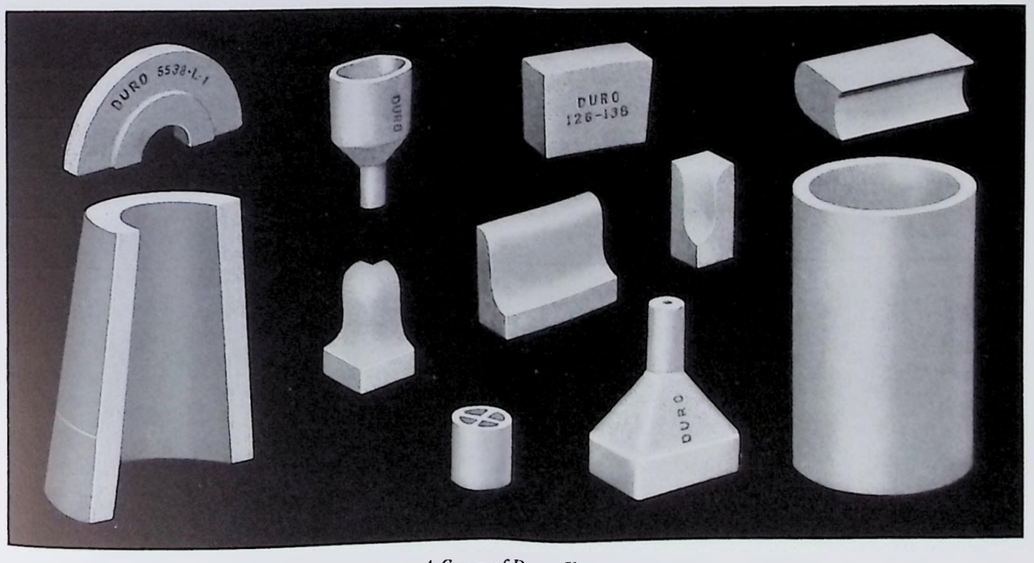
DURO Grid Tile: These tile permit uniform vertical distribution of gas and liquid. Each tile is provided with legs for substantial construction and space for equalization of pressure. The tile are aligned vertically and can be used in both rectangular and circular towers.

Rectangular Packing Tile: DURO and W-ACID Packing Tile, 12″ x 6″ x 1½″, are exceedingly durable and highly efficient as packing for acid towers. They afford ample exposed surface area, and the sharp edges cause a break in the flow of the liquid, insuring maximum contact between liquid and gases. Since most of the contact faces are vertical, channeling effects in the circulation are practically eliminated, and the operation of the tower is highly efficient.

Various tile having dimensions larger than 12″ x 6″ x 1½″ are also used in some cases to provide larger openings required to prevent clogging by dust from gases.

SOME APPLICATIONS OF DURO AND W-ACID BRICK

- Absorbing Towers
- Accumulators for Paper Mills
- Acid Cooler Linings
- Acid Filters
- Acid-Storage Tanks
- All-Masonry Acid Towers
- Blow-Pit Linings
- Bottoms of Lead Sulfuric Acid Chambers
- Chlorinators
- Concentrating Towers
- Concentrator Pan Settings
- Cottrell Precipitators
- Dipping Vats
- Electrolytic Tanks
- Filter Linings for Purifying Acid
- Floors
  - Acid Room (except hydrofluoric)
  - Chemical Plants
  - Dairies
  - Dye Works
  - Electroplating Plants
  - Food Processing Plants
  - Galvanizing Plants
- Meat Packing Plants
- Paper Mills
- Rayon Plants
- Steel Pickling Areas
- Textile Mills
- Flues for Conducting Acid Gases and Fumes
- Gay-Lussac Towers
- Glover Towers
- Insulators for Electrolytic Cells
- Leaching Tank Linings
- Magnesium Cells
- Muriatic Acid Towers
- Nitric Acid Retort Linings
- Phosphoric Acid Hydrators
- Phosphoric Acid Towers
- Pickling Tanks
- Scrubbers for Blast-Furnace Gas
- Sewers and Drains in Chemical Plants
- Stacks for Chemical Plants
- Stacks for Smelters
- Tower Packing



A Group of DURO *Shapes.*

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DURO PACKING RINGS AND TILE



Tower Packing Ring
Diameter 3″,
Length 3″



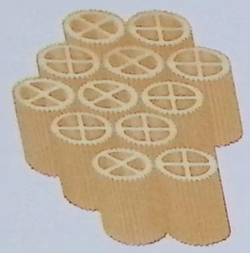
Tower Packing
Partition Ring
Diameter 3″,
Length 3″



Tower Packing
Partition Ring
Diameter 4″,
Length 4″

Shape Number	HW-1043	263	515
Number of Pieces Per Cubic Foot *	74	74	31.2
Square Feet of Exposed Surface Per Cubic Foot	28.6	45.6	29.0
Per Cent Open Area	60.3	53.5	52.3

* Set for closest packing.



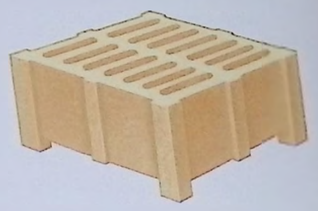
Assembly of Rings



Tower Packing
Partition Ring
Diameter 6″,
Length 6″



Tower Packing
Partition Ring
Diameter 6″,
Length 6″

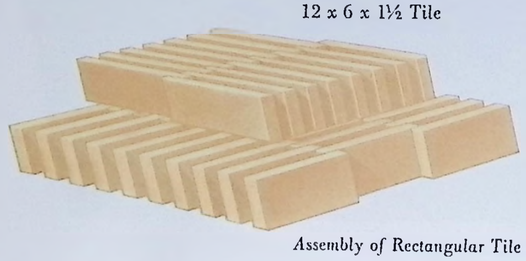


H-W Grid
Packing Tile
7½″ x 7½″ x 4½″

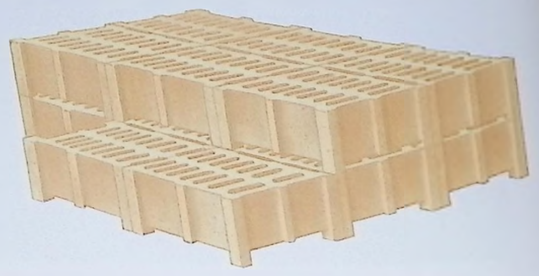
Shape Number	364	404	HW-800
Number of Pieces Per Cubic Foot *	9.2	9.2	6.88
Square Feet of Exposed Surface Per Cubic Foot	24.1	25.9	21.63
Per Cent Open Area	55.4	52.2	40.39

* Set for closest packing.

12 x 6 x 1½ Tile



Assembly of Rectangular Tile



Assembly of Grid Tile



HIGH-TEMPERATURE INSULATION

HARBISON-WALKER REFRACTORIES COMPANY

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HARBISON-WALKER BRANDS OF HIGH-TEMPERATURE INSULATIONS

Brand	Maximum Temperature Limit at Hot Face	Page
INSULATING FIREBRICK		
H-W 16-20	1600°F.-2000°F.*	127
H-W 20	2000°F.	127
H-W 23	2300°F.	127
H-W 23-LI	2300°F.	127
H-W 26	2600°F.	127
H-W 28	2800°F.	127
H-W 30	3000°F.	127
H-W 33	3300°F.	127
Vegalite	3000°F.	127
Rototherm	1600°F.	127
Lotherm	2300°F.**	127
BONDING MORTARS FOR INSULATING FIREBRICK		
H-W Insulating Brick Mortar	Heat-Setting	128, 143
Ankorite 65	Heat-Setting	128, 142
Vega Bond	Heat-Setting	128, 142
Harwaco Bond	Air-Setting	128, 144
Penseal	Air-Setting	129, 144
MINERAL FIBER INSULATION		
H-W Block Insulation	1700°F.	129
H-W Mineral Fiber Coating	1800°F.	129
H-W Finishing Cement	1200°F.	130
LIGHTWEIGHT INSULATING CASTABLES		
H-W Lightweight Castable 10	1000°F.***	153, 166
H-W Lightweight Castable 20	2000°F.	153, 166
H-W Lightweight Castable 22	2200°F.	153, 166
H-W Low-Iron Lightweight Castable 22	2200°F.	153, 167
H-W Lightweight Castable—Extra Strength	2300°F.	153, 167
H-W Lightweight Castable 26	2600°F.	153, 167
H-W Lightweight Castable 28	2800°F.	153, 167
H-W Lightweight Castable 30	3000°F.	153, 167
LOOSE FILL AND LIGHTWEIGHT AGGREGATES		
H-W Diatomaceous Earth (Powder)	1500°F.	
H-W Diatomaceous Earth (Coarse)	1500°F.	
Calag (Calcined Diatomaceous Earth)	1800°F.	

For data on thermal and other properties of H-W Insulating Firebrick, see tables on pages 131 and 132.

*In exposed applications up to 1600°F., and for back-up applications to 2000°F.

**In rotary kiln service approximately 2100°F.

***1800°F. when used as a back-up material, or in noncyclic operations.

ADVANTAGES OF HIGH-TEMPERATURE INSULATION

Refractory insulating materials offer significant advantages in the construction and operation of furnaces of many types. Proper selection and application of the insulation result in important savings of fuel, time, space, and weight. In addition, insulation of furnaces renders possible closer temperature control, and contributes to more comfortable working conditions for the furnace operators.

Economy in Fuel: Saving of fuel is one of the most important reasons for insulating industrial furnaces. Heat energy flows through a furnace wall or roof from the inner hot face to the outer cold face, where it is dissipated and lost by radiation and convection. The amount of heat so lost often constitutes a considerable portion of the total heat input required to maintain the desired operating temperature. Such heat losses may be reduced greatly by building the walls partly or entirely of high-temperature insulation, either as backing for denser refractory brick or, when conditions permit, as inner linings exposed directly to furnace atmospheres.

In the case of intermittently operated furnaces, the quantity of heat required to bring the furnace to operating temperature is lost when the furnace is allowed to cool, and is often of greater significance in the over-all heat balance than that required to maintain the desired temperature for the few hours per day of operating time. In such furnaces, the use of insulating firebrick for the inner linings, in place of denser refractories, reduces both (1) the amount of heat which flows through the linings and is lost to the outside air, and (2) that which is stored temporarily in the brickwork, and lost when the furnace cools.

Economy in Time: At a given rate of heat input with available burner capacity, the time required to bring a cold furnace to operating temperature depends upon the heat-storage capacity of the furnace lining and upon the rate at which heat penetrates it. Through the use of insulating refractories, the heat-storage capacity may be reduced as much as 60 to 70 per cent, the rate of heat penetration about the same, and the time required to bring the furnace to operating temperature 80 to 90 per cent. When firing is reduced or discontinued, a setting built of insulating firebrick will cool rapidly unless the furnace is sealed.

Low heat-storage capacity is a fundamental requirement for furnaces operated intermittently, such as those used for annealing metals, where sharp response to desired temperature changes is necessary. The low heat storage desired may be obtained by the use of lightweight furnace insulating materials for the construction of entire walls and roofs.

Economy in Space: Where desirable, the use of insulating firebrick in place of dense fireclay brick makes thinner walls practicable. For example, either a 9-inch wall of insulating firebrick or a 13½-inch composite wall, consisting of 9 inches of dense fireclay brick and 4½ inches of insulating firebrick backing, has greater insulating value than a 27-inch wall of dense fireclay brick.

Economy in Weight: Through the use of insulating firebrick and other lightweight insulations, the weight of a furnace structure may be reduced as much as 60 to 70 per cent. This permits the use of a lighter foundation and a lighter furnace superstructure. Lightweight refractories have made possible the design of highly efficient covers for portable annealing furnaces. These covers are well within the load limits of available crane facilities.

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SELECTION OF HIGH-TEMPERATURE INSULATIONS

Effect of Interface Temperature: When high-temperature insulation is used as backing for a more refractory lining material, the interface temperature is a determining factor in the choice of the insulating material, and an important factor in the selection of the denser refractory. When insulating material is usable as the working lining, the maximum operating temperature of the furnace is the major factor governing the choice of the brand.

Obviously, the insulating firebrick selected for backing a dense firebrick wall must be sufficiently refractory to withstand the temperature at the interface between the denser firebrick and the insulating backing. If the working lining may be expected to wear away gradually as by slag attack, its ultimate safe working thickness should be estimated as a basis for determining the maximum interface temperature.

As a factor of safety to provide against surges in furnace temperatures, and against possible shrinkage of the insulating firebrick during long continued use, it is good practice to design the construction for an interface temperature 100° to 200° below the "maximum temperature limit" of the insulating firebrick as given on page 124. This is especially true for interface temperatures above 2400°F. For insulating firebrick used directly in contact with furnace gases, under some conditions it is advisable to provide a safety factor by using brick having a "maximum temperature limit" 200° to 300° above the furnace operating temperature.

Other Factors Involved in Selection: The furnace operating temperature alone does not indicate the class of insulating firebrick that should be used. It is often necessary to consider not only the temperature limit, thermal conductivity, weight, and heat capacity of the brick, but also the destructive factors affecting the interior lining, the degree of insulation, the duration of heating, and the nature of the gases within the furnace.

Many furnaces are operated with atmospheres of carbon monoxide, hydrogen, dissociated ammonia, or exothermic and endothermic gases produced from natural gas, which may react with some types of refractories. Proper selection of the lining materials is essential. It is important that they have a low content of iron oxide and titania when they are to be used in an atmosphere of carbon monoxide, hydrogen, or treated natural gas, or in service where iron poisoning of platinum catalysts must be avoided. In a hydrogen atmosphere, the flow of heat through refractories is accelerated, and low permeability can thus be an asset. In general, lightweight castables have lower permeabilities than insulating firebrick.

Composite Wall Construction: In furnaces operated continuously, the relatively high heat-storage capacity of dense fireclay brick has little effect upon the over-all heat balance. Actually, in certain types of furnaces, high heat storage in the refractories is a definite benefit because of its cushioning effect against excessive fluctuations in temperature. Such furnaces are usually built to best advantage with composite walls or roofs in which the inner parts of the furnace structure consist of dense refractories, and the exterior backing of lightweight insulating materials.

The application of an insulating backing to an existing firebrick wall or arch reduces the temperature drop through the dense firebrick. With a high furnace temperature, and a high degree of insulation, the mean temperature of the working lining may become higher than the brick can withstand. Hence, the insulation of an existing furnace may render necessary the use of brick of higher refractoriness for the working lining or perhaps even a redesign of the furnace to reduce the pressure to which the brick are subjected.

For lining industrial furnaces, many combinations of high-temperature insulating materials and denser refractories are practicable. In some furnace constructions, refractory insulating materials of various kinds, used as backing, serve most efficiently in providing for the thermal expansions of dense refractories. Harbison-Walker, with complete lines of practically all types of refractories, can furnish the correct combination for any requirement.

INSULATING FIREBRICK

In its various brands of insulating firebrick, Harbison-Walker has achieved a balance between the important properties of thermal efficiency and mechanical strength. Lightness of weight, which is so essential to high insulating value and to low capacity for heat storage, has been attained to the greatest possible degree consistent with adequate strength.

All Harbison-Walker brands of insulating firebrick may be used for the working linings of furnaces at temperatures not exceeding their maximum temperature limits, where high temperature alone is involved. However, insulating firebrick as a class are not so used in applications when they would be subjected to slag attack, to abrasion, or to mechanical abuse.

H-W 16-20, H-W 20, H-W 23, H-W 23-LI, and **H-W 26** are fired products having a fireclay base; **H-W 28, H-W 30,** and **H-W 33** are fired brick with a high-alumina base. Their relative insulating values are shown in the table on page 131. All of these products are highly resistant to thermal shock over the entire range of temperatures for which they are suitable.

VEGALITE, the unique lightweight silica brick, corresponds closely to VEGA silica brick in composition, thermal expansion, and refractoriness, and is the ideal material for the insulation of silica brick construction, especially the crowns of glass furnaces. It is used also for the construction of tunnel kiln crowns.

ROTOTHERM is a strong lightweight brick singular in its combinations of properties which are particularly suited for the insulation between rotary kiln shells and hard refractory brick linings. Most significant among these desirable qualities is its characteristic of slight surface compressibility with unusual resistance to pressure rubbing. The surface in contact with the hard refractory brick tends to compress very slightly rather than abrade away. ROTOTHERM brick may be used at temperatures up to 1600°F. One inch of ROTOTHERM has approximately the same insulating value as 5 inches of dense fireclay brick.

LOTHERM, an insulating firebrick, was developed especially to meet the requirement of high physical strength and good insulating value. It is much stronger than the usual grades of insulating firebrick, and has a thermal conductivity approximately equal to that of H-W 28. The maximum service limit of LOTHERM is approximately 2100°—2300°F., depending upon the conditions of service. It is used for rotary cement kiln liners, insulation for glass-tank flux blocks, and other applications.

Good dimensional stability within the recommended temperature limits is an important property of all Harbison-Walker insulating firebrick. A program of testing at every stage of manufacture, conducted in works control laboratories, assures uniformity of quality.

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BRICK SIZES

Harbison-Walker insulating firebrick are manufactured both in standard sizes and in a wide variety of special shapes. In general, they are molded in the form of rectangular blocks or billets, which are fired and then cut to specified dimensions. Brick of the arch, wedge, or key types are cut to any desired taper. Consequently, either a ring or an arch of a given radius can be constructed with brick of one size only.

Insulating firebrick are shipped in heavy cardboard cartons which contain 25 standard 9″ x 4½″ x 2½″ straights, or approximately the same volume of other standard 9-inch sizes.

Brand	Standard Sizes
H-W 16-20	9″ x 4½″ x 2½″ Straight and sizes.
H-W 20 H-W 23 H-W 23-LI H-W 26	9″ x 4½″ x 2½″ Straight and corresponding series of sizes, as shown on pages 478 and 479.
H-W 28 H-W 30 H-W 33	9″ x 4½″ x 3″ Straight and corresponding series of sizes, as shown on page 479.
Vegalite	9″ x 4½″ x 2½″ Straight. 9″ x 4½″ x 3″ Straight.

BONDING MORTARS FOR INSULATING FIREBRICK

Insulating firebrick should be laid with mortar having properties compatible with those of the brick. It is recommended that insulating firebrick exposed directly to flame or to products of combustion be brush-coated on the exposed surfaces with a mortar which has the same characteristics and does not crack or peel.

H-W INSULATING BRICK MORTAR is used in applications requiring a heat-setting mortar for laying H-W 16-20, H-W 20, H-W 23, H-W 23-LI, and H-W 26 brick.

ANKORITE 65, a heat-setting mortar of the high-alumina class, is used for laying H-W 28, H-W 30, and H-W 33 insulating firebrick. It has high refractoriness, and is volume-stable at temperatures up to the 3000-3100°F. range. It can readily withstand soaking heat at high furnace temperatures.

VEGA BOND is used for laying Vegalite brick.

The three mortars mentioned require only the addition of water and thorough mixing to bring them to the proper consistency for dipped or troweled joints or for surface coating. They are heat-setting and require heat to develop their maximum strength. They are shipped in sacks of 100 pounds net weight.

HARWACO BOND air-setting mortar is used advantageously for laying H-W 20, H-W 23, H-W 23-LI, H-W 26, H-W 28, and H-W 30, and for brush coating exposed faces for service in which an air-setting bonding mortar is desirable. In laying insulating brick with an air-setting mortar, it is advisable to dampen the brick immediately before the application of the mortar. This retards the absorption of the liquid portion of the mortar and helps in the development of air-setting properties.

Harwaco Bond, when used as a mortar, is applied liberally to the dampened brick. Any surplus mortar is removed with a trowel after the brick has been pressed into place. When used as a brush coating, Harwaco Bond is applied similarly to a final thickness of not over 1/16 inch. It is shipped wet in drums of 25, 50, 100, and 200 pounds net weight, and also dry in paper sacks of 100 pounds net weight.

PENSEAL bonding mortar may be used when an air-setting mortar is desired for laying any H-W brand of insulating firebrick, except Vegalite, for use at furnace operating temperatures up to about 2800°F. Penseal has a slightly lower softening temperature than Harwaco Bond, and develops strong impervious joints at lower temperatures.

Penseal bonding mortar has excellent workability, low shrinkage, good adherence strength, and long storage life. It is shipped wet ready for use in 100- and 200-pound drums. The insulating brick should be dampened before the application of Penseal bonding mortar.

For further information on Harbison-Walker mortar materials, see pages 138 to 146.

MINERAL FIBER INSULATION

Harbison-Walker furnishes a variety of mineral wool products for application as furnace insulating materials. The use of these materials results in greater furnace efficiency and economy, since mineral wool is one of the most efficient of industrial insulating materials. H-W mineral wool insulation is supplied in three forms; as block insulation, as mineral fiber coating, and as finishing cement.

H-W BLOCK INSULATION possesses the combination of properties which makes it the most effective and economical insulation for many industrial applications. It is composed of long, straight, spun mineral fibers, which are tightly interlaced, resulting in a strong, light, and resilient structure. With a density of 15 pounds per cubic foot, H-W Block Insulation offers excellent insulating value together with good dimensional stability up to 1700°F. It is shipped in blocks of 18-inch and 36-inch lengths, 6-inch or 12-inch widths, and various thicknesses from 1 inch to 4 inches. It is easily applied, since its handling strength is good, and it can be cut, sawed, or drilled to fit irregular contours, or pressed down to cover rivet or bolt heads.

H-W Block Insulation is used primarily as a back-up material for other refractories. However, under moderate temperature conditions, it can be exposed directly to furnace gases. It is used as backing in boiler furnace walls, ceramic kilns, blast-furnace stoves, soaking pits, oil refining units, annealing ovens, heat-treating furnaces, parts of glass-tank furnaces, ducts, and breachings.

H-W MINERAL FIBER COATING is the ideal insulation for many troweling applications. Tiny mineral granules, each of which contains thousands of minute air cells, are combined with asbestos fiber and a strong adhesive binder to form resilient H-W Mineral Fiber Coating.

When mixed with water, H-W Mineral Fiber Coating can be applied readily to any clean surface, hot or cold, rough or smooth, metallic or refractory, vertical or overhead. After wetting, it is very plastic and is merely daubed on the surface to be insulated. If a thicker coating than ¾ inch is required, subsequent coats of ¾ inch each may be added but each layer must be allowed to dry before applying the next. After every 1½-inch thickness, it is necessary to stretch a layer of 20-gauge galvanized wire mesh tightly over the surface before applying additional coats. H-W Mineral Fiber Coating is usable at all temperatures up to 1800°F. When used in applications that do not exceed 1200°F., this material can be removed, mixed with water, and used again.

Because of its versatility and efficiency at all temperatures up to 1800°F., use of H-W Mineral Fiber Coating reduces the necessity of

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maintaining stocks of several different insulating materials. Its excellent plasticity and adhesiveness facilitate quick installation with appreciable savings in time and labor. H-W Mineral Fiber Coating is also unusual in its extensive coverage; 50 pounds of material (one bag) will cover about 25 square feet of surface to a thickness of 1 inch.

H-W FINISHING CEMENT is adapted primarily for troweling over H-W Block Insulation, H-W Mineral Fiber Coating, or other insulating materials, as a shield against mechanical scuffing. It is a dry blend of mineral wool fibers, with a hydraulic-setting binder and plasticizers which impart excellent workability and adhesiveness. Its maximum service temperature is 1200°F. One coat seals and provides a clean, white hard finish. It has low shrinkage and makes a surface free from cracks, having good thermal insulating value.

LIGHTWEIGHT INSULATING CASTABLES

H-W Lightweight Castables are insulating refractories which may be mixed and poured like concrete. They are shipped in dry form, and when mixed with water to the desired consistency, are poured or tamped into place, or applied by means of an air gun, forming joint-free surfaces. They have excellent workability, and after application take a strong hydraulic set at room temperatures. They maintain adequate strength until a ceramic puoq is developed as the temperature is increased.

H-W Lightweight Castables comprise the different castables suitable for use over the range of temperatures of 1000°F. to 3000°F. Enhanced properties in various combinations are physical strength, high-temperature stability of volume, resistance to thermal shock, and resistance to appreciable abrasion. Each brand most economically fulfills the needs for various furnace designs and operating conditions. Typical examples of their widely different usages are linings of catalytic cracking units, in oil refineries, soaking-pit covers, furnace doors, and ceramic kilns.

The various brands of Harbison-Walker Lightweight Castables are discussed individually on pages 166 and 167, and some data are tabulated on page 153.



Standard Carton for Shipment of Harbison-Walker Insulating Firebrick.

Packaging in these sturdy cartons assures safe transportation and efficient handling. Packed 25 to a carton.

PROPERTIES OF H-W INSULATING FIREBRICK

	H-W 16-20	H-W 20	H-W 23	H-W23LI	H-W 26	H-W 28	H-W 30	H-W 33	Vegalite
Maximum Temperature Limit at Hot Face	1600°F.* 2000°F.*	2000°F.	2300°F.	2300°F.	2600°F.	2800°F.	3000°F.	3300°F.	3000°F.
Approximate Weight in Pounds Per Cubic Foot	36	38	46	31	49	56	60	83	59
Modulus of Rupture in Pounds Per Sq. In.	70-100	100-150	100-170	110-120	150-200	170-300	400-600	600-650	160-200
Cold Crushing Strength in Pounds Per Sq. In.	90-110	200-260	110-190	130-150	150-200	170-300	800-1000	1400-1500	150-200
Approximate Relative Insulating Value**	5.6	5.0	4.3	8.0	3.5	3.3	3.0	1.4	2.3
Approximate Heat-Storage Capacity**	25%	25%	32%	21%	34%	39%	41%	59%	41%

*Normally H-W 16-20 brick are used at temperatures up to 1600°F. when exposed directly to furnace atmospheres. In some back-up applications they serve satisfactorily at temperatures not exceeding 2000°F.

**All ratios based on Alamo Superduty Fireclay Brick (145 pcf) = 1, except Vegalite, which is based on Star silica brick.

NOTE: Some of the properties of Rototherm and Lotherm are discussed on page 127.

NOTE: H-W Insulating Brick Mortar is used for laying H-W 16-20, H-W 20, H-W 23, H-W 23-LI, and H-W 26 insulating firebrick, and Ankorite 65 for the H-W 28, H-W 30, and H-W 33 brands. If an air-setting mortar is desired, use Penseal or Harwaco Bond. Vega Bond is used for laying Vegalite brick.

Approximately 200-250 pounds of bonding mortar are required per 1,000 9-inch straights for dipped joints.

SOME TYPICAL APPLICATIONS FOR HARBISON-WALKER HIGH-TEMPERATURE INSULATIONS

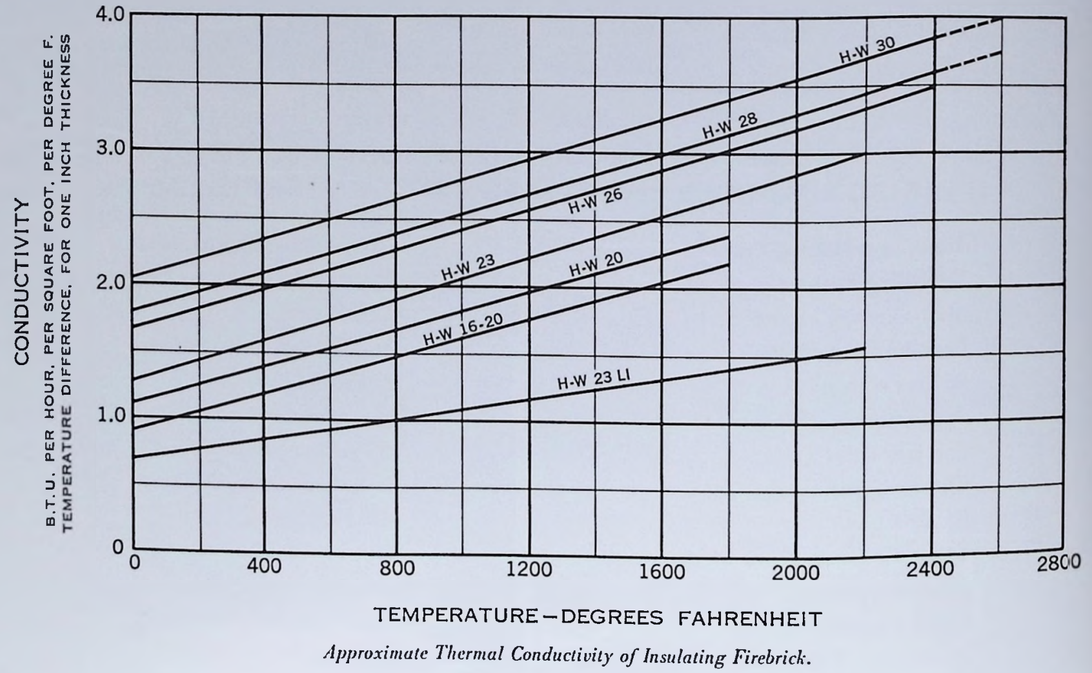
Aluminum-Melting Furnaces
Annealing Furnaces
Blast-Furnace Piping
Blast-Furnace Stoves
Boiler Settings
Carbon-Baking Furnaces
Ceramic Kilns
Chemical Reactors
Coke Ovens
Domestic Combustion Chambers
Electric Furnaces
Forge Furnaces
Glass-Tank Regenerators
Glass-Tank Superstructure
Heating Furnaces
Lime Kilns
Metallurgical Furnaces
Multiple-Hearth Furnaces
Normalizing Furnaces
Oil Refinery Equipment
Producer Gas Mains
Roasting Furnaces
Rotary Kilns
Soaking Pits
Stress-Relieving Furnaces
Sound-Absorption Cells

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APPROXIMATE THERMAL CONDUCTIVITIES OF HIGH-TEMPERATURE INSULATIONS

Btu per Hour, per Square Foot, per Degree F. Temperature Difference, for One-Inch Thickness

	Temperature—Degrees F.														
	0	200	400	600	800	1000	1200	1400	1600	1800	2000	2200	2400	2600	2800
H-W 16-20	0.92	1.06	1.20	1.34	1.48	1.63	1.77	1.91	2.05	2.19	....	....	....	....	....
H-W 20	1.12	1.26	1.40	1.54	1.68	1.83	1.97	2.11	2.25	2.40	....	....	....	....	....
H-W 23	1.28	1.44	1.59	1.75	1.91	2.06	2.22	2.38	2.53	2.69	2.85	3.00	....	....	....
H-W 23-LI	0.70	0.78	0.86	0.94	1.02	1.09	1.17	1.25	1.33	1.41	1.48	1.56	....	....	....
H-W 26	1.68	1.83	1.98	2.13	2.28	2.43	2.58	2.73	2.88	3.03	3.18	3.33	3.48	....	....
H-W 28	1.80	1.95	2.10	2.25	2.40	2.55	2.70	2.85	3.00	3.15	3.30	3.45	3.60	3.75	3.90
H-W 30	2.05	2.20	2.35	2.50	2.65	2.80	2.95	3.10	3.25	3.40	3.55	3.70	3.85	4.00	4.15
H-W 33	6.9	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.1	7.1	7.2	7.4	7.7	8.0	8.4
Vegalite	1.88	2.07	2.30	2.58	2.87	3.20	3.60	4.00	4.46	4.96	5.5	6.2	6.8	7.6	8.4
H-W Block Insulation	0.30	0.36	0.42	0.51	0.63	0.76	0.90	1.05	....	....	....	....	....	....	....
H-W Mineral Fiber Coating	0.49	0.57	0.65	0.73	0.81	....	....	....	....	....	....	....	....	....	....



Approximate Thermal Conductivity of Insulating Firebrick.



SILICON CARBIDE AND ZIRCON REFRACTORIES

HARBISON-WALKER REFRACTORIES COMPANY

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HARBISON-WALKER BRANDS OF SILICON CARBIDE AND ZIRCON REFRACTORIES

Brand Name	Base Material	Kind of Bond or Set	Form as Shipped	Containers	Net Weight Pounds
H-W SILICON CARBIDE REFRACTORIES					
Harbide Brick	Silicon Carbide	Fired	....	.....	...
Mulcarb Brick	Silicon Carbide	Fired	....	.....	...
Harbide Bonding Mortar	Silicon Carbide	Heat-Set	Dry	Sacks	100
H-W ZIRCON REFRACTORIES					
H-W Zircon Brick	Zircon	Fired	....	.....	...
H-W Zircon Bonding Mortar	Zircon	Air-Set	Wet	Drums	200
			Dry	Sacks	100
H-W Zircon Ramming Mix	Zircon	Air-Set	Dry	Sacks	100

In various industrial processes, furnace lining materials are required which surpass the more commonly used types of refractories in one or more of their essential properties. Among the more important of these materials, based on quantities used, are the super-refractories silicon carbide and zircon, both of which are manufactured by Harbison-Walker.

The company has designed and placed in operation special facilities for the manufacture of silicon carbide and zircon refractories, so that the properties in which these materials particularly excel are developed to the greatest possible degree. For example, many sizes and shapes are formed by impact or vibration pressing, in order to obtain the most homogeneous texture, low porosity, and high strength. Moreover, the brick are fired in special kilns which are capable of being heated and cooled closely in accordance with predetermined schedules, and with accurate control of the kiln atmosphere.

SILICON CARBIDE REFRACTORIES

Silicon carbide refractories have distinctive properties which make them invaluable in many furnace applications. The exceptionally high thermal conductivity, which is more than ten times that of high-duty fireclay brick, is especially important in muffle furnaces, retorts, and similar construction where the process is dependent on a high rate of heat transfer. The thermal expansion of silicon carbide brick is low. The brick withstand rapid temperature changes without adverse effects and can bear heavy loads at high furnace temperatures. This combination of properties makes them very useful for such service as kiln furniture. The inherent hardness and strength of silicon carbide brick account for their outstanding ability to resist mechanical abrasion with a minimum of wear. They have high resistance to corrosion by various fluxing agents, including coal ash of certain types.

HARBIDE brick are made from silicon carbide grains of highest quality, of different particle sizings, which are blended in proper proportions. Standard sizes and many shapes are formed by impact or vibrating pressing to obtain homogeneous texture, low porosity, and high strength. The brick are fired under controlled optimum conditions. The characteristics of properly burned silicon carbide brick are low permeability, dense, impervious surfaces, and high resistance to oxidation.

Some of the applications for which Harbide brick are recommended include ceramic kiln furniture, for example setter tile (illustrated in a later chapter, entitled "Sizes and Shapes") and girder tile; boiler furnace settings, especially in the clinker zone and along the chain grate where abrasion is most severe; furnace hearths which are exposed to severe mechanical abrasion; linings of cyclone dust collectors; skid rails in billet-heating furnaces; muffle arches or hearths which must have a very high rate of heat transfer; retorts; slag and abrasion areas of incinerators; recuperator tubes, radiant tubes, and thermocouple tubes; and other applications where the unique properties of silicon carbide are important.

MULCARB brick consist of high-quality silicon carbide grains in a groundmass of refractory clay. In manufacture, the components are blended in varying proportions depending upon the service application for which the brick are intended. To obtain the best properties, the carbide grains are restricted to certain sizes. Under the high-temperature firing conditions the clay is largely converted to mullite.

Mulcarb brick have good resistance to abrasion and to thermal shock, and their thermal conductivity is high. They are used with advantage for nose blocks and lifters in rotary kiln service, for recuperator tile in slab-heating furnaces, and in other applications where rapid heat transfer and high resistance to abrasion are important.

HARBIDE BONDING MORTAR is a heat-setting mortar used for laying silicon carbide refractories in various installations. It is supplied in dry form, requiring only the addition of water to prepare it for use. When subjected to furnace heat it develops strength and other properties similar to those of silicon carbide brick.

Whenever service conditions are such that a mortar with air-setting characteristics is needed, Harwaco Bond should be used for laying the silicon carbide brick.

For more complete information concerning the above bonding mortars, the reader is referred to pages 143 and 144.

ZIRCON REFRACTORIES

Zircon refractories are made from the refined naturally occurring mineral zircon, the silicate of zirconium ($ZrO_2 \cdot SiO_2$), which contains 67.2 per cent zirconia and 32.8 per cent silica.

Zircon is mildly acidic in character and is especially suited for use in contact with other acidic refractories or with siliceous fluxes.

H-W ZIRCON brick, made in many rectangular shapes and sizes from the purified mineral, are formed by impact pressing. This method of manufacture was developed by Harbison-Walker. By a unique vibrating action it contributes a close texture, excellent density and strength, and precise dimensions to the finished product. Some shapes, too intricate for machine pressing, are air-rammed, or slip-cast in plaster molds. Other physical properties of H-W Zircon brick are resistance to thermal spalling and fluxing conditions, and constancy of volume under soaking heat in excess of 2900°F.

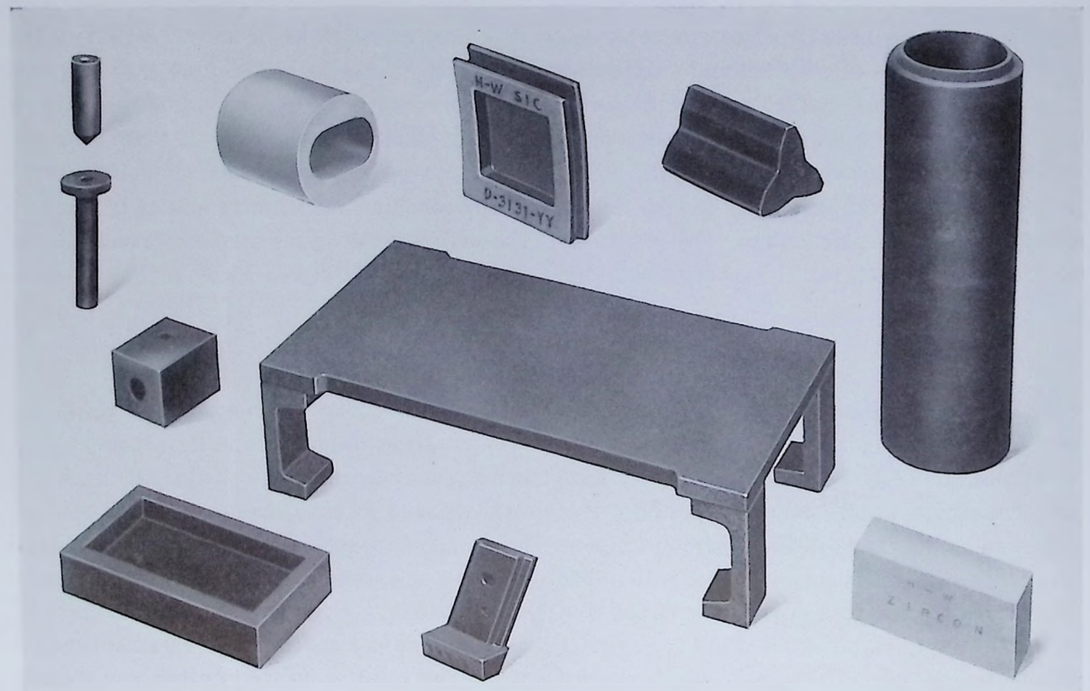
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The unusually high density and low porosity of impact-pressed H-W Zircon brick (about 230 pounds per cubic foot) and their minute and homogeneous pore structure account for their ability to resist the wetting and penetration of molten glasses and slags. They are successfully used to pave glass-tank bottoms and port floors, and to form the facing of shadow walls and the invert arches. Other uses include the linings of metaphosphate and sodium silicate furnaces, taphole blocks for aluminum and some other nonferrous melting, and nozzles for continuous steel castings operations.

H-W ZIRCON BONDING MORTAR and **H-W ZIRCON RAMMING MIX** are also made from the high-purity beneficiated mineral with the addition of chemical binders and of plasticizers.

H-W Zircon Bonding Mortar is supplied either dry, or in wet form ready for use. Both forms contain an air-setting agent which develops a strong bond before the construction work is brought to operating temperature. After heating to furnace operating temperatures, the mortars form a continuous mass with the brick.

H-W Zircon Ramming Mix is shipped in dry form. When mixed with water, rammed into place and dried, it takes on a strong air-set. A special particle sizing formula contributes to the high bulk density of about 210 pounds per cubic foot when rammed into place. It is very refractory, and has excellent volume stability at furnace operating temperatures. Because of its ability to resist various fluxing constituents, H-W Zircon Ramming Mix is used for paving glass-tank ports. It may also be used for lining high-frequency induction furnaces melting stainless steel, carbon steels, special alloy steels, and in the melting of gray iron.



Some Harbison-Walker Silicon Carbide and Zircon Shapes.



MORTAR

MATERIALS

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HARBISON-WALKER BRANDS OF MORTAR MATERIALS

Brand Name	Base Material	Form as Shipped	Container	Net Weight Pounds
HEAT-SETTING MORTARS (Pages 140 to 143)				
H-W High-Duty Fire Clay	Fire Clay	Dry	Bulk	...
		Dry	Sacks	100
H-W Special Mortar	Fire Clay	Dry	Bulk	...
		Dry	Sacks	100
H-W Superduty Mortar	Fire Clay	Dry	Bulk	...
		Dry	Sacks	100
H-W Weathered Bond B Clay	Fire Clay	Dry	Bulk	...
		Dry	Sacks	100
Kaosil Fire Clay	Semi-Silica	Dry	Bulk	...
		Dry	Sacks	100
H-W Sillimanite Bonding Mortar	High-Alumina	Dry	Sacks	100
Ankorite 65	High-Alumina	Dry	Sacks	100
H-W Star Silica Fire Clay	Silica	Dry	Bulk	...
		Dry	Sacks	100
H-W Coke Oven Silica Fire Clay	Silica	Dry	Bulk	...
		Dry	Sacks	100
Starbond	Silica	Dry	Sacks	100
Vega Bond	Silica	Dry	Sacks	100
H-W Washington Furnace Magnesite	D. B. Magnesite	Dry	Sacks	100
H-W Special Furnace Chrome	Chrome Ore	Dry	Sacks	100
H-W Insulating Brick Mortar	Fire Clay	Dry	Sacks	100
Harbide Bonding Mortar	Silicon Carbide	Dry	Sacks	100
AIR-SETTING MORTARS (Pages 143 to 146)				
Penseal	Fire Clay	Wet	Drums	200 and 100
Harwaco Bond	High-Alumina	Wet	Drums	200, 100, 50, and 25
		Dry	Sacks	100
Harwaco Mastic	High-Alumina	Wet	Drums	200
		Dry	Sacks	100
H-W Super Harbond	High-Alumina	Wet	Drums	200
		Dry	Sacks	100
Coralite Bonding Mortar	High-Alumina	Wet	Drums	200
		Dry	Sacks	100
Coralbond	High-Alumina	Wet	Drums	200
Korundal Bonding Mortar	High-Alumina	Dry	Drums	100
H-W Corundum Bonding Mortar	High-Alumina	Dry	Drums	100
Firebond	Silica	Dry	Drums	200
		Dry	Sacks	100
H-W Periklase Bonding Mortar	D. B. Magnesite (High-Periclase)	Dry	Drums	175
		Dry	Sacks	100
Forsterite Bonding Mortar	Forsterite	Dry	Drums	175
		Dry	Sacks	100
Thermolith	Chrome Ore	Dry	Drums	200
		Dry	Sacks	100
H-W Alkamortar	Fire Clay	Dry	Sacks	100
H-W Zircon Bonding Mortar	Zircon	Dry	Drums	100

D. B. Magnesite = Dead-Burned Magnesite.

MORTAR MATERIALS

Masonry built of refractory brick consists of many relatively small units, laid together to conform to a definite prescribed plan or design. The strength of the masonry depends upon the strength of the individual brick, the manner in which they are laid together and the nature of the mortar material used in the joints. The purpose of the mortar is to fill the joints, and to bond the individual brick together; it should protect the joints from attack by slag and other fluxes, and provide resistance to infiltration of cold air and to the outward flow of gases.

Users of refractories realize that poorly made joints, or joints filled with improper material, may greatly shorten the life of a refractory structure. They know that the mortar material should be selected as carefully as the brick with which it is to be used.

Refractory mortar materials are divided into two general classes:

1. Heat-setting mortars.
2. Air-setting mortars.

Heat-setting mortars require relatively high temperatures to develop a ceramic set, in contrast with air-setting mortars which take a rigid set merely upon drying. Included in each of these groups are materials of various compositions, each with a definite field of application.

The compositions of all Harbison-Walker mortar materials and the methods of preparation have been developed through extensive laboratory investigations, to develop the particular combination of properties each bonding mortar should possess. Among the factors included are workability, plasticity, water retention, fineness of grind, drying and firing shrinkages, chemical composition, refractoriness, cold and hot bonding strengths, vitrification temperature, and resistance to chemical attack.

The conditions which a bonding mortar must meet in service are often extremely exacting, and require a nicely adjusted balance of properties. For economy and convenience in laying, a mortar should have good working properties when mixed to either dipping or troweling consistency. With excellent workability and water retention over a range of consistencies, a mortar can be used for dipped or troweled joints, as a surface coating for walls, or for patching. The mortar should not shrink excessively upon drying or heating, nor should it overfire and become vesicular at the maximum service temperature. The thermal expansion of the mortar should be approximately the same as that of the brick with which it is used; otherwise, temperature changes will affect the bond between brick and mortar, and cause surface coatings to crack or peel. If strong joints are needed, the mortar material must be affected sufficiently by the heat to develop a strong ceramic bond. However, the refractoriness must be sufficiently high so that the mortar will not melt or flow from joints at high temperatures.

In some cases, there must be sufficient chemical reaction between brick and mortar to develop a strong bond between them, but in no case should the chemical reaction be sufficient to damage the brick. In many types of service, it is essential that the joint material be highly resistant to chemical attack by the furnace charge, slag, dust, volatilized fluxes or gases; and for certain uses it is important that the mortar material should not discolor nor otherwise contaminate the material being processed in the furnace. Mortars which do not develop a strong bond are often desirable for use in laying brick walls which are subjected alternately to soaking heat and cooling cycles.

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HEAT-SETTING BONDING MORTARS

HEAT-SETTING bonding mortars consist of finely ground raw or calcined refractory material, or a mixture of these. These mortars usually are of compositions and properties similar to those of the brick with which they are to be used.

The distinguishing characteristic of a heat-setting mortar is that it develops a ceramic set with a strong bond only at furnace temperatures. The bonding temperature usually lies between 1800° and 2500°F., depending on the composition, and with a temperature gradient through the refractory wall, only a partial thickness of the wall attains temperatures high enough to develop the ceramic bond. These mortars provide flexibility in expansion and contraction of the brick lining as the furnace temperature is raised and lowered. They may also compensate for the high thermal expansion of certain brick, and for differences in thermal expansion between brick of different types used in the same furnace.

Heat-setting mortars of various compositions are supplied for laying refractory brick for service in which full or solid joints with minimum shrinkage are especially desirable and in which a very strong bond through the entire wall thickness is not an essential requirement. They are especially adapted for high-temperature service where temperature fluctuations are extreme.

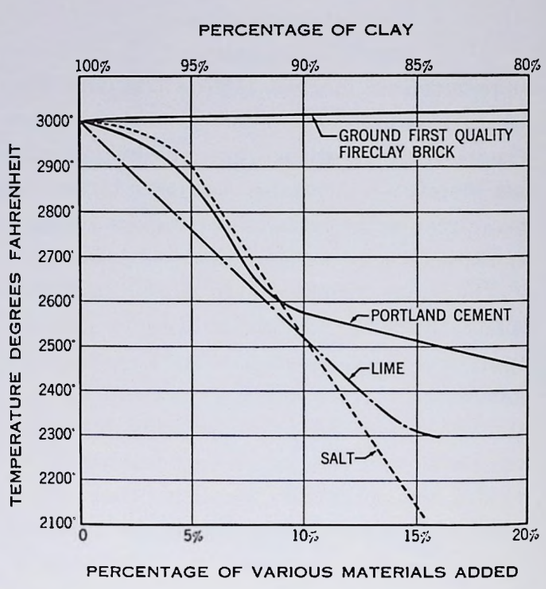
Most materials of this kind have excellent working properties. They are prepared for use by mixing them with a sufficient amount of water to give the desired consistency for either troweled or dipped joints, as may be desired. Usually thin joints are best.

H-W fine ground fire clays are shipped in bulk or in sacks. Other heat-setting mortars are shipped in sacks, and sometimes in drums.

H-W HIGH-DUTY FIRE CLAY is a heat-setting mortar generally used for laying fireclay brick. For dipped joints, the mortar material is thoroughly mixed with water to form a thin slurry.

The addition of portland cement, lime, asbestos, salt, or other foreign materials to finely ground fire clay to be used as mortar material for brick entering into high-temperature operation, is not recommended. Such materials, even in small proportions, may lower the refractoriness of the mortar considerably. This fact is illustrated in the accompanying figure, which shows the effect of certain materials on the melting point of a plastic fire clay. Fluxing agents added to fireclay mortar not only decrease its refractoriness, but also render it more vulnerable to attack by slags.

Fireclay brick of superior quality should never be laid with inferior fire clays. Such



Fusion Temperatures of Mixtures of a Plastic Fire Clay and other Materials.

materials may shrink excessively at even moderate temperatures. At higher operating temperatures they may swell or soften sufficiently to flow from the joints. Very impure clays at high temperatures will react chemically with the brick, and cause serious damage.

In each manufacturing district, Harbison-Walker prepares finely ground fire clays which are especially adapted for use as mortar materials for laying H-W fireclay brick of the various brands produced in that district.

H-W SPECIAL MORTAR is a blend of plastic fire clay and a calcined refractory fire clay that has been completely shrunk at a high temperature. The plastic clay lends good working characteristics to the mortar, and develops good bonding strength at moderate furnace temperatures.

H-W SPECIAL MORTAR is appreciably more refractory than are the fine ground fire clays generally used for laying high-duty fireclay brick, and its shrinkage at high temperatures is negligible. It is supplied for laying either high-duty or superduty fireclay brick and is especially adapted for high-temperature service where temperature fluctuations are extreme. Since it does not bond the brick rigidly together, it permits them to expand or contract freely when changes in temperature occur. Several modifications are made for certain special uses and specifications.

H-W SUPERDUTY MORTAR is a heat-setting mortar material, designed mainly for use in laying superduty fireclay brick. It consists of calcined flint clay and highly refractory bonding clays, blended to give the most desirable combination of properties. It has excellent working qualities, and can be used for either dipped or troweled joints. It is highly refractory, has negligible shrinkage, and develops a strong ceramic bond at moderate furnace temperatures. H-W SUPERDUTY MORTAR serves well for laying either superduty or high-duty fireclay brick, and in some special applications for laying high-alumina brick.

H-W WEATHERED BOND B CLAY possesses an unusual combination of desirable properties, including high plasticity, relatively strong bond when merely air-dried, high strength after firing, high fusion point, moderate shrinkage, and exceptional uniformity.

Finely ground H-W WEATHERED BOND B CLAY gives exceptional service when used for laying high-duty fireclay brick. When thoroughly mixed with water, it passes almost entirely into suspension, forming a slurry which can be supplied to brickmasons in an elevated structure by means of a plunger pump.

KAOSIL FIRE CLAY is a heat-setting mortar prepared from a combination of plastic and calcined clays. This mortar material is shipped dry, and when mixed with water has good spreading and water retention characteristics, and very little shrinkage upon drying.

KAOSIL FIRE CLAY is produced especially for laying KAOSIL semi-silica fireclay brick in various constructions. It has approximately the same composition as the brick.

H-W SILLIMANITE BONDING MORTAR is a heat-setting high-alumina refractory mortar. It has excellent workability and forms strong joints with maximum resistance to penetration by gases. It has unusual resistance to slagging and corrosive effects of various fluxes and volatile alkalies. Upon air-drying and heating to furnace operating temperatures, H-W SILLIMANITE BONDING MORTAR is rapidly transformed to mullite with virtually no volume change. It is highly refractory and can be used safely at temperatures up to 3100°F.

H-W SILLIMANITE BONDING MORTAR is used advantageously for laying high-alumina brick and superduty or other fireclay brick in various

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high-temperature furnaces. It is especially suited for laying blast-furnace brick. Other applications include linings for blast-furnace stoves, hot-metal mixers, and hot-metal cars.

ANKORITE 65 is an exceptional heat-setting bonding mortar of the high-alumina class designed primarily for laying superduty fireclay brick and some classes of high-alumina brick. It has high refractoriness, and is volume-stable at temperatures up to the 3000-3100°F. range. It has excellent resistance to ferrous slags, metal, and gases by virtue of its dense, volume-stable character. It is recommended for use in hot-metal cars and holding-vessels, for laying superduty fireclay blast-furnace brick, and for application in malleable iron furnaces or others where severe operating conditions exist.

H-W STAR SILICA FIRE CLAY is a refractory mortar material or "silica cement" specifically adapted for laying silica brick. It consists of a mixture of finely ground silica material and a siliceous plastic clay. It readily enters into suspension when mixed with water, and can be spread easily and smoothly with a trowel, or used for dipped joints.

H-W Star Silica Fire Clay, of the standard composition, fulfills all of the usual requirements of mortar material employed in laying silica brick. Its refractoriness is high, and it forms a strong ceramic bond at furnace temperatures. Several modifications are supplied for special service conditions.

H-W COKE OVEN SILICA FIRE CLAY is a mixture of finely ground silica material and a siliceous plastic clay, and is somewhat more refractory than the usual silica fire clays. While its main application is in laying silica coke-oven brick, it is also used in glass tank and other furnaces. It develops a strong ceramic bond when heated to furnace operating temperatures.

STARBOND is a heat-setting bonding mortar containing a higher content of silica and lower content of alumina and accessory oxides than the standard classes of silica cements. It is approximately equal in refractoriness to Star silica brick. It contains a plasticizing agent which imparts exceptional working properties. Advantage is taken of the superior properties of Starbond in its use in constructions where the refractories are subject to corrosion or to other extremely severe operating conditions.

VEGA BOND superduty silica mortar is the ultimate attainable in silica mortars. It was developed mainly for use with Vega superduty silica brick, and corresponds to Vega in chemical composition and refractoriness.

Upon mixing with water, Vega Bond develops excellent plasticity. When brought to a creamy consistency, it can be used for laying silica brick with thin but full joints. As a stiffer mortar it serves for laying brick with relatively thick joints, as for leveling up courses. Vega Bond is used economically also for laying any silica brick for service under severe operating conditions, and for laying Vegalite insulating silica brick.

H-W WASHINGTON FURNACE MAGNESITE consists of finely ground dead-burned magnesite. While prepared particularly for use as a heat-setting mortar material in laying magnesite brick, it also finds application for patching, and in mixtures with granular magnesite material it serves for the construction of rammed linings and monolithic furnace hearths.

The use of H-W Washington Furnace Magnesite as a mortar material differs from the usual practice of most other mortars in that it is not mixed with water. It is used mostly in dry form, but for some constructions, it is mixed with water glass or linseed oil in proportions ranging from 5 to 15 per cent. When H-W Washington Furnace Magnesite is used in dry form, as for example in electric furnace bottoms, the brick are first laid with open joints of approximately a trowel's thickness; after each course is laid, the H-W Washington Furnace Magnesite is dusted or swept into the joints. For buttered or dipped joints, H-W Periklase Bonding Mortar, an air-setting high-temperature cement, is generally preferred.

H-W Washington Furnace Magnesite, blended with magnesite grains, is sometimes mixed with hot tar for patching or for rammed linings and furnace hearths.

H-W SPECIAL FURNACE CHROME is prepared from carefully selected chrome ores of high refractoriness. It is used to advantage for laying chrome brick, and in many instances for laying silica or magnesite brick. Joints formed with it are resistant to attack by a wide range of furnace slags and other fluxing agents. It is used as a daubing material for the protection of brickwork in various types of furnaces, as for example, in center walls of soaking pits.

H-W INSULATING BRICK MORTAR is a heat-setting mortar material especially adapted for laying H-W insulating firebrick. The mortar consists of finely ground fire clays of highest quality, blended carefully to obtain the most desirable properties. H-W Insulating Brick Mortar is shipped in dry form and when mixed with water develops excellent workability. It may be used in service up to 2600°F. For service at higher temperatures, Ankorite 65 is recommended. When it is desirable to use an air-setting mortar for laying insulating firebrick, Penseal for moderate temperatures and Harwaco Bond for high temperatures give excellent service.

HARBIDE BONDING MORTAR is a highly refractory heat-setting bonding mortar made from silicon carbide powder of high purity. The grains are blended with refractory bonding agents which develop a strong bond upon heating to approximately 2500° to 2700°F. The properties of Harbide Bonding Mortar, after development of the ceramic bond, are practically identical with those of Harbide brick.

Harbide Bonding Mortar is shipped in dry form and is usually prepared for use by the addition of water to bring it to the desired working consistency. It has good volume stability and does not develop cracks upon drying and heating. It is used in various applications for laying Harbide brick which will be subjected to very high temperatures. Whenever furnace temperatures are not high enough to develop fully the bond of this mortar, it is generally preferable to lay the Harbide brick with Harwaco Bond, a mortar with air-setting properties.

AIR-SETTING BONDING MORTARS

Air-setting bonding mortars are those which take a rigid set when dried. They are prepared from suitable refractory materials by proper selection and combination. Chemical binders impart air-setting properties, and maintain the strength of the bond up to the temperature at which the ceramic bond takes effect. Air-setting mortars form mechanically strong joints with high resistance to abrasion and erosion. They bond the wall the whole way through—from the hot to the cold surface.

Bonding mortars of the air-setting type are recommended for service in which a strong bond over a wide range of temperatures is desirable. They are used extensively for laying all types of refractory brick, especially in those portions of industrial furnace masonry where operating conditions are most severe.

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In order to preserve maximum workability, the mortars should be stored in a cool place. Any unused portion of mortar will retain excellent working qualities if the container is kept tightly sealed to prevent drying.

PENSEAL is an air-setting high-temperature bonding mortar having a fireclay base shipped in wet form. It has excellent workability and can be troweled directly from the drum or made to a dipping consistency by adding water. PENSEAL has low shrinkage, good adherence, and long life in storage. An illustration of an important application of PENSEAL is the cementing of sleeve assemblies on stopper rods in iron and steel plant ladles.

HARWACO BOND is a nonshrinking, air-setting, high-temperature bonding mortar with a high-alumina base. It is shipped either dry or wet. As shipped in wet form, it contains just the proper amount of liquid to make it suitable for the average troweled joint. Any unused portion of the mortar will retain excellent working qualities if the container is kept tightly sealed.

HARWACO BOND is exceptionally plastic. It can be worked with a trowel, even on a porous brick, without drying too rapidly. With the addition of water, it can be brought to the proper consistency for either dipped joints or for surface coating.

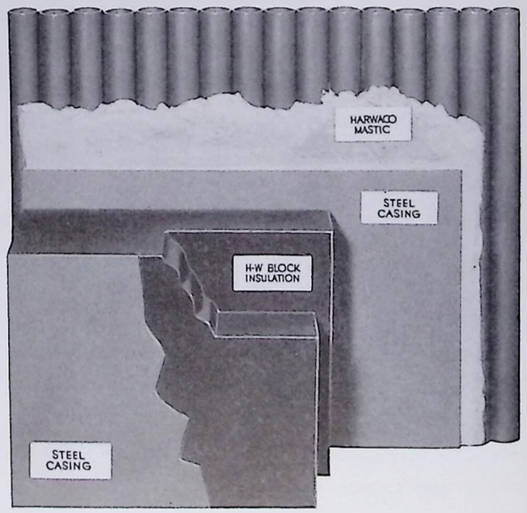
HARWACO BOND is recommended for use as a daubing mixture and for laying fireclay, superduty fireclay, or high-alumina brick. Its high bonding strength adapts it for moderate heat-duty service, and its high refractoriness renders its use advantageous for applications where high working temperatures prevail. When applied as a thin coating to the inner surfaces of furnace walls, HARWACO BOND under some conditions contributes to the reduction of gas leakage and air infiltration, especially at high operating temperatures.

HARWACO MASTIC is a plastic air-setting refractory material composed of minerals of high mullite content with plastic bonds. The thick troweling consistency of HARWACO MASTIC renders it suitable for application directly onto boiler tubes and for coatings with expanded metal lath.

HARWACO MASTIC as shipped is used for laying brick with thick joints. It can be adapted for normal bricklaying by thorough mixing with water.

HARWACO MASTIC is used with excellent results for many applications, including the following: pointing or sealing cracks in brickwork; protective coatings for burner nozzles; sealing outside faces of tangential boiler tubes; protective linings in piping and ducts such as used in petroleum refineries; patching material in many kinds of furnaces; and protective coatings on oxygen lances.

H-W SUPER HARBOND is an air-setting high-alumina bonding mortar. It is highly refractory, as shown by its P.C.E. of 33 to 34, and has excellent bonding strength and volume stability through its entire temperature range. It develops unusually high strength upon air-drying as well as over the intermediate temperature range where most air-setting mortars exhibit their lowest strength. It shows virtually no shrinkage when dried and heated to furnace temperatures.



Typical Boiler Wall Construction Illustrating Use of HARWACO MASTIC.

Shipped in wet form, H-W SUPER HARBOND contains just the proper amount of moisture for use in troweling. With the addition of water, it can be brought to the proper consistency for dipped joints or for surface coating.

H-W SUPER HARBOND finds application in various constructions where good bonding strength, high refractoriness, and slag resistance are required, and where extremely severe operating conditions prevail. It was primarily developed for laying high-duty and superduty fireclay brick in blast-furnace linings.

CORALITE BONDING MORTAR is an air-setting high-temperature mortar with a high-alumina base, supplied in either wet or dry form. It has high refractoriness and bonding strength, and is particularly suited for laying brick which are used in contact with molten metals and various corrosive slags. It is used also for laying fireclay and high-alumina brick in the bottoms and sidewalls of both ferrous and nonferrous metallurgical furnaces.

CORALBOND is a phosphate-bonded high-alumina bonding mortar which is shipped wet in drums ready for use. This mortar is designed for troweled joints and should not be thinned for dipping. Rolling the drums prior to opening them will assist in mixing the mortar to its natural consistency. Heating to a minimum of 500°F., after preliminary drying, will help to develop a strong bond.

Among numerous mortars of many compositions, CORALBOND is outstanding in its resistance to penetration and corrosion by aluminum alloys at furnace operating temperatures. It is used widely in aluminum-melting furnaces.

KORUNDAL BONDING MORTAR, an air-setting mortar, was developed specifically for use with KORUNDAL brick. One of its most significant properties is extremely high refractoriness, imparted by its alumina content of more than 80 per cent. It is used with all classes of high-alumina brick in applications where temperatures are unusually high.

H-W CORUNDUM BONDING MORTAR is an air-setting high-temperature mortar having an alumina content of 98+ per cent when heated in place. This composition commends it for use in applications where purity of the product is essential. Its exceedingly high refractoriness adapts it for use with H-W CORUNDUM and other brick of very high alumina content.

FIREBOND is a high-temperature mortar of the siliceous type, which is shipped dry. It can be quickly prepared for use by mixing it with just enough water to form a mortar of the desired consistency for either dipped or troweled joints. An excess of water is to be avoided, to assure retention of the lightest particles. FIREBOND has excellent working properties. It sets as it dries, forming a strong bond which is maintained at furnace operating temperatures. It is resistant to the corrosive action of siliceous slags, and retards slag penetration at joints.

FIREBOND is recommended for laying fireclay or silica brick. When applied as a coating to the inner wall surfaces of furnaces, it reduces leakage of gases and infiltration of air.

H-W PERIKLASE BONDING MORTAR, an extremely refractory high-temperature air-setting mortar of exceptionally high magnesia content, is ideally suited for laying H-W PERIKLASE brick. However, it may be used successfully with other types of basic brick in all applications where a chemically basic mortar is required.

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H-W Periklase Bonding Mortar is a dry mortar material and needs only to be mixed with water to prepare it for use.

FORSTERITE BONDING MORTAR is used primarily with Forsterite brick, and its composition is substantially the same as that of the brick. Bonding agents are blended with the mortar material for the purpose of imparting strong air-setting properties and a strong ceramic bond.

THERMOLITH is a dry high-temperature mortar having a chrome ore base. It is mixed with water to produce an air-setting mortar of exceptional merit. Because of its nearly neutral chemical character it forms joints which are extremely resistant to chemical corrosion by a wide variety of slags. Its high bonding strength and other desirable properties adapt it for service as a bonding material in applications covering a wide range of temperatures.

Thermolith can be easily prepared for use by mixing it thoroughly with a sufficient amount of water to form a thick mortar for troweled joints, or a slightly thinner mortar for dipped joints. An excess of water should be avoided, to insure uniform consistency of the mortar. For surface coatings, Thermolith is usually applied by means of an air gun.

Thermolith may be used also to form heavy troweled joints when such joints are needed. It begins to set soon after being spread, forming firmly bonded joints, and the bond is maintained throughout its entire range of operating temperatures.

Thermolith is recommended for use in laying basic brick of all types, fireclay brick, high-alumina brick, and silica brick; or as a neutral layer between brick which tend to react with each other at high temperatures. It also serves to advantage as a bond for daubing mixtures used in making repairs to damaged brickwork. Thermolith is shipped in air-tight steel drums and in moistureproof sacks.

H-W ALKAMORTAR is a smooth-working air-set mortar which is highly resistant to caustic solutions of moderate concentrations at atmospheric temperatures. It is shipped dry and requires only the addition of water for use.

H-W Alkamortar was primarily developed for laying W-Acid and Duro brick in dissolving and storage tanks in the kraft paper industry. It may be used advantageously in other installations where alkaline conditions prevail, within its temperature and concentration limits.

H-W ZIRCON BONDING MORTAR is an air-setting mortar with a base of zircon, developed for laying H-W Zircon brick. It acquires high strength upon drying, and exhibits excellent bonding properties throughout its entire service temperature range. It has good volume stability, and shows no shrinkage cracks upon drying and heating.

H-W Zircon Bonding Mortar contains a high percentage of zircon, which is properly ground and sized for best spreading properties and maximum workability. It has high refractoriness and its properties are compatible with the properties of H-W Zircon brick.

SELECTION OF HIGH-TEMPERATURE CEMENTS

Choice of a bonding mortar for any specific application depends not only upon the type of refractory brick to be bonded, but also upon the operating conditions to which the brick are to be exposed. Service conditions vary so widely in different furnaces and usually in different parts of the same furnace that many kinds of brick and bonding mortars are needed. The correct choice of both will be assured by consultation with a Harbison-Walker representative.



SPECIAL CLAYS

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SPECIAL CLAYS

At most Harbison-Walker clay-working plants, in ten states, various special clays are produced for substantially all refractory fireclay requirements. These include highly plastic bonding clays, the most refractory calcined flint clays, and others possessing certain enhanced physical properties especially suited for many diversified purposes. Some of these clays which are most widely used industrially are briefly described in the following pages.

BONDING CLAYS

H-W ATHENS PLASTIC CLAY is a bonding clay of the siliceous type obtained from deposits near Athens, Texas. It is very plastic and has good bonding properties. It is open-burning and when fired has excellent resistance to thermal spalling. Its low content of impurities and its relatively high content of free silica impart mechanical strength and rigidity at high temperatures. H-W Athens Plastic Clay is particularly suited for use in the manufacture of zinc retorts, condensers, saggers, and of setting tile which are subjected to transverse loads.

H-W WEATHERED BOND B CLAY possesses a remarkable combination of desirable properties, including high plasticity, strong bond when merely air dried, high strength after firing, high fusion point, moderate shrinkage, and exceptional uniformity. It is mined from an unusually large deposit, the extent and quality of which have been determined by thorough core drilling. A steady, uniform output is assured for the future.

Like most plastic clays of high fusion point, H-W Weathered Bond B Clay is in comparatively hard lump form as mined. While plasticity and good bonding qualities are acquired merely upon grinding and tempering with water, these properties are not developed to the fullest extent except by weathering. H-W Weathered Bond B Clay is weathered for at least one year, to disintegrate and slake the lumps, to make the clay more plastic, and to develop its bonding strength. A series of stock piles provides a uniform and adequate supply.

Finely ground H-W Weathered Bond B Clay gives exceptional service when used for laying high-duty fireclay brick; for mixing with ground silica ganister or with ground calcined clay in making monolithic bottoms and linings; for mixing with calcined grog to be used in making repairs to furnace linings by application with an air-placement gun; and for laying bungs, and for daubing in malleable iron furnaces. When thoroughly mixed with water, H-W Weathered Bond B Clay passes almost entirely into suspension, forming a slurry which can be supplied to brickmasons in an elevated structure, such as blast-furnace lining, by means of pumps of various types.

H-W CRUCIBLE CLAY is prepared from thoroughly weathered clay by fine grinding, pugging, and storing for many months in a sweating room. It is then passed through a combination pug mill and auger machine. This treatment develops the plasticity and bonding strength to the utmost degree.

H-W Crucible Clay is used in the manufacture of various products which require clay of high refractoriness as well as of high plasticity and bonding power, as for example, refractory graphite products. It is shipped in dobie form, either wet or dry, or finely ground.

H-W D CLAY is a white burning siliceous kaolin with an extremely low flux content. It is produced from a large deposit in central Pennsylvania. Selective mining assures quality control and uniformity of product.

H-W D Clay is used as the open-burning constituent in sagger and tile batches. It is also advantageously employed in potteries as a constituent of various ceramic bodies. H-W D Clay is well adapted for use in monolithic bodies and for any other purpose requiring clay of extremely low shrinkage and high refractoriness. It is supplied ground to the degree of fineness desired.

H-W FOUNDRY CLAY is a plastic bond clay which is well adapted for patching and daubing in cupolas and malleable iron furnaces, and for general foundry use. The shrinkage of H-W Foundry Clay at high temperatures is very low. Consequently, it does not tend to peel or separate from brickwork. When heated it becomes hard and strong and at furnace operating temperatures readily acquires a glazed surface, resistant to penetration by slags.

H-W MOLDSAND BOND is a finely ground extremely plastic bonding clay of high refractoriness. As described in a later section on Refractory Molding Media, it is especially adapted to the making of synthetic mixtures with clean sand or with Calamo and as a rejuvenating agent for molding sand in foundries which are equipped with chaser mills or mullers.

The minute particles of the ground bond clay become much more finely divided when tempered with water; consequently, homogeneous clay-sand mixtures are easily prepared. Because of its high refractoriness, H-W Moldsand Bond does not fuse at metal-pouring temperatures. The most desirable degree of cohesiveness and permeability can be secured by adding suitable amounts of H-W Moldsand Bond to the molding sand.

CALCINED CLAYS

The stability of many refractory products made of fire clay is dependent upon the character and amount of grog used in the batch. In refractories intended for use where they are required to withstand severe service conditions, the grog must be of superior quality. Highly refractory flint clays possess the characteristics necessary for such grog.

H-W CALCINED MISSOURI FLINT CLAY is a selected clay of high refractoriness which has been calcined in a rotary kiln. It is of extremely uniform burn, and of high density. It ranges in size from pieces of approximately 2½ inches in diameter to particles of ⅛-inch size, including a small proportion of fines. It is also furnished ground to specification.

H-W CALCINED PENNSYLVANIA FLINT CLAY is prepared from lumps of highly refractory clay obtained from the company's mines in central Pennsylvania, and calcined in a rotary kiln. Uniformity in quality is assured by careful laboratory control testing. The temperature of calcination is sufficiently high to effect practically complete shrinkage. When crushed, the calcined clay breaks down into angular fragments, so desirable in mixes used in the manufacture of clay bodies which must be mechanically strong and well bonded.

H-W Calcined Flint Clays, from Missouri and Pennsylvania, are used in the manufacture of refractory blocks for the glass industry and in the manufacture of zinc retorts and condensers. They also serve admirably as the grog constituent in monolithic linings and patching

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mixes, and as the grog component of saggers and various other refractory bodies.

H-W CALCINED KAOLIN is obtained through calcination of selected high-grade material at high temperature in a rotary kiln. It is of hard burn and of high density. The calcines range in size from a maximum diameter of 2½ inches down to ⅛-inch, including a small percentage of finer particles. The high refractoriness and density of H-W CALCINED KAOLIN adapt it for use in ramming mixes, refractory concrete, saggers, mortars, and various other refractories.

H-W CALCINED HIGH-DUTY FIRE CLAY is manufactured from refractory clays that have been burned at high temperatures to eliminate the shrinkage. It is supplied in various standard grinds, or in special sizings as may be required for particular applications. H-W CALCINED HIGH-DUTY FIRE CLAY is used in the preparation of ramming mixes, saggers, zinc retorts, and as the grog constituent in a wide variety of other refractory products.

SOME RECOMMENDED USES FOR H-W SPECIAL CLAYS

Application	Materials
Air Gun Mixes	H-W WEATHERED BOND B CLAY H-W CALCINED CLAYS
Ceramic Bodies	H-W WEATHERED BOND B CLAY H-W D CLAY H-W CALCINED CLAYS H-W CALCINED KAOLIN
Cupolas (Patching and Daubing)	H-W FOUNDRY CLAY
Foundry Service. General Patching and Daubing Synthetic Molding Mixtures	 H-W FOUNDRY CLAY H-W MOLDSAND BOND
Ganister Mixes	H-W WEATHERED BOND B CLAY (with H-W GROUND QUARTZITE)
Glass House Refractories	H-W CRUCIBLE CLAY H-W CALCINED FLINT CLAY
Graphite Products	H-W CRUCIBLE CLAY H-W CALCINED CLAYS
Malleable Furnaces For Laying Bungs and Daubing Mixtures	 H-W WEATHERED BOND B CLAY
Monolithic Linings and Patching Mixes	H-W WEATHERED BOND B CLAY H-W D CLAY H-W CALCINED CLAYS H-W WEATHERED BOND B CLAY (with H-W GROUND QUARTZITE)
Mortar for Laying Brick	H-W WEATHERED BOND B CLAY
Zinc Condensers and Retorts	H-W CALCINED CLAYS H-W ATHENS PLASTIC CLAY



MONOLITHIC REFRACTORIES

HARBISON-WALKER REFRACTORIES COMPANY

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HARBISON-WALKER BRANDS OF MONOLITHIC REFRACTORIES

Brand Name	Base Material	Kind of Set	*Max. Service Temperature	Pounds Required Per Cu. Ft.	Form As Shipped
H-W Plastic Refractories (Pages 155, 157, 158)					
H-W Standard Plastic Firebrick	H.D. Fire Clay	Heat	2800°F.	135	Wet
H-W Standard Plastic CS	H.D. Fire Clay	Air	2800°F.	137	Wet
H-W Super Plastic Firebrick	SD. Fire Clay	Heat	3000°F.	137	Wet
H-W Super Plastic CS	SD. Fire Clay	Air	3000°F.	137	Wet
H-W Black Patch	SD. Fire Clay (with graphite)	Heat	2900°F.	130	Wet and Dry
Apache Plastic Refractory	High-Alumina	Heat	3100°F.	145	Wet
Apache Plastic CS	High-Alumina	Air	3100°F.	140	Wet
Apachite Plastic Refractory	High-Alumina (with graphite)	Heat	3000°F.	145	Wet
H-W Mullite Plastic Refractory	High-Alumina	Heat or Air	3200°F.	153	Wet
Coralite Plastic Refractory	High-Alumina	Heat or Air	3250°F.	166	Wet
Plastic Thermolith Batch	Chrome Ore	Air	2700°F.	190	Wet
H-W Ramming Mixes (Pages 158, 159, 160)					
H-W Mullite Ramming Mix	Mullite	Air	3200°F.	155-160	Wet and Dry
Coralite Ramming Mix	High-Alumina	Air	3250°F.	170	Wet
Coral Ramming Mix	High-Alumina	Chemical	3000°F.	180	Wet
Korundal Ramming Mix	High-Alumina	Air	3300°F.	175	Dry
Harcor	High-Alumina	Chemical	3200°F.	185	Wet
H-W Corundum Ramming Mix	Corundum	Air	3600°F.	188	Dry
H-W Induction Furnace Mix	Spinel ($MgO \cdot Al_2O_3$)	Air	3300°F.	162	Dry
H-W Magnamix	D.B. Magnesite	Air	3000°F.	160	Dry
H-W Magnamix 85	D.B. Magnesite	Air	3600°F.	168	Dry
H-W C-Mix	D.B. Magnesite (Periclase)	Air	3700°F.	172	Dry
H-W Periklase Batch	D.B. Magnesite (Periclase)	Air	3300°F.	170	Dry
H-W Oximix	D.B. Magnesite-Dolomite	Heat	3200°F.	180	Wet
Thermolith Batch	Chrome Ore	Air	3100°F.	195	Dry
H-W Zircon Ramming Mix	Zircon	Air	3500°F.	210	Dry
H-W Gun Mixes (Pages 161, 162, 163)					
Kuplomix	Silica	Heat	2900°F.	140	Dry
H-W Standard Gun Clay	H.D. Fire Clay	Heat	2800°F.	135	Dry
H-W Standard Gun Clay CS	H.D. Fire Clay	Air	2800°F.	135	Dry
H-W Super Gun Clay	SD. Fire Clay	Heat	3000°F.	137	Dry
H-W Super Gun Clay CS	SD. Fire Clay	Air	3000°F.	137	Dry
Apache Gun Clay	High-Alumina	Heat	3100°F.	140	Dry
Apache Gun Clay CS	High-Alumina	Air	3100°F.	140	Dry
H-W Magnamix S	D.B. Magnesite	Air	3500°F.	158	Dry
H-W Special Furnace Chrome GG	Chrome Ore	Heat	3000°F.	150	Dry
H-W Gunshot	Chrome Ore	Heat	3000°F.	150	Dry

H.D. = High-Duty; SD. = Superduty; D.B. = Dead-Burned;

* NOTE: The "Maximum Service Temperatures" can be regarded as safe operating temperatures in the absence of destructive factors other than high temperature. The softening temperatures of the alumina-silica compositions, as evaluated by the usual P.C.E. determinations, would in most cases be appreciably higher.

Variables in service conditions such as corrosive fluxes and fumes, destructive gases, pressure, and others, influence the safe temperature limit. In selecting the proper refractory, careful consideration should be given to all the operating conditions involved.

HARBISON-WALKER BRANDS OF MONOLITHIC REFRACTORIES (Continued)

Brand Name	Base Material	Kind of Set	*Max. Service Temperature	Pounds Required Per Cu. Ft.	Form As Shipped
H-W High-Duty Fireclay Castables (Pages 163, 164)					
H-W RC Castable	H.D. Fire Clay	Hyd.	1000°F.**	114	Dry
H-W Baffle Mix	H.D. Fire Clay	Hyd.	2400°F.	120	Dry
H-W Standard Castable	H.D. Fire Clay	Hyd.	2400°F.	111	Dry
H-W Extra Strength Castable	H.D. Fire Clay	Hyd.	2400°F.	114	Dry
H-W Extra Strength Castable LI	H.D. Fire Clay	Hyd.	2600°F.	120	Dry
H-W Superduty Fireclay Castables (Page 164)					
H-W Super Castable	SD. Fire Clay	Hyd.	2700°F.	113	Dry
H-W Harcast	SD. Fire Clay	Hyd.	2800°F.	123	Dry
H-W Harcast BF	SD. Fire Clay	Hyd.	2800°F.	117	Dry
H-W High-Alumina Castables (Pages 164, 165)					
H-W High-Alumina Castable	High-Alumina	Hyd.	3000°F.	123	Dry
H-W Castolast	High-Alumina	Hyd.	3200°F.	143	Dry
H-W Castolast G	High-Alumina	Hyd.	3200°F.	165	Dry
H-W Basic Castables (Pages 165, 166)					
H-W Chrome Castable	Chrome Ore	Hyd.	2600°F.	166	Dry
H-W Chrome Fill	Chrome Ore	Hyd.	2600°F.	166	Dry
H-W Harchrome Castable	Chrome Ore	Hyd.	2600°F.	166	Dry
H-W Harchrome G	Chrome Ore	Hyd.	2600°F.	166	Dry
H-W Chromepak	Chrome Ore-D.B. Magnesite	Air	3000°F.	179	Dry
H-W Perimix	D.B. Magnesite	Air	3600°F.	168	Dry
H-W Lightweight Castables (Pages 166, 167)					
H-W Lightweight Castable 10	Lightw. Agg.	Hyd.	1000°F.***	30	Dry
H-W Lightweight Castable 20	Lightw. Agg.	Hyd.	2000°F.	30	Dry
H-W Low-Iron Lightweight Castable 22	Lightw. Agg.	Hyd.	2200°F.	51	Dry
H-W Lightweight Castable 22	Lightw. Agg.	Hyd.	2200°F.	50	Dry
H-W Lightweight Castable—Extra Strength	Lightw. Agg.	Hyd.	2300°F.	78	Dry
H-W Lightweight Castable 26	Lightw. Agg.	Hyd.	2600°F.	54	Dry
H-W Lightweight Castable 28	Lightw. Agg.	Hyd.	2800°F.	85	Dry
H-W Lightweight Castable 30	Lightw. Agg.	Hyd.	3000°F.	90	Dry

H.D. = High-Duty; SD. = Superduty; D.B. = Dead-Burned; Hyd. = Hydraulic; Lightw. Agg. = Lightweight Aggregate.

* NOTE: The "Maximum Service Temperatures" can be regarded as safe operating temperatures in the absence of destructive factors other than high temperature. The softening temperatures of the alumina-silica compositions, as evaluated by the usual P.C.E. determinations, would in most cases be appreciably higher.

Variables in service conditions such as corrosive fluxes and fumes, destructive gases, pressure, and others, influence the safe temperature limit. In selecting the proper refractory, careful consideration should be given to all the operating conditions involved.

** 1500°F. when used in continuous operations at reasonably constant temperatures.

*** 1800°F. when used as a back-up material, or in continuous operations at reasonably constant temperatures.

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MONOLITHIC REFRACTORIES

Monolithic or monolith-forming refractories are special mixes or blends of dry granular or stiffly plastic refractory materials with which virtually joint-free linings are formed. They embrace a wide range of mineral compositions, and vary greatly in their physical and chemical properties. Some are relatively low in the scale of refractoriness; others have such high melting temperatures that they are properly termed "super-refractories."

Monolithic refractories are packaged in suitable containers for convenience in handling and shipping. With little or no preparation, they can be applied either to form monolithic or joint-free furnace linings in new construction or to repair existing refractory masonry.

In various types of furnaces, monolithic refractories are used to advantage over brick construction. By their use, prompt installation can be made, avoiding delays for the manufacture of special brick shapes. They frequently eliminate difficult bricklaying tasks which may be accompanied by weakness in construction. They are of major importance in the maintenance of furnaces; substantial repairs can be made with a minimum loss of time and in some instances even during operations. Also, as compared with fired refractory brick, under certain conditions monolithic linings of the same chemical composition provide better insulation, lower permeability, and improved resistance to the spalling effects of thermal shock.

Common usage divides monolithic refractories into the following groups:

1. Plastic Refractories
2. Ramming Mixes
3. Gun Mixes
4. Castables

Plastic Refractories are mixtures of refractory materials, prepared in stiff plastic condition of the proper consistency for use without further preparation. They are generally rammed into place with pneumatic hammers, but may also be pounded into place with a mallet.

Ramming Mixes consist essentially of ground refractory materials, carefully graded as to relative proportions of different particle sizes, with minor amounts of other materials added to make the mixes workable and self-bonding. Most ramming mixes are supplied dry; some are shipped in wet form ready for use. The dry ramming mixes are prepared for use by adding water and mixing. Upon ramming into place, drying, and heating, they form dense, strong monolithic refractory structures. Some ramming mixes can be applied successfully with air-placement guns.

Gun Mixes consist of granular refractory materials specifically prepared for application with air-placement guns. They are sprayed from the guns, or "gunned," at high velocity and pressure, forming very homogeneous and densely compacted linings essentially free from lamination cracks. Basically, there are two types of air-placement guns, the dry and the wet. With the dry gun, the dry mix becomes uniformly moistened with water while it is passing through the nozzle during the gunning operation. For use with the wet gun, the material is mixed with water within the chamber of the gun before it is fed to the nozzle. Gun mixes are generally furnished in dry form. Some have air-setting properties; others are heat-setting.

Castables consist of granular refractory materials, combined with a suitable hydraulic-setting bonding agent. Castables are furnished in dry form, and upon mixing with water, they develop an unusually strong hydraulic set. They are usually poured or cast in much the same manner as ordinary concrete. They may be troweled, rammed, or tamped into place or applied with air-placement guns for certain specific applications. They form strong monolithic linings, possessing combinations of properties which adapt them for many uses.

Classification of a monolith-forming refractory product into one of the four groups described in the preceding paragraphs suggests the manner in which the material is most commonly installed. However, not infrequently, material of one group may be installed also by a technique more common to another group. For example, some castables are applied with an air-placement gun for certain applications, or they may be tamped or rammed into place like a ramming mix. Likewise, some ramming mixes may be used as gun mixes, and some gun mixes as ramming mixes.

When air-setting or hydraulic-setting monolithic refractories are used, the entire thickness of a lining becomes hard and strong throughout at atmospheric temperatures. The strength is somewhat lower through the intermediate temperature range, but increases at higher temperatures with the development of a ceramic bond.

Heat-setting monolithic refractories have very low cold strength, and depend on relatively high temperatures to develop a ceramic bond. In the case of a furnace wall having the usual temperature drop throughout its thickness, the temperature in the cooler portion of the wall is usually not high enough to develop a ceramic bond. However, by the use of a suitable refractory insulating material as a backup, the temperature of the lining will usually be high enough to develop good strength throughout its entire thickness.

Monolithic refractory constructions of appreciable size are generally anchored with refractory brick shapes or high-temperature metal supports. A typical plastic firebrick installation is illustrated on page 156, which shows a method of anchoring monolithic construction. (See also page 168.)

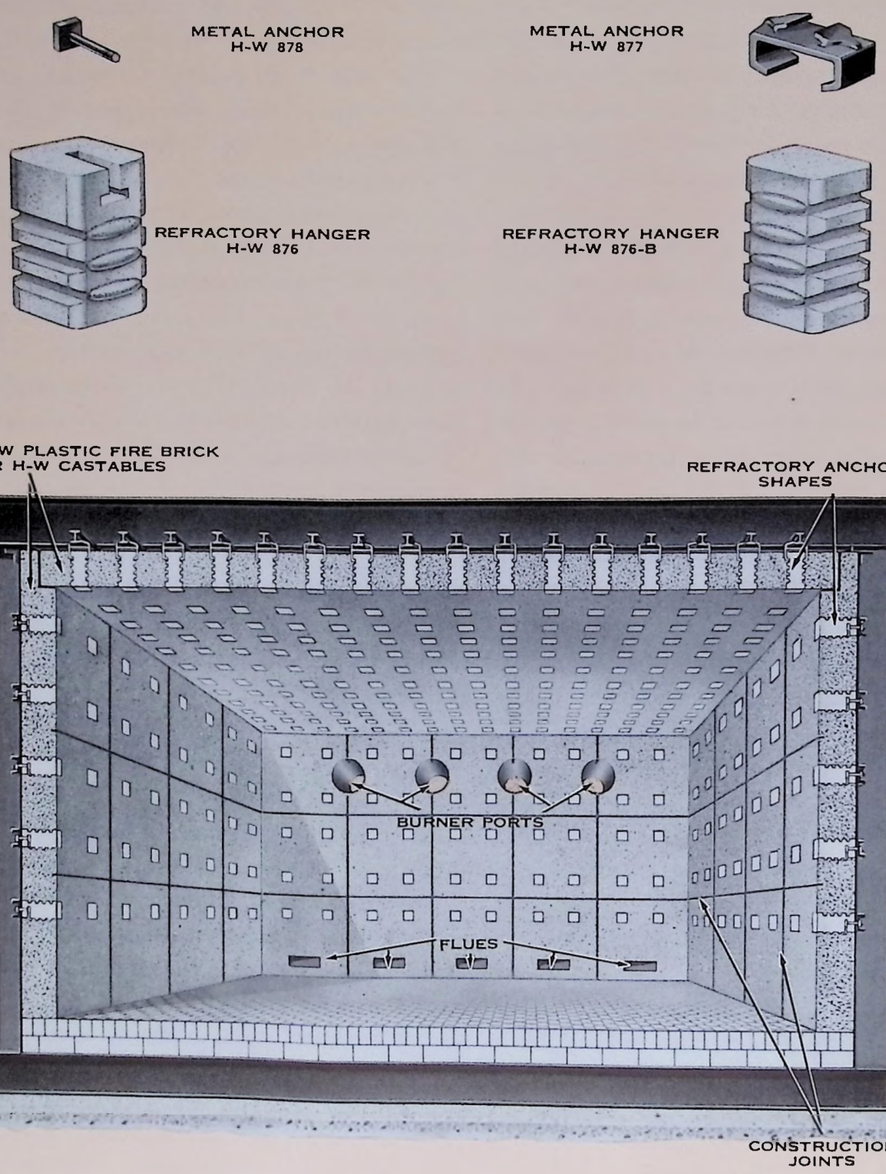
H-W PLASTIC REFRACTORIES

H-W plastic refractories are used for forming refractory monolithic linings in various furnaces, and are especially adaptable for making quick, economical emergency repairs. They are easily rammed to any shape or contour. By their use, the necessity of waiting for manufacture and delivery of special shapes when urgently needed may be avoided.

The high refractoriness, the range in refractoriness of H-W plastic refractory materials, and the ease with which they can be rammed into place make them suitable for many important applications. Typically, these include boiler settings, oil still settings, and oil burner installations; the linings of heating furnaces, soaking pits, forge furnaces, annealing ovens and furnaces, small brass-melting furnaces, coke-oven ascension pipes, cupolas, ladles, lehrs, incinerators, and bake ovens; burner blocks and furnace door linings. H-W plastic refractories are highly resistant to destructive spalling and slagging influence of furnace operation.

Harbison-Walker's plastic refractories include all the types best adapted for the many different operating conditions. They comprise all the fireclay, clay-graphite, high-alumina, high-alumina-graphite, and chrome types. They are packaged in strong, easy-to-handle, mois-

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Typical Monolithic Furnace Construction.

tureproof "zip-open" cartons containing 100 pounds net weight, and in steel drums containing 200 pounds. They are of proper consistency for use without further preparation.

H-W STANDARD PLASTIC FIREBRICK, a heat-setting refractory, is equivalent to high-duty fireclay brick in refractoriness, and in many refractory constructions is used successfully under conditions for which high-duty fireclay refractories are adequate.

H-W STANDARD PLASTIC CS has the same high refractoriness as H-W STANDARD PLASTIC FIREBRICK, but contains a chemical binder to make it air-setting. It develops moderate strength upon air-drying and through the low-temperature range in advance of the heat-developed ceramic bond.

H-W SUPER PLASTIC FIREBRICK, which is heat-setting, is recommended for conditions beyond the service limits of H-W STANDARD PLASTIC FIREBRICK. Manufactured from highest quality calcined flint clays and bond clays, it serves the purposes for which the higher refractoriness of superduty fire clay is needed.

H-W SUPER PLASTIC CS is an air-setting plastic refractory prepared from the same high-quality clays as H-W SUPER PLASTIC FIREBRICK. An added chemical binder imparts the desirable air-setting property.

H-W BLACK PATCH is a heat-setting plastic refractory of superduty quality containing graphite. Its outstanding physical properties are unusual resistance to wetting and penetration by molten ferrous and nonferrous metals and slags; excellent resistance to severe erosive and corrosive effects of metals and slags; very high refractoriness, and low spalling tendency when subjected to rapid temperature changes.

H-W BLACK PATCH is an excellent patching and lining material. When heated it develops a strong ceramic set and a close texture which, together with oxidation inhibitors, greatly retards burning of the carbon. Some typical applications for which H-W BLACK PATCH serves to great advantage are holding ladles, pouring ladles, hand ladles, malleable furnace runners and spouts, blast-furnace runners, cupola runners and spouts, cupola iron- and slag-tapping holes, and cupola tuyere facings.

H-W BLACK PATCH is usually shipped wet, packed in conveniently sized "zip-open" cartons, or in steel drums, and is ready for use as shipped. It is also shipped dry in 100-pound sacks, requiring only the addition of water and mixing for use.

APACHE PLASTIC REFRACTORY is a heat-setting plastic refractory material of high-alumina quality. It has good volume stability at high temperatures and excellent spalling resistance. APACHE PLASTIC REFRACTORY is designed to meet requirements for complete linings, as well as for general patching and repairs in such installations as boilers, soaking pits, forge furnaces, and other high-temperature applications.

APACHE PLASTIC CS has the same composition as APACHE PLASTIC REFRACTORY, and in addition contains a chemical binder to make it air-setting.

APACHITE PLASTIC REFRACTORY is made of the same base material as APACHE PLASTIC REFRACTORY, but in addition contains graphite, which imparts the properties of resistance to wetting and to penetration by molten metals and slags. APACHITE PLASTIC REFRACTORY is excellent for use in lining cupolas, ladles, foundry runners, spouts, and tapholes and for maintenance of the walls and bottoms of the air furnaces of the malleable iron industry.

H-W MULLITE PLASTIC REFRACTORY is a plastic refractory material with an alumina content of over 70 per cent. It is furnished in both air-setting and heat-setting forms. It is volume-

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stable even at very high furnace operating temperatures and has excellent resistance to thermal spalling.

H-W Mullite Plastic Refractory is used in roofs of electric steelmelting furnaces, for linings of nonferrous low-frequency induction furnaces, in lower walls of soaking pits, in slab-heating furnace hearths, and for many other high-temperature furnaces.

CORALITE PLASTIC REFRACTORY is highest in refractoriness of all H-W high-alumina plastic refractory materials, having an alumina content of about 84 per cent. It is made of highest quality materials and is shipped both as a heat-setting and an air-setting monolith-forming material. Coralite Plastic Refractory has excellent workability, unusual resistance to thermal spalling, very good stability of volume even at temperatures up to 3150°F., and good hot load-bearing strength.

Coralite Plastic Refractory is used to form center sections in roofs of electric steelmelting furnaces, for lining and patching high-temperature heating furnaces, for forming burner ports, and many other applications.

PLASTIC THERMOLITH BATCH consists of carefully graded sizes of refractory chrome ore, with added plasticizing and bonding agents, and is supplied in ready-to-use form. It is easily applied and upon drying sets to form a dense, well-bonded monolith. When heat is applied, its density increases, and it becomes very resistant to the various corrosive slags.

Plastic Thermolith Batch is used in door facings, bridge walls, and runners and spouts of open-hearth furnaces; and for the construction of heating and forge furnace hearths where the corrosive action of ash, slag, or scale is a destructive factor. It is widely regarded as the standard refractory for the monolithic portions of chemical recovery furnaces in the kraft paper industry. It also is used advantageously in the linings of slag-tap bottoms for boiler furnaces. For dry Thermolith Batch see page 160.

H-W RAMMING MIXES

Ramming mixes of various types and compositions continue to increase in favor for making monolithic furnace hearths and linings. Based upon a thorough knowledge of the requirements, Harbison-Walker has developed ramming mixes which have become established as standard in many industrial plants.

Harbison-Walker supplies a well-balanced selection of ramming materials, which include compositions with base materials of silica, high-alumina, magnesia-alumina spinels, corundum, mullite, dead-burned magnesite, periclase, chrome ore, zircon, and others. They are particularly suitable for forming dense monolithic hearths, for linings of induction furnaces, and for numerous other monolithic constructions.

H-W MULLITE RAMMING MIX is a monolithic refractory with a mullite base. A chemical binder provides a moderate air-set with adequate strength in the low-temperature range until the ceramic bond develops at higher temperatures. With its high degree of purity, H-W Mullite Ramming Mix is very refractory and has excellent volume stability at high temperatures, with a maximum service temperature of 3200° Fahrenheit.

H-W Mullite Ramming Mix is particularly suitable for rammed linings in various induction and direct-arc furnaces, for many types of open-flame furnaces, and for ramming the center or electrode sections of electric-arc furnace roofs. In low-frequency induction furnaces in which yellow brass and alloys high in copper are melted, H-W Mullite Ramming Mix is used for the lining of crucibles, and the forming of secondary blocks. In glass-tank furnaces, it serves advantageously for making burner blocks, for ramming the bottoms of tunnels and ports, and for patching. In nonferrous foundries it is used for lining ladles.

H-W Mullite Ramming Mix is shipped wet, ready for use, as well as in dry form. The dry mix requires approximately three quarts of clean water per 100 pounds for ramming consistency.

CORALITE RAMMING MIX is a high-alumina product of exceptionally high refractoriness. Its P.C.E. value is above Cone 38, which has a softening temperature of 3360°F. It is shipped ready for ramming, and upon drying develops moderate air-set strength. Its maximum strength is developed by heating above 2000°F.

CORAL RAMMING MIX is a phosphate-bonded high-alumina ramming mix of over 85 per cent alumina content. It develops high strength, and exhibits unusual resistance to penetration by molten aluminum.

KORUNDAL RAMMING MIX corresponds closely in refractoriness to the 90 per cent alumina brick Korundal. The mix is used for patching, for making rammed shapes such as burner blocks, and for monolithic linings. Thus it is possible to secure most of the advantages of Korundal brick quality even when time does not permit the manufacture of special shapes, or when the design of the shapes required is such that it is impracticable to make them.

Korundal Ramming Mix is shipped in dry form. When mixed with water, rammed into place and dried, it forms a dense body of good strength and of exceptional refractoriness.

HARCOR is a phosphate-bonded high-alumina ramming mix, consisting principally of hard, crystalline alumina grains. When rammed into place and thoroughly dried, it develops and maintains great strength throughout its service temperature range. Strength develops after drying at 500°F. and increases progressively with rising temperatures through the entire intermediate temperature range. After heating, Harcor has remarkable resistance to abrasion and to mechanical impact. With an alumina content of over 90 per cent, it is extremely refractory.

Applications for Harcor include linings for cyclones, feed lines, duct work, aluminum- and brass-melting furnaces, induction furnaces, and the port floors and burner blocks of glass tanks. Some modifications of Harcor which have certain enhanced properties best fulfill various specific needs.

H-W CORUNDUM RAMMING MIX contains over 96 per cent alumina and is correspondingly high in refractoriness. In service, it develops moderate strength upon air-drying, and the strength increases as the furnace is brought up to operating temperatures. It is strong over the entire temperature range of its usefulness. H-W Corundum Ramming Mix has excellent resistance to thermal spalling, and remarkable linear and volume stability.

H-W INDUCTION FURNACE MIX is an air-setting magnesia-alumina ramming mix developed especially for the linings of high-frequency induction furnaces used for melting steel alloys. This material is highly refractory and has excellent volume stability. It does not shrink or develop cracks when heated and cooled. This is a most important physical property for induction furnace linings, as cracks permit penetration of molten metal, resulting in short-circuiting of the electric current. H-W Induction Furnace Mix forms crystalline magnesia-alumina spinel at furnace operating temperatures, which im-

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stable even at very high furnace operating temperatures and has excellent resistance to thermal spalling.

H-W Mullite Plastic Refractory is used in roofs of electric steelmelting furnaces, for linings of nonferrous low-frequency induction furnaces, in lower walls of soaking pits, in slab-heating furnace hearths, and for many other high-temperature furnaces.

CORALITE PLASTIC REFRACTORY is highest in refractoriness of all H-W high-alumina plastic refractory materials, having an alumina content of about 84 per cent. It is made of highest quality materials and is shipped both as a heat-setting and an air-setting monolith-forming material. Coralite Plastic Refractory has excellent workability, unusual resistance to thermal spalling, very good stability of volume even at temperatures up to 3150°F., and good hot load-bearing strength.

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PLASTIC THERMOLITH BATCH consists of carefully graded sizes of refractory chrome ore, with added plasticizing and bonding agents, and is supplied in ready-to-use form. It is easily applied and upon drying sets to form a dense, well-bonded monolith. When heat is applied, its density increases, and it becomes very resistant to the various corrosive slags.

Plastic Thermolith Batch is used in door facings, bridge walls, and runners and spouts of open-hearth furnaces; and for the construction of heating and forge furnace hearths where the corrosive action of ash, slag, or scale is a destructive factor. It is widely regarded as the standard refractory for the monolithic portions of chemical recovery furnaces in the kraft paper industry. It also is used advantageously in the linings of slag-tap bottoms for boiler furnaces. For dry Thermolith Batch see page 160.

H-W RAMMING MIXES

Ramming mixes of various types and compositions continue to increase in favor for making monolithic furnace hearths and linings. Based upon a thorough knowledge of the requirements, Harbison-Walker has developed ramming mixes which have become established as standard in many industrial plants.

Harbison-Walker supplies a well-balanced selection of ramming materials, which include compositions with base materials of silica, high-alumina, magnesia-alumina spinels, corundum, mullite, dead-burned magnesite, periclase, chrome ore, zircon, and others. They are particularly suitable for forming dense monolithic hearths, for linings of induction furnaces, and for numerous other monolithic constructions.

H-W MULLITE RAMMING MIX is a monolithic refractory with a mullite base. A chemical binder provides a moderate air-set with adequate strength in the low-temperature range until the ceramic bond develops at higher temperatures. With its high degree of purity, H-W Mullite Ramming Mix is very refractory and has excellent volume stability at high temperatures, with a maximum service temperature of 3200° Fahrenheit.

H-W Mullite Ramming Mix is particularly suitable for rammed linings in various induction and direct-arc furnaces, for many types of open-flame furnaces, and for ramming the center or electrode sections of electric-arc furnace roofs. In low-frequency induction

furnaces in which yellow brass and alloys high in copper are melted, H-W Mullite Ramming Mix is used for the lining of crucibles, and the forming of secondary blocks. In glass-tank furnaces, it serves advantageously for making burner blocks, for ramming the bottoms of tunnels and ports, and for patching. In nonferrous foundries it is used for lining ladles.

H-W Mullite Ramming Mix is shipped wet, ready for use, as well as in dry form. The dry mix requires approximately three quarts of clean water per 100 pounds for ramming consistency.

CORALITE RAMMING MIX is a high-alumina product of exceptionally high refractoriness. Its P.C.E. value is above Cone 38, which has a softening temperature of 3360°F. It is shipped ready for ramming, and upon drying develops moderate air-set strength. Its maximum strength is developed by heating above 2000°F.

CORAL RAMMING MIX is a phosphate-bonded high-alumina ramming mix of over 85 per cent alumina content. It develops high strength, and exhibits unusual resistance to penetration by molten aluminum.

KORUNDAL RAMMING MIX corresponds closely in refractoriness to the 90 per cent alumina brick Korundal. The mix is used for patching, for making rammed shapes such as burner blocks, and for monolithic linings. Thus it is possible to secure most of the advantages of Korundal brick quality even when time does not permit the manufacture of special shapes, or when the design of the shapes required is such that it is impracticable to make them.

Korundal Ramming Mix is shipped in dry form. When mixed with water, rammed into place and dried, it forms a dense body of good strength and of exceptional refractoriness.

HARCOR is a phosphate-bonded high-alumina ramming mix, consisting principally of hard, crystalline alumina grains. When rammed into place and thoroughly dried, it develops and maintains great strength throughout its service temperature range. Strength develops after drying at 500°F. and increases progressively with rising temperatures through the entire intermediate temperature range. After heating, Harcor has remarkable resistance to abrasion and to mechanical impact. With an alumina content of over 90 per cent, it is extremely refractory.

Applications for Harcor include linings for cyclones, feed lines, duct work, aluminum- and brass-melting furnaces, induction furnaces, and the port floors and burner blocks of glass tanks. Some modifications of Harcor which have certain enhanced properties best fulfill various specific needs.

H-W CORUNDUM RAMMING MIX contains over 96 per cent alumina and is correspondingly high in refractoriness. In service, it develops moderate strength upon air-drying, and the strength increases as the furnace is brought up to operating temperatures. It is strong over the entire temperature range of its usefulness. H-W Corundum Ramming Mix has excellent resistance to thermal spalling, and remarkable linear and volume stability.

H-W INDUCTION FURNACE MIX is an air-setting magnesia-alumina ramming mix developed especially for the linings of high-frequency induction furnaces used for melting steel alloys. This material is highly refractory and has excellent volume stability. It does not shrink or develop cracks when heated and cooled. This is a most important physical property for induction furnace linings, as cracks permit penetration of molten metal, resulting in short-circuiting of the electric current. H-W Induction Furnace Mix forms crystalline magnesia-alumina spinel at furnace operating temperatures, which im-

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parts to the lining unusual resistance to penetration by molten metals.

H-W MAGNAMIX is air-setting. It consists mainly of dead-burned magnesite, and contains approximately 80 per cent magnesia. It is used for building the bottoms of basic open-hearth, electric steelmelting, and various ferroalloy furnaces, and for maintaining the banks and tapholes of basic hearths.

More complete information concerning H-W Magnamix is given on page 113.

H-W MAGNAMIX 85 contains a minimum of 85 per cent magnesia. It is an air-setting ramming material, and develops a strong bond merely upon drying. It is used extensively for the construction and maintenance of the hearths and lower sidewalls in open-hearth and electric steelmelting furnaces, in lower sidewalls and bottoms of soaking pits, in hearths of slab-heating furnaces, and for lining ferroalloy ladles.

H-W C-MIX is an air-setting ramming mix, containing about 92 per cent magnesia. It is prepared from high-purity dead-burned magnesite (periclase) obtained by processing sea water or other brines.

The most common application of H-W C-Mix is in the monolithic hearths of basic open-hearth and electric steelmelting furnaces. It is also used to form the linings of induction furnaces for melting alloy steels, and in the ferroalloy industry to form hearths and ladle linings for the manufacture of ferromanganese and ferrochromium. H-W C-Mix is installed with pneumatic rams or air-placement guns. Additional information concerning H-W C-Mix is given on page 112.

H-W PERIKLASE BATCH is an air-setting ramming material with a magnesia base. It consists of a mixture of carefully graded sizes of low-iron dead-burned magnesite (periclase) with minor amounts of plasticizers and bonds to make it workable and self-bonding. When tamped into place it sets upon drying to form a dense, well-bonded monolith having many of the excellent characteristics of H-W Periklase brick.

H-W OXIMIX is a basic ramming mix produced especially for use in oxygen-process steelmaking vessels. It has a bitumen bond and is shipped in moistureproof paper sacks ready for use. It contains more than 60 per cent magnesia on a calcined basis. It is used to form the monolithic hearth of the vessel and the intermediate monolith between the working lining of Oxiline brick and the protective lining of Oxibak or H-W Magnesite brick against the steel shell.

THERMOLITH BATCH in dry form is an air-setting ramming mix with a chrome ore base. The addition of water is necessary to develop bonding properties and prepare it for use.

Thermolith Batch is resistant to chemical attack by slags of various compositions. It does not shrink appreciably in service, and it withstands the spalling influences of rapid changes in temperature. It closely corresponds to Plastic Thermolith Batch in many properties and uses (see page 158).

H-W ZIRCON RAMMING MIX is shipped in dry form. When mixed with water, rammed into place and dried, it takes on a strong air-set. A special particle sizing formula contributes to the high bulk density of about 210 pounds per cubic foot when rammed into place. It is very refractory, and has excellent volume stability at furnace operating temperatures. Because of its ability to resist various fluxing constituents in glass batches, H-W Zircon Ramming Mix is used advantageously for paving glass-tank ports, and for leveling of glass-tank bottoms upon which a zircon brick bottom is installed. It is also used for lining high-frequency induction furnaces melting stainless steel, carbon steels, special alloy steels, or gray iron.

H-W GUN MIXES

In some industrial furnace operations, it is frequently desirable to make repairs to the refractory furnace linings without greatly reducing the operating temperatures. Numerous methods of shooting refractory patching materials into interior furnace parts have been used, and very efficient air-placement guns are available. Since their development, gun mixes have become used with certain advantages in some new constructions. Dense, homogeneous monolithic linings can be gunned without the use of forms and with a marked saving in time.

Harbison-Walker's gun mixes include those of siliceous, fireclay, high-alumina, dead-burned magnesite, and chrome types. In addition, most H-W castables and some ramming mixes can be applied successfully with pneumatic guns.

KUPLOMIX, which is highly siliceous, consists of a mixture of ground quartzite of proper grain sizing and a finely ground refractory weathered bond clay. These components are properly blended and intimately mixed to insure a thorough coating of the silica grains with the plastic bond clay, thus giving maximum adhesive property to the batch. Segregation in handling is negligible, and shipment can be made in bulk without harmful effects on the uniformity.

Kuplomix is used with good results in the melting-zone linings of cupolas, pouring troughs, and ladles in iron and steel foundries. Its superiority is evidenced by the ease with which it can be applied, by its excellent adherence to brickwork with the minimum rebound when applied with an air gun, and by its resistance to abrasion and attack by acid slags.

H-W STANDARD GUN CLAY is a blend of calcined fire clay and plastic bond clays designed for application with air-placement guns. The sizing of the grains and the amount of bond clay are carefully controlled to insure a minimum amount of rebound during the gunning.

H-W Standard Gun Clay is heat-setting and may be used for patching or for certain new constructions in high-duty service. It is shipped in dry form and when gun-applied it forms a dense uniform monolithic lining.

H-W STANDARD GUN CLAY CS has essentially the same composition and properties as H-W Standard Gun Clay, but contains a chemical binder to make it air-setting.

H-W SUPER GUN CLAY is suitable for applications in which service conditions are too severe for H-W Standard Gun Clay. It is prepared from highly refractory calcined flint clay and bond clay, and meets the requirements for general superduty service. The mix contains just the right amount of plastic clay to develop a strong ceramic bond when heated. With the closely controlled grain sizing of H-W Super Gun Clay, monolithic linings are made with ease by the use of air-placement guns.

H-W SUPER GUN CLAY CS is made from the same refractory clays as H-W Super Gun Clay; however, with an added chemical binder, this mix develops good strength upon drying.

APACHE GUN CLAY is a high-alumina gun mix. It is more refractory than the usual fireclay mixes, and accordingly is suitable for applications where temperature and slag conditions are too severe for products of the fireclay classes. It has good volume stability.

Apache Gun Clay is furnished in dry form with a particle sizing best suited for gun application. It is heat-setting and forms a strong, spall-resistant monolithic lining.

APACHE GUN CLAY CS corresponds to Apache Gun Clay in composition and physical properties, and in addition sets strongly on drying.

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Installation of a Monolithic Furnace Lining by Means of an Air-Placement Gun.

H-W MAGNAMIX S is a blend of dead-burned magnesite and bonds, containing over 80 per cent magnesia, especially adapted for application with air-placement guns. Its carefully controlled grain sizing provides maximum density with minimum rebound. It takes a firm set upon drying and develops a strong ceramic bond at furnace temperatures.

H-W MAGNAMIX S acquires a strong set very rapidly, and is especially suited for maintenance of sidewalls, banks, and hearths of open-hearth furnaces and electric steelmelting furnaces. It may be used for hot or cold repairs or for new construction. In open-hearth furnaces, H-W MAGNAMIX S is applied to critical areas of the hearths between heats as necessary. It maintains them in good working condition and prolongs furnace life.

H-W SPECIAL FURNACE CHROME GG consists mainly of chrome ore ground to a particle sizing that is most suitable for application with pneumatic guns. It is heat-setting and is used extensively for the maintenance or hot repairs of open-hearth back walls, skewbacks, bridge walls, ports, and jambs. This gun-emplaced refractory becomes densely compacted while being applied at a rapid rate. It has good resistance to various corrosive slags, and gives excellent service along the skew line and back wall in open-hearth furnaces.

H-W GUNSHOT is an air-setting chrome-base material developed primarily for the maintenance of front walls, back walls, and skews in basic roofs, and the sealing of uptakes and end walls of open-hearth furnaces. This gun mix is of fine grind, and is blended with binders to insure good adhesion to the surfaces of hot refractory linings. A modification of H-W GUNSHOT with a chrome-magnesite base provides an extra margin of refractoriness for applications where temperatures are very high.

H-W GUNSHOT is furnished in dry form, and is mixed with water to a slurry consistency in a mixer for application with a "wet gun." Carefully engineered equipment, comprising an efficient mixer and gun, has been designed by Harbison-Walker specifically for the application of H-W GUNSHOT.

H-W CASTABLES

H-W castables are hydraulic-setting refractories, consisting of granular refractory aggregates and chemical binders, accurately controlled for sizings and compositions. They are shipped in dry form, and when mixed with water to the desired consistency may be poured like concrete, tamped or rammed into place, troweled, or applied with an air gun. H-W castables take a strong hydraulic set at room temperatures, and maintain good strength until the desired ceramic bond is developed as the temperature is increased.

H-W castables are especially suited for furnace linings of irregular contours, for patching brickwork, and for casting special shapes which may be urgently needed.

The various H-W castables are designed to meet widely diversified service requirements, and have a wide range in composition, refractoriness, and other properties. These castables have negligible shrinkage in service and low coefficients of thermal expansion. They are resistant to spalling; some withstand severe abrasion, and some have high insulating values.

H-W castables are available in a number of base materials, including fire clay, high-alumina, chrome-magnesite, chrome ore, and refractory insulating aggregates.

H-W RC CASTABLE is a refractory concrete material made with a sized, calcined fireclay aggregate. It is used to good advantage in constructions where resistance to abrasion and impact are essential and where prevailing temperatures are high enough to weaken and disintegrate the usual concrete structures. It may be regarded as intermediate between regular concrete and refractory castables.

H-W RC CASTABLE is particularly suited for paving around furnaces, for low-temperature flues, for storage floors for steel shapes or other products that are hot, and for similar uses.

H-W BAFFLE MIX is prepared from calcined fireclay aggregate and a hydraulic-setting binder. It has low spalling characteristics and is suitable for service at temperatures up to 2400°F. It is shipped dry, and when mixed with water takes a strong set at room temperatures.

H-W BAFFLE MIX is used primarily for forming close-fitting monolithic baffles in boiler furnaces. By sealing against gas leakage through the baffle walls, the monolithic construction of H-W BAFFLE MIX provides for the travel of all the combustion gases through the complete length of each pass in the boiler and thus increases boiler efficiency and lowers the temperature of the stack gases.

H-W STANDARD CASTABLE, a hydraulic-setting castable with a fireclay base, is prepared for use by mixing with water to a pouring or tamping consistency. It develops a strong hydraulic bond without the application of heat. It affords a convenient and economical means of forming special shapes, domestic furnace linings, baffles, arches, walls, door linings, and furnace hearths.

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H-W EXTRA STRENGTH CASTABLE is a mixture of hard-fired refractory aggregate and a hydraulic binder. It is an unusual refractory concrete material in that it combines the properties of good refractoriness and extremely high initial strength with high strength throughout the intermediate temperature range within which most castables are relatively weaker. The hydraulic set imparts the initial strength, similar to that of structural concrete. High strength is maintained over the entire temperature range during the heating-up of the furnace until a strong ceramic bond is developed.

H-W Extra Strength Castable is used with excellent results in many applications, including boiler furnace ash pits, piers, hoppers, annealing furnace car tops, tunnel kiln car bottoms, oil refining catalytic regenerators, iron blast-furnace mains, linings for chain sections of rotary kilns, feed ends of limestone kilns, and doors, flues, and subbottoms of various types of furnaces. It serves well for patching worn brickwork, and for coating interior walls of furnaces. It can be poured, tamped, or applied with an air-placement gun.

H-W Extra Strength Castable (Coarse), a modification of H-W Extra Strength Castable, is stronger and more volume-stable. It is preferred for car tops and for building arches of wide span and certain other massive furnace structures. It does not lend itself to application with air guns.

H-W EXTRA STRENGTH CASTABLE LI, another modification of H-W Extra Strength Castable, has the combination of outstanding properties of high density, excellent strength, and less than 2 per cent iron oxide content. It serves to advantage in applications where carbon monoxide or other reducing gases are present.

H-W SUPER CASTABLE is a hydraulic-setting refractory having a margin of 300°F. in its service temperature limit above standard castables. It consists of a scientifically sized superduty fireclay aggregate blended with a very refractory hydraulic binder. The refractory fireclay base material is prefired at high temperatures, and has negligible shrinkage up to the temperature of its normal service limit. When H-W Super Castable is heated, its hydraulic set is succeeded by a ceramic bond. Because of its texture, volume stability, and high refractoriness, its resistance to spalling is excellent.

H-W HARCAST is a hydraulic-setting castable of low iron content in the superduty class, with a base of alumina-silica aggregate. It has high refractoriness, excellent resistance to erosion and abrasion, and exceptional strength at all temperatures up to its service limit of 2800°F. H-W Harcast shows no linear or volume change when heated in a standard laboratory reheat test at 2550°F. The low iron content adequately meets specifications for various oil refining constructions.

H-W HARCAST BF, with its very low iron content of less than one per cent, is designed for gunning linings in the bosh, inwall, and top sections of blast furnaces. It has similar composition and physical characteristics to regular H-W Harcast.

H-W HIGH-ALUMINA CASTABLE is a refractory concrete material of unusually high refractoriness, consisting of an accurately-sized high-alumina aggregate blended with a special hydraulic cement of very high purity. The hard-fired refractory aggregate imparts the property of constancy of volume at extremely high working temperatures. The hydraulic set provides high initial strength comparable to that of structural concrete. When heated, H-W High-Alumina Castable develops a strong ceramic bond which is maintained throughout a wide range of temperatures.

H-W High-Alumina Castable is used mainly for making durable refractory monolithic linings for high-temperature furnaces of many types. It forms a dense structure which is highly impervious to penetration by various slags, molten metals, and corrosive fumes. Other applications include burner blocks, car tops, ladle linings, and preformed shapes.

H-W CASTOLAST is a high-alumina castable of even higher refractoriness than H-W High-Alumina Castable. It consists almost entirely of alumina aggregate, bonded with low-iron calcium aluminate cement. The alumina content is over 93 per cent. While the maximum service temperature is regarded as about 3200° F., its temperature of fusion is somewhat higher.

H-W Castolast is shipped in dry form. Upon mixing with water, it develops and maintains exceptionally high strength and volume stability throughout the entire temperature range up to its limit of use. It is exceedingly resistant to abrasion and impact.

H-W Castolast is suited for lining petrochemical units requiring a castable of high purity, for high-temperature burner blocks, and for various other applications in which high temperatures, abrasion, and spalling conditions prevail. It has good workability and can be cast, troweled, or applied with an air-placement gun.

H-W CASTOLAST G is a modification of H-W Castolast, designed for gun application. It develops a strong set very rapidly, and among other applications is used for gunning linings in petroleum refinery equipment, and cyclones.

H-W CHROME CASTABLE has a strong hydraulic set, and when heated develops a ceramic bond of unusual strength which is maintained over a wide range of temperatures.

H-W Chrome Castable is made from chrome ore aggregate of superior quality, together with stabilized binders. Because of its high density, any penetration by corrosive fumes and molten fluxes is kept to the minimum. Among the more important applications of H-W Chrome Castable are its use in the bottoms and lower sidewalls of paper mill recovery furnaces, slag-tap boiler furnaces, and subbottoms of furnaces melting nonferrous metals.

H-W Chrome Castable is shipped dry, and is prepared for use by merely mixing with water to the consistency best suited for pouring like concrete or for tamping into place. For many purposes it is advantageously applied with various types of air-placement guns.

H-W CHROME FILL is a chrome-base castable in dry form. When mixed with water, usually to tamping consistency, it develops a moderate hydraulic set. Its primary use is in open-hearth and electric furnaces for fill and for forming the contours for the brick subhearths.

H-W HARCHROME CASTABLE is a hydraulic-setting castable with a chrome ore base designed for applications that require an exceedingly strong and abrasion-resistant refractory. Because of its chemical composition, it also possesses some unique properties. For example, it has excellent resistance to "wetting" by aluminum metal and slag, and to corrosive conditions such as prevail in the bottoms of recovery furnaces used in kraft paper mills.

H-W Harchrome Castable is shipped in dry form and is prepared for use by mixing with water to the desired consistency. It may be applied by casting, tamping, ramming, or with an air-placement gun.

H-W HARCHROME G is a castable of chrome ore base, designed for installation by gunning. It develops a strong hydraulic set rapidly upon wetting with water. With its excellent resistance to abrasion, it is used advantageously in catalyst-carrying piping of oil refinery units and other ducts carrying dust-laden gases.

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H-W CHROMEPAK is considerably higher in refractoriness than most chrome-base castables or plastic chrome ores. It is air-setting but for maximum strength requires heating between 400°F. and 600°F. It should be heated as soon as possible after installation.

H-W CHROMEPAK may be applied by casting, ramming, or tamping into place, or by means of an air-placement gun. It is shipped in dry form, and requires only to be mixed with clean water to the desired consistency. It forms an unusually strong and hard monolith upon heat drying. H-W CHROMEPAK is well adapted for use in patching. It can be applied directly to hot surfaces of refractory furnace linings.

H-W PERIMIX is an extremely refractory magnesite castable material of high-purity periclase, having a magnesia content of about 90 per cent. It is shipped dry, and is mixed with water for use. It develops high strength upon drying and has excellent stability of volume even at very high temperatures. It lends itself readily to casting by the use of an immerse-type vibrator.

H-W PERIMIX is used primarily for casting tapholes, bank areas, and portions of bottoms of open-hearth furnaces.

H-W LIGHTWEIGHT CASTABLES

H-W lightweight castables combine the properties of refractoriness and excellent insulating value in constructions which are virtually joint-free. With the use of these castables, heat losses from furnace walls are materially reduced. Their low capacities for storage of heat facilitate rapid heating to operating temperatures and add measurably to economy of operations.

H-W lightweight castables have excellent working qualities and can be poured like concrete or applied with a trowel or by means of various types of guns. For pouring or casting, they are mixed with water to the desired consistency. At operating temperatures they have excellent strength and stability of volume. Their thermal conductivities are approximately proportional to their bulk densities.

H-W LIGHTWEIGHT CASTABLE 10 is highly efficient in insulating value, with its fired density of only 25 to 30 pounds per cubic foot. Normally, it is recommended for use in various types of installations at temperatures up to 1000°F. However, this castable may be used satisfactorily at temperatures close to 1800°F. as a back-up material, in continuous operations at reasonably constant temperatures.

H-W LIGHTWEIGHT CASTABLE 20 is made from lightweight aggregates and asbestos fiber, together with a highly refractory binder. It has a fired density in the range of 25 to 30 pounds per cubic foot, and performs very well at furnace temperatures up to 2000°F., even in intermittent operations. Upon mixing with water, H-W LIGHTWEIGHT CASTABLE 20 has good workability, and develops a strong hydraulic set. The combination of very light weight, refractoriness of 2000°F., and relatively good strength even after heating at intermediate temperatures makes this an important castable in the field of monolithic insulation.

H-W LIGHTWEIGHT CASTABLE 22 is an insulating castable of unusual merit, consisting mainly of blended lightweight aggregates. It has a fired density of 50 to 55 pounds per cubic foot, good strength, dimensional stability, and a service temperature limit of 2200°F. It is regarded as standard for some uses at many plants. It shows great versatility in installation technique, and is widely used in steel heating and treating furnaces, tunnel kilns, aluminum-melting furnaces, and metal-refining furnaces. It can be used either as a working lining or as back-up insulation.

H-W LOW-IRON LIGHTWEIGHT CASTABLE 22 is very similar to H-W LIGHTWEIGHT CASTABLE 22 in all its physical and chemical properties except in its content of iron oxide. With the very low iron oxide content of less than 0.5 per cent this castable is particularly adapted for service in special atmospheres, such as those having a high content of carbon monoxide or methane gas. This high-purity castable is also used successfully in operations where iron impurities may contaminate the final product or catalysts used in the manufacturing process. It is used for both working and back-up linings.

H-W LIGHTWEIGHT CASTABLE—EXTRA STRENGTH is a hydraulic-setting insulating castable with a fireclay base containing lightweight aggregates. It combines good insulation with unusual strength. This castable has a fired density of 80 to 85 pounds per cubic foot, but is stronger than some fireclay or high-alumina castables of the usual densities. It is recommended for use as the primary lining up to 2300°F. even in furnaces where the lining is subjected to abrasion of moderate intensity.

H-W LIGHTWEIGHT CASTABLE 26 is a hydraulic-setting insulating castable with an alumina-silica base. It has a fired density of only 50 to 55 pounds per cubic foot, and can be used in soaking temperatures of 2600°F. even in primary linings, if not subjected to abrasion. Furnace roofs, sidewalls, and doors are excellent applications for this castable in the 2300° to 2600°F. temperature range. When used as back-up insulation, H-W LIGHTWEIGHT CASTABLE 26 makes possible reductions in the thickness of walls.

H-W LIGHTWEIGHT CASTABLE 28 has the general properties and advantages of H-W LIGHTWEIGHT CASTABLE 26, except for the higher fired density of 85 pounds per cubic foot and higher refractoriness. This castable may be used at the maximum temperature of 2800°F. either in the primary lining or as back-up material in high-temperature furnaces.

H-W LIGHTWEIGHT CASTABLE 30 is very similar to the two preceding high-temperature castables in its general properties. The fired density is in the range of 85 to 90 pounds per cubic foot and the maximum recommended service temperature is 3000°F. Its uses include soaking-pit covers, heating furnaces, boilers, and others.

H-W ANCHORS FOR MONOLITH-FORMING REFRACTORIES CONSTRUCTION

The use of H-W Anchors in various monolith-forming refractory constructions provides support for arches and walls, prevents bulging, and permits vertical and horizontal movement for expansion and contraction. Either refractory or metal anchors are supplied in accordance with the requirements.

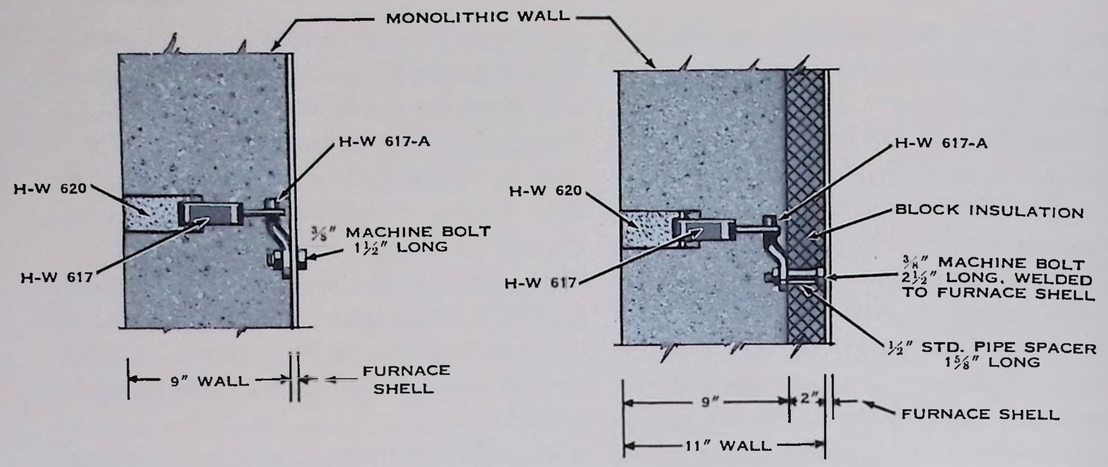
H-W Refractory Anchors are employed where extremely high temperatures or corrosive action do not permit the use of metal. They are of superduty fireclay quality and have excellent resistance to thermal shock, slag action, and stresses at high temperatures.

For typical illustrations of some refractory anchors see pages 156 and 168.

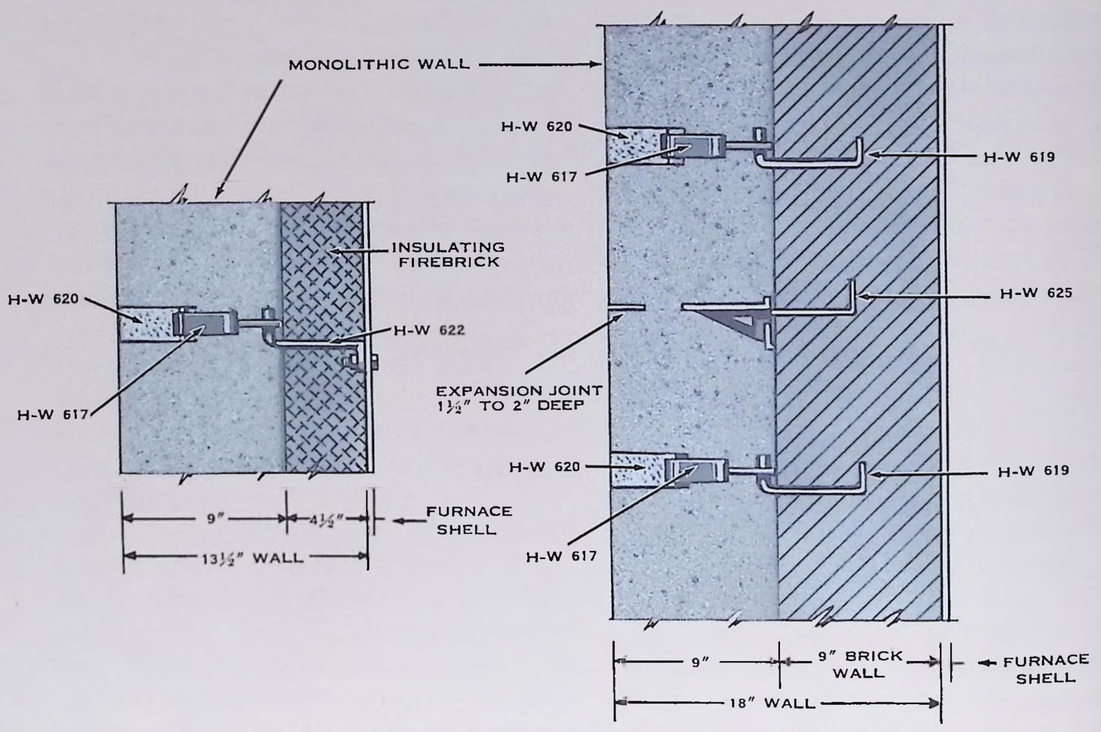
H-W Refractory Anchors of various designs, in addition to those illustrated, are available for particular needs.

H-W Metal Anchors of various designs and alloys are available for use where highest strength is important and temperatures are not too high for metals.

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NOTE:
H-W 617 IS A HIGH-TEMPERATURE ALLOY
H-W 620 IS A REFRACTORY BRICK ANCHOR



Vertical Sections Illustrating Methods of Anchoring Monolithic Wall Construction.



REFRACTORY MOLDING MEDIA

HARBISON-WALKER REFRACTORIES COMPANY

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HARBISON-WALKER BRANDS OF REFRACTORY MOLDING MEDIA

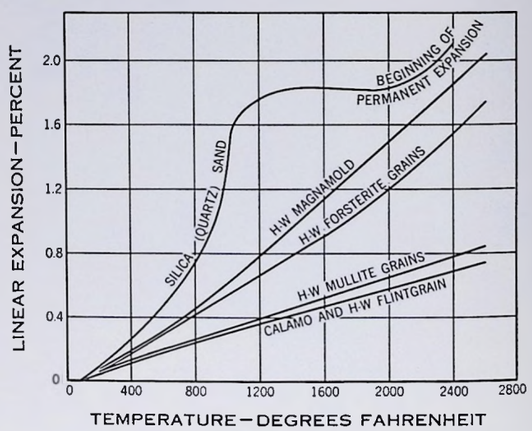
Brand Name	Base Material	Apparent Specific Gravity	Bulk Density Lbs./Cu. Ft As Shipped
CALAMO	Alumina-Silica Refractory	2.45	85-100
H-W FLINTGRAIN AND FLOUR	Alumina-Silica Refractory	2.52	95-110
H-W FLINT-MULL GRAINS	High-Alumina Blend	2.71	95-105
H-W MULLITE GRAINS AND FLOUR	Synthetic Mullite	2.79	95-115
H-W FORSTERITE GRAINS AND FLOUR	Forsterite (Magnesium Silicate)	3.20	120-135
H-W MAGNAMOLD	Dead-Burned Magnesite	3.15	115-130

From time immemorial, quartz sand has played an important role as a molding medium in the production of metal castings. It has the advantages of abundance, wide geographic distribution, low cost, and some very desirable physical and chemical properties. However, for a wide range of casting conditions, it does not fully meet the requirements of the modern foundry. The production of many ferrous castings and of heavy castings in general taxes the utility of silica sand molds to their utmost.

The great amount of time, energy, and money spent in cleaning, chipping, and grinding to reclaim castings in the foundry cleaning room is striking evidence that quartz sand as a molding medium is often inadequate. In the casting of metals and alloys which melt at high temperatures, particularly, many defects occur which have their origin in the high thermal expansion of quartz sand (see chart). Other casting defects occur which may be traceable partly to erosion of the poorly bonded molding media by the flowing metal, and partly to the fluxing reaction of metallic oxides with the silica molds. These factors account for the desirability of using molding media which will meet the severe conditions involved in the production of many kinds of castings.

In precision casting, the effects of thermal expansion of the molding media and of metal-mold reactions become even more important. The closest approach to dimensional stability of the molds, obtained with the use of materials of low expansion rates in either investment or ceramic shell molds, is very desirable in precision work. Mold-metal reactions which are accepted without question in conventional casting may cause surface defects which necessitate rejection of precision castings.

Harbison-Walker molding media products



Approximate Reversible Thermal Expansion of Molding Media.

are supplied for both conventional and precision casting. They are furnished regularly in a variety of base compositions, including alumina-silica, high-alumina, mullite, forsterite, and magnesia. Special grinding and screening facilities, and rigid quality control, assure consistency in particle-size distribution from one shipment to another.

CALAMO, one of the extensively used Harbison-Walker products for molding, is a fired alumina-silica refractory of optimum sizings for various molding mixtures. Its high fusion point, approximately 100°F. higher than that of normal silica sand mixtures, enables it to be used in mold mixtures for the casting of many high-temperature-melting metals and alloys.

The chart shows the exceedingly desirable expansion curve of CALAMO as compared with that of silica sand.

In conventional molding procedures, CALAMO may be used as the only molding medium or it may be used in combination with quartz sand in rammed or in slinger-placed sand molds. CALAMO, when added to silica sand molding mixtures in similar sizings, decreases the thermal expansion rate of the mold through the temperature range of 70° to 1200°F., thus reducing the amount of spalling and cracking of the mold. It may be bonded with the usual plastic clay-type binders, or by oils, cereals, resins, pitch, sulfite, and protein bonds. CALAMO may be used with inorganic silicates and set with CO_2 gas or hardened thermally or by dehydration.

In precision-casting processes, CALAMO may be used either in single- or two-layer investment molds, or in multidip coated ceramic shell molds. Some of the coarser sizings of CALAMO are frequently used alone or in combination with quartz sand as a backup to both the investment or ceramic shell molds. The binders used with CALAMO in these applications are usually either organic or inorganic silicates. CALAMO, used as the major component of precision-casting investment mixes, improves the dimensional constancy of the molds, and makes them stronger and more resistant to erosion by metal flow. Investment costs are reduced because a lower amount of bonding agent is needed.

H-W FLINTGRAIN is a fired superduty alumina-silica refractory, similar in composition to CALAMO, having the same very desirable low expansion characteristics, but slightly higher in refractoriness, and having harder and more angular grains. The angular shape of the grains and their optimum size distribution makes H-W FLINTGRAIN ideal for securing maximum compactness and density in the mold.

H-W FLINTGRAIN and FLOURS were developed especially for use in making ceramic-bonded shell molds in precision-casting processes and for similar applications in which dense, compact mold sections of greatest volume stability at all temperatures are important.

H-W FLINT-MULL GRAINS are a blend of the highly refractory granular materials H-W FLINTGRAIN and synthetic mullite, to form closely controlled "gap grinds," with little or no material of intermediate sizings. These blends have been developed especially to meet the requirements of precision-casting processes in which semipermanent patterns are used either to form "book" molds or in match-plate molding methods.

H-W MULLITE GRAINS are produced from high-alumina material, low in basic oxides and of approximately 75 per cent alumina content. The grains are hard and dense, and have excellent strength and high resistance to fluxing. H-W MULLITE is much more refractory than even CALAMO. Its thermal expansion is lower and more uniform than that of silica sand.

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Developed especially for use in precision-casting processes, the grains and flours of this material may be used either in single- or double-layer investment molds or in single-layer ceramic shell molds with or without backup. In these applications the binders used with H-W Mullite Grains are usually either organic silicate or colloidal silica-sol bonding agents.

H-W FORSTERITE GRAINS consists of highly refractory magnesium silicate molding material, possessing physical properties which make it especially suited for resin-bonded shell molding for low-carbon steel castings. Its high-temperature stability and uniform thermal expansion contribute to its excellent performance. One of its properties of major importance is its comparatively high rate of heat transfer.

When metals and alloys which melt above 2900°F. are cast into resin-bonded silica sand shell molds, discontinuities in the casting surface frequently occur. These imperfections seemingly are caused by gases, produced by the decomposition of the binder at high temperatures, forcing their way into the metal during a critical state of solidification. Such penetration of the gases may be inhibited through the use of a molding medium such as H-W Forsterite Grains, having a high rate of heat transfer, particularly within the temperature range 70° to 1200°F. Such a mold material will absorb heat rapidly from the casting as its own temperature rises, and in doing so chill the skin surface of the casting, and cause it to solidify quickly and to develop sufficient strength to resist outside gas pressure and inside ferrostatic pressure.

With the use of H-W Forsterite Grains for shell molding of high - temperature - melting metals and alloys, smoother surfaces are obtained than is ordinarily possible with various other molding media.

H-W Forsterite Grains are supplied in controlled sizings best suited for securing the most satisfactory shell molded casting surfaces.

H-W Forsterite Flours are furnished for use as additives to the H-W Forsterite Grains and resin mix to provide for the ultimate in surface smoothness, particularly of castings with heavy sections.

H-W MAGNAMOLD, a ground dead-burned magnesite material containing approximately 80 to 85 per cent magnesia, is especially adapted to making molds which will resist the corrosive action of metallic oxides which normally react with silica materials. It meets the needs for a molding medium which is suitable for casting alloy steels high in manganese. H-W Magnamold is supplied in a variety of grinds, including a flour for wash-coating molds and cores. It may be bonded by customary binders such as plastic clays, bentonite, cereals, and oils to develop the required strength of both green sand and dry sand.

For molding applications in which the high temperatures required are beyond the working limits for silica sand or for alumina-silica materials, and even for the high-alumina mullite material, H-W Magnamold may be used advantageously. It consists essentially of crystalline magnesia (periclase), and is extremely refractory, melting completely only at temperatures well above 3500°F. It can absorb large amounts of ferrous and ferric oxides with relatively little effect upon its refractoriness. Thus the usual fluxing action of metallic oxides with silica molds is avoided when this highly basic molding material is used.

Corrosive metal-mold reactions involving metals and alloys high in manganese and low in silicon may be appreciably lessened by using the basic H-W Magnamold material in place of the conventional molding media. Selection of suitable binders for the magnesia molds will insure adequate refractoriness without decreasing the desired passivity to the corrosive action of the oxides of manganese.

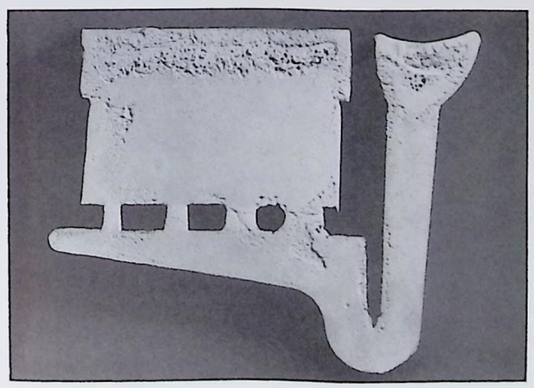
Fireclay Binders for Molding Mixtures: Among the factors which directly affect foundry operating costs is the durability of the bond of the molding mixtures. For economy, the amount of binder which must be added to maintain the strength of molding mixtures must be low. H-W Moldsand Bond and H-W Weathered Bond B Clay are unexcelled in durability. This is an important advantage in the production of heavy iron and steel castings, for which the bonding strength of the mold must be maintained for relatively long periods of time at high temperatures.

Among the advantages of H-W Moldsand Bond and H-W Weathered Bond B Clay are these: (1) high refractoriness, (2) adequate "developed hot strength," (3) low hot contraction above 1500°F. which minimizes cracking of molds and casting surface defects, (4) excellent flowability and resilience, and (5) maintenance of workability of molding mixtures during storage periods, and (6) uniformity of physical properties year after year.

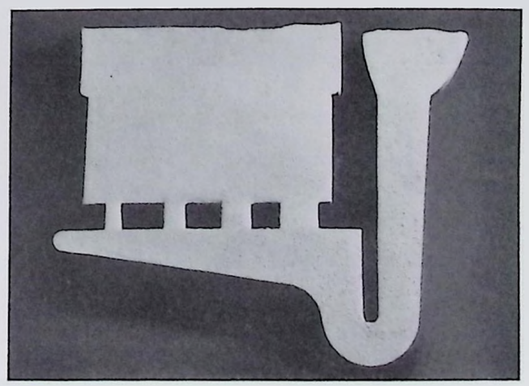
Used alone or with other binders, H-W Moldsand Bond and H-W Weathered Bond B Clay impart enhanced hot strength to molds and in some mixes replace, wholly or in part, binders of higher cost. They are used with equally good results for the usual rammed mixes with sand or Calamo.

Types of Molding and Casting Processes: Three general types of molding procedures are employed which may be grouped according to the kind of pattern and the manner in which the pattern is used. In the tabulation on page 174 they are grouped as follows: (1) process type No. I, permanent patterns used at atmospheric temperature; (2) process type No. II, permanent patterns used at high temperatures; and (3) process type No. III, expendable patterns, such as wax or organic plastic which are removed from the mold by melting. Each of these three general types is subdivided into different groups, related to the kind of mold and bonding agent most applicable.

Harbison-Walker brands of refractory molding media which in current practice are employed in the several molding procedures are listed in the last column of the tabulation on the following page.



Low-Carbon Steel Casting Produced in Silica-Sand Shell Mold With 5 Per Cent Resin.



Low-Carbon Steel Casting Produced in H-W Forsterite Shell Mold With 5 Per Cent Resin.

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PROCESSES OF MOLDING AND CASTING AND HARBISON-WALKER MOLDING MEDIA USED

Type of Process	Pattern Used in Process	Kind of Mold	Bonding Agent	Molding Media
I-a	Wood or Cold-Metal	Dry Sand*	H-W Moldsand Bond or Bentonite	1. Calamo 2. H-W Mullite Grains
	Wood or Cold-Metal	Dry Sand	H-W Moldsand Bond or Bentonite	3. H-W Forsterite Grains
	Wood or Cold-Metal	Dry Sand	H-W Moldsand Bond or Bentonite	4. H-W Flintgrain
	Wood or Cold-Metal	Dry Sand	H-W Moldsand Bond or Bentonite	5. H-W Magnamold
I-b	Wood or Cold-Metal	Dry Sand or Fired Shell	Organic Silicates	1. Calamo
	Wood or Cold-Metal	Dry Sand or Fired Shell	Organic Silicates	2. H-W Mullite Grains
	Wood or Cold-Metal	Dry Sand or Fired Shell	Organic Silicates	3. H-W Flintgrain
I-c	Wood or Cold-Metal	Dry Sand	Cold-Set Oil	1. Calamo
I-d	Wood or Cold-Metal	Green Sand	Inorganic Silicates (CO_2 Cure)	1. Calamo
	Wood or Cold-Metal	Green Sand	Inorganic Silicates (CO_2 Cure)	2. H-W Flintgrain
II-a	Heated-Metal	Shell	Phenolic Resins	1. H-W Forsterite Grains
III-a	Wax	Dry Sand	Organic Silicates	1. Calamo
	Wax	Dry Sand	Organic Silicates	2. H-W Mullite Grains
	Wax	Dry Sand	Organic Silicates	3. H-W Flintgrain
III-b	Wax	Fired Shell	Organic Silicates	1. Calamo
	Wax	Fired Shell	Organic Silicates	2. H-W Mullite Grains

*In foundry practice, the term "sand" refers to any fine granular molding medium.

Process I-a pertains to conventional molding procedures such as air-ramming, sand-slinger, jolt-squeeze, and hand-ramming. Binders used with various H-W molding media for this application require dry sand practice, i.e., the baked mold and core method.

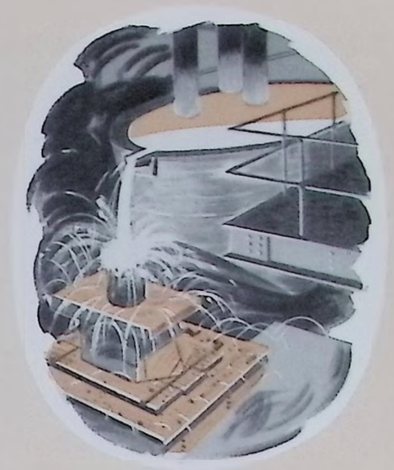
Process I-b is one of the precision-casting processes. The rapid firing and setting of the organic silicate binder, after careful removal or extraction of the pattern from a split mold, is the principal feature of this process.

Process I-c may be used as a precision molding method if care is exercised in pattern removal. Where temperatures are not high, the binder provides excellent internal cores with exceptionally smooth surfaces.

Process I-d may also be employed as a precision molding method, but has greater use as backup for investment molds of the double-investment or layer type.

Process II-a refers to the phenolic resin-bonded shell molds such as those made of H-W Forsterite Grains for casting low-carbon steels.

Processes III-a and b comprise the two types of investment molding processes for making precision castings. Harbison-Walker's various products are used either alone or as additives to obtain extraordinary refractoriness or to reduce thermal expansion of the mold within controllable limits, or both.



FUSED-CAST REFRACTORIES

PRODUCTS OF

HARBISON-CARBORUNDUM CORPORATION, *Falconer, New York*
affiliate of Harbison-Walker Refractories Company

HARBISON-WALKER REFRACTORIES COMPANY

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PRODUCTS OF HARBISON-CARBORUNDUM CORPORATION, FALCONER, NEW YORK

THE new Harbison-Carborundum Corporation, organized late in 1959, brought together the advanced technology and wide resources of two large organizations—each a leader in its own field—for the engineering, manufacture, and sale of fused-cast refractories. The products of Harbison-Carborundum will embrace a complete range of fused-cast shapes and auxiliary products for the glass industry, and metallurgical and diversified industries.

Harbison-Carborundum now owns and operates the recently modernized and greatly expanded plant at Falconer, New York, formerly owned by The Carborundum Company. In this plant, MONOFRAX® fused-cast refractories, used mainly in the glass industry, are manufactured. Other important uses continue to develop. Long-range plans call for an intensive program of research and product development, expanded engineering service, and provision of additional manufacturing facilities as required to meet the growing demands for these specialized products.

Fused-cast refractories with an alumina base are being used successfully in many applications in addition to the glass industry. They are giving good service in sodium silicate furnaces and in electrolytic cells for the reduction of magnesium. The chemical industry uses fused-cast refractories in certain reactors, catalytic crackers, and synthesis gas generators. These materials are superior in resistance to impact and abrasion, and are used for some purposes at atmospheric temperatures.

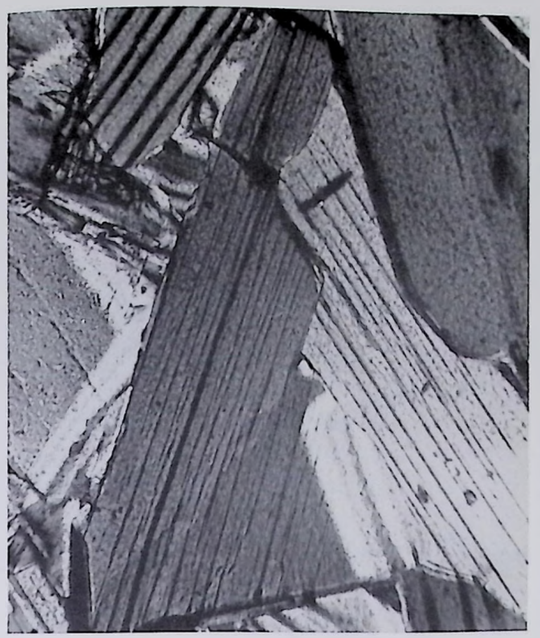
The company's products include fused-alumina refractory mortar and ramming mixes.

MONOFRAX® REFRACTORIES

The trade-mark MONOFRAX® includes a group of fused-cast refractories that are cast from molten compositions in which alumina predominates. They are used mainly in glass furnaces in the form of relatively large blocks. Years of service in the manufacture of practically all types of glass have established their unusual merit for resistance to corrosion and erosion by molten glass, batch dusts, and fumes at extremely high temperatures. Chemical stability, impermeability, and resistance to corrosion and erosion at all working temperatures account for their wide use in glass-melting furnaces. The use of fused-cast refractories has improved the quality of the glass, while increasing furnace life and furnace production rates.

The selection from four different fused-cast refractories, having different crystal compositions, provides for balanced service life in glass-tank furnaces. These are designated as MONOFRAX S, M, H, and K. Blocks of other compositions are made as required. All blocks are manufactured to close tolerances, with true-fitting surfaces, and sharp corners and edges.

MONOFRAX S is composed mainly of alpha alumina, zirconia, and siliceous glass. Resistance to extreme erosive and corrosive conditions is its outstanding feature. It is also relatively resistant to thermal shock. MONOFRAX S refractories are applied to throat, doghouse, sidewalls, paving, and sump of high-production glass melters. Where operating conditions so indicate, they are also used in the first and second port floors and jambs and adjoining tuckstones.



Photomicrograph of a Thin Section of MONOFRAX® *H. Transmitted Light. Linear Magnification, 125.*

The section has a characteristic single-phase structure, and consists of large crystals of beta alumina.



Photomicrograph of a Thin Section of MONOFRAX® *M. Transmitted Light. Linear Magnification, 125.*

The section shows a fine-grained dense structure, consisting of interlacing crystals of alpha and beta alumina.

MONOFRAX M refractories are composed almost entirely of alpha and beta alumina. The content of interstitial glass is negligible. The crystals are small and tightly interlaced, providing a dense structure that is highly resistant to corrosion and erosion by molten glass. MONOFRAX M blocks are used in direct contact with the molten glass where glass purity is especially important. Because of their high purity, they cause no discoloration or seeding of the glass. They are used in the refining ends, feeder channels, some melters, and in pavings.

MONOFRAX H refractories consist essentially of crystalline beta alumina, relatively free from interstitial glass. MONOFRAX H shapes are preferred for use throughout the glass-furnace superstructure because of their superior resistance to the stresses caused by the repeated changes in temperature involved in regenerative firing, and their resistance to impinging flame and chemical attack by volatilized alkalies.

MONOFRAX K is composed of a mixture of alpha alumina and chrome spinel. It is remarkably resistant to corrosion, but as chrome is a potential coloring agent, its use is restricted to furnaces melting certain colored glasses or in limited amount in other furnaces where corrosion is extremely severe.

MONOFRAX R is a zirconia-alumina-silica refractory produced by methods which give good dimensional accuracy and resistance to wear. It is used to line ball mills, cyclones, and coke and sinter chutes where resistance to abrasion and impact are most important. MONOFRAX R also serves as a refractory where temperature fluctuations are only slight.

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MANUFACTURE

At present, the compositions consist mainly of (1) alumina, (2) zirconia-alumina-silica, and (3) alumina plus chromite. A small proportion of other minerals is added to control the crystalline structure and physical properties of the end products. After a controlled period of mixing, the batch is discharged from the blender and transported to the electric furnace platform for charging into one of the furnaces.

The lining of the furnaces is formed from the material being melted, and is maintained by water cooling. After a furnace has been brought into operation, a pool of molten material is maintained and the furnace is operated continuously 24 hours a day until it is necessary to shut down to make a change in composition or for some other reason. The casting temperature for some compositions may exceed 3800°F.; for other compositions, it is somewhat lower.

Graphite molds are used for certain compositions. Some compositions of lower melting temperatures are cast into molds consisting of resin-bonded alumina grain material. Shrinkage during solidification is considerable.

After the block has partially solidified, the mold is stripped from the casting, which is then placed in an annealing bin and covered with powdered alumina. After careful annealing, the casting is cleaned with pneumatic chisels and inspected. The blocks produced vary in weight from only a relatively few pounds to almost two tons.

QUALITY CONTROL

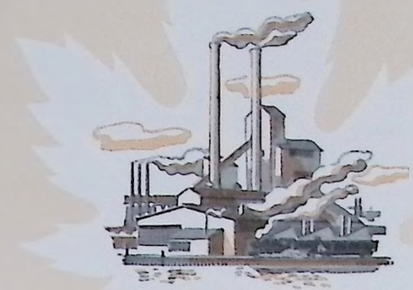
Each step of production is rigidly controlled to maintain established quality standards. The raw materials are sampled before going to the storage bins. Special print scales on the weigh hoppers record the weights. After blending, all batches are sampled and tested. Various aspects of the electric furnace operations are controlled and recorded. The mold stripping schedule is timed in advance. Every block is weighed to provide a check on density, and is examined for dimensional accuracy and surface flatness. A 9-inch cube is taken frequently from regular production pouring for thorough checking of physical properties.

LABORATORY AND PILOT PLANT

The laboratory includes mineral identification facilities for research and sales service, and a chemistry department for research and quality control.

The pilot plant serves mainly for research and product development. One of the most important pieces of equipment is a versatile three-phase research electric-arc furnace capable of pouring several hundred pounds of melt at one time.

The pilot plant contains four small glass-melting furnaces for testing the resistance to corrosion of fused-cast refractories. These furnaces permit the testing of several 9-inch brick at one time, with 22 pounds of glass batch or cullet, at a temperature of 2730°F. Another testing furnace—a miniature glass tank—operates up to 3100°F. The pilot plant also contains a GLOBAR®-heated electric furnace used mainly for testing the resistance of fused-cast refractories to thermal shock. Mineral compositions of high-temperature stability, other than those regularly manufactured, are continuously in process of development in the pilot plant.



REFRACTORIES

MADE IN CANADA

PRODUCTS OF

CANADIAN REFRACTORIES LIMITED, *Montreal, Quebec*
subsidiary of Harbison-Walker Refractories Company

CLAYBURN-HARBISON LIMITED, *Vancouver, British Columbia*
affiliate of Canadian Refractories Limited

HARBISON-WALKER REFRACTORIES COMPANY

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PRODUCTS OF CANADIAN REFRACTORIES LIMITED (CRL)

Brand Name	Class	Kind of Bond
BASIC BRICK (Pages 183, 184, 185)		
†CRL Brucite	Magnesite	Fired
†CRL Periklase	Magnesite	Fired
Perecon	Magnesite	Fired
††Magnecon	Magnesite	Fired
†BRC-60	Magnesite-Chrome	Chemical
†BRC-60 Metalkase	Magnesite-Chrome	Chemical
†CRB-20	Chrome-Magnesite	Fired
CRL Chrome	Chrome	Fired
CRL Chrome	Chrome	Chemical
HIGH-ALUMINA BRICK (Page 185)		
CRL Corundum	Corundum	Fired
†CRL Korundal	90% Alumina	Fired
†CRL Sillimanite	Mullite	Fired

Brand Name	Base Material	Kind of Bond	Max. Service Temperature	Approx. Crushing Strength, Lbs./Sq. In.
INSULATING BRICK (Page 188)				
†Moler Hiporous	Danish Moler Clay	Fired	1600°F.	210
†Moler Supra	Danish Moler Clay	Fired	1600°F.	1100
†Moler Rotol	Danish Moler Clay	Fired	1600°F.	1400

Brand Name	Base Material	Kind of Set	Form as Shipped	Container	Net Weight Pounds
BONDING MORTARS (Page 185)					
†Magset	Magnesite	Heat	Dry	Sacks	100
Brucite Cement	Magnesite	Heat	Dry	Sacks	100
CRL Chrome Mortar	Chrome	Air	Dry	Sacks	100
†Kyanex	Kyanite	Air	Wet	Drums	100
			Dry	Sacks	100
†Korundal Bonding Mortar	High-Alumina	Air	Dry	Sacks	100
†CRL Sillimanite Mortar	Mullite	Air	Dry	Sacks	100
†Silica 40	Silica	Heat	Dry	Sacks	100
CRL Silicon Carbide Mortar	Silicon Carbide	Heat	Dry	Sacks	100

† Trade-marks registered in Canada.

†† Trade-marks registered in Canada and U.S.A.

NOTE: Any brand of CRL basic brick may be metal encased on three or four sides. Many basic brick brands are metal encased and internally plated; or metal encased and internally plated and fitted with a steel suspension member known as a Tabkase. The word "Metalkase," with a brand name, signifies that the brick are metal encased; "Tabkase," that the brick are metal encased and provided with a suspension member. The suffix XP indicates that the brick have a single internal steel plate; XXP, two internal plates. Thus the brand "BRC-60 Metalkase" designates a metal-encased BRC-60 brick; "BRC-60 Metalkase XXP," a metal-encased BRC-60 brick provided with two internal steel plates. Similarly, the term "BRC-60 Tabkase XXP" signifies brick of BRC-60 composition, provided with a Tabkase and two internal plates. The CRL Metalkase, Tabkase, XP, and XXP types of metal-encased brick correspond to the equivalent Harbison-Walker metal-encased brick illustrated on pages 102 and 103.

PRODUCTS OF CANADIAN REFRACTORIES LIMITED (CRL)

Brand Name	Type*	Base Material	Kind of Set	Max. Service Temperature	Pounds Required Per Cu. Ft.	Form as Shipped
MONOLITH-FORMING REFRACTORIES (Pages 186, 187, 188)						
†CRL Ramix	RM	Magnesite	Air	3000°F.	155	Dry
†695 Plastic	PL	Magnesite-Chrome	Air	2700°F.	170	Dry
CRL Plastic Chrome Ore	PL	Chrome	Air	3100°F.	200	Wet
†Kromecrete	CA	Chrome	Hydraulic	2900°F.	165	Dry
†CRB-20 Gunpatch	GM	Chrome	Air	3050°F.	180	Dry
††Magnifrit	PM	Magnesite	Heat	3300°F.	135	Dry
††QX Magnifrit	PM	Magnesite	Heat	3300°F.	145	Dry
††Magnifrit Cement	PM	Magnesite	Heat	3200°F.	...	Dry
†Kromore	PM	Chrome	Heat	3200°F.	...	Dry
†Korundal Ramming Mix	RM	High-Alumina	Air	3200°F.	175	Dry
CRL Sillimanite Ramming Mix	RM	Mullite	Air	3200°F.	150	Dry or Wet
†Sillcrete	CA	Mullite	Hydraulic	2750°F.	122	Dry
†Duropatch	PL	High-Duty Fire Clay	Heat	2800°F.	133	Wet
†Super Duropatch	PL	Superduty Fire Clay	Heat	3000°F.	137	Wet
†Durocrete	CA	High-Duty Fire Clay	Hydraulic	2600°F.	115	Dry
CRL Silicon Carbide Ramming Mix	RM	Silicon Carbide	Heat	.....	145	Dry
INSULATING CASTABLES (Page 188)						
†Molercrete	CA	Danish Moler Clay	Hydraulic	1800°F.	60	Dry
†Micacrete	CA	Vermiculite	Hydraulic	1800°F.	30	Dry
†Novalite	CA	Vermiculite	Hydraulic	1700°F.	20	Dry
†Durolite 22	CA	Lightweight Aggregate	Hydraulic	2200°F.	56	Dry
†Durolite 24	CA	Lightweight Aggregate	Hydraulic	2400°F.	75	Dry
BULK INSULATION (Page 188)						
†Moler-AG		Danish Moler Clay	.....	1600°F.	50	Dry
†Micalite		Vermiculite	.....	1600°F.	4.5	Dry
†Micaseal		Vermiculite	Heat	1800°F.	16	Dry

* PL = Plastic Refractory RM = Ramming Mix PM = Patching Mix GM = Gun Mix CA = Castable

† Trade-marks registered in Canada.

†† Trade-marks registered in Canada and U.S.A.

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PRODUCTS OF CANADIAN REFRACTORIES LIMITED (CRL)

Canadian Refractories Limited, a subsidiary of Harbison-Walker Refractories Company, manufactures in Canada a complete range of basic brick, together with many other refractory products. The main office is located at Montreal, Quebec, and district sales offices at Hamilton and Ottawa, Ontario. Warehouses are maintained at Hamilton, Toronto, Montreal, and Marelan (Que.), and with agents and warehouses at Vancouver and Edmonton, the company is in an excellent position to supply, most advantageously, all refractory requirements across Canada.

The present-day manufacture of refractories by Canadian Refractories Limited at their plants at Kilmar and Marelan, Quebec, is the outcome of long and extensive research work on the production of refractories from magnesite of a unique type which had been discovered at Kilmar, Quebec, prior to World War I.

Exhaustive investigations demonstrated the fact that the composition of the Kilmar magnesite is such as to lead to the production of refractories having unique chemical and physical properties which render their use particularly advantageous for specific applications in various large-scale operations. An entirely new group of refractories was developed and the service obtained from these new materials is such that substantial quantities now are used in many countries.

These special refractories have since been supplemented by other products of high magnesia content, manufactured in part from brucite of high purity produced in Canada. The Kilmar magnesite and the Canadian brucite, together with imported magnesites, chrome ores, and other domestic and foreign raw materials, form the basis for a manufacturing operation in which a wide range of refractory products are made. The company manufactures dead-burned grain magnesite, basic brick, ramming mixes, castables, and refractory mortars, comprising in all more than 50 different products. These products are marketed extensively in Canada, and some of them are shipped in large quantities to the United States and many other countries in all continents.

Canadian Refractories Limited has at all times emphasized the importance of research in its operations. The improvement of established products and the development of new ones are essential to maintain pace with the rapidly expanding technology of modern industry. The facilities and equipment of the laboratory built in 1943 became inadequate and a new refractories research laboratory and pilot plant were constructed at Marelan, Quebec in 1958. The resourceful and highly competent research staff of Canadian Refractories Limited is at the service of the operating and sales organization, as well as industry itself.

Joining with Canadian Refractories Limited, Harbison-Walker Refractories Company demonstrated its faith in the future of Canadian industries and its appreciation of the quality of CRL products. The way was thus cleared for exchange of technical information to the advantage of consumers of the refractories manufactured by both companies. The progressive policies of Canadian Refractories Limited were continued and the program of expansion accelerated.

The magnesite mine and the beneficiation and dead-burning plants are located at Kilmar, Quebec, 70 miles northwest of Montreal. Thorough prospecting by diamond drilling has developed sufficient reserves of raw materials

to last for many years. Mining operations are carried out on various levels down to a depth of over 1000 feet. At the surface the rock is fed to a heavy media separation plant for beneficiation before being tranported to the nearby dead-burning plant. Here various additions may be made depending upon the product desired. The magnesite is dead-burned at temperatures up to 3300°F. in a rotary kiln 245 feet long. After crushing and sizing, certain dead-burned magnesite products are shipped for use in furnace bottoms, and others are transported by a company-owned railway to the modern refractories plant at Marelan, Quebec, where they are further processed for the manufacture of brick and a wide variety of other products.

In the Marelan brick plant, Canadian Refractories Limited has incorporated all the latest equipment in conjunction with the most modern processes used in the refractories industry. A specially designed brick drier and two tunnel kilns process chemically-bonded and hard-burned brick to the specifications required by industry. Modern grinding, crushing, and packing facilities provide for the efficient output of mortars, plastic refractories, castables and ramming mixes.

Quality control is exercised through every step of mining and manufacture. Both the feed to the rotary kiln and the dead-burned granular products from the kiln are sampled and tested at frequent intervals. Both in process and after completion of manufacture, the brick are subjected to control tests in the laboratory. Automatic sampling of brick mixes, followed by physical tests and chemical analyses, insure uniformity of quality. Physical tests of the brick include among others determinations of density, porosity, and strength. The workmanship of all sizes and shapes is carefully checked through every stage of molding, drying, and firing. Mortars, plastic refractories, castables, and ramming mixes are tested for all essential properties, including plasticity, refractoriness, setting properties, and bonding strength.

The brick manufactured at Marelan are shipped in railroad cars on pallets, in cartons, or loose, depending upon the requirements of the user. Brick for export are shipped on skids or in cartons.

Canadian Refractories Limited maintains a complete engineering service to assist the user in the selection and application of refractory materials. In addition to the products manufactured in Canada the company supplies all Harbison-Walker products.

BASIC BRICK

Included in the full complement of classes of basic brick manufactured by CRL from dead-burned magnesite, chrome ores, and from combinations of these materials are the following: **CRL BRUCITE** and **CRL PERIKLASE** brands are hard-burned magnesite brick having high magnesia contents and containing no chrome ore. The more important uses are for the linings of nickel and copper smelting and refining furnaces, secondary nonferrous metal furnaces, aluminum-melting furnaces, copper converters and electric steelmelting furnaces, and for the construction of subhearths in open-hearth furnaces. **PERECON**, which is highly resistant to hydration, is a modification of CRL PERIKLASE. Other modifications include CRL PERIKLASE-93 and CRL PERIKLASE-NS both of which have enhanced resistance to spalling.

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MAGNECON brick, which are made from the magnesite mined at Kilmar, Quebec, have unique properties making them especially suited for certain particular applications. Outstanding properties of MAGNECON are high resistance to basic slags, superior resistance to spalling, and in particular, the characteristic of acquiring and holding protective coatings on linings of rotary cement kilns. MAGNECON is world-famous, due to its use in many countries with splendid results for the high-temperature zone linings of rotary cement kilns.

MAGNECON brick serve advantageously for the linings of furnaces in which the slag is high in lime or in which basic dusts come into contact with the refractories. They are resistant to iron oxide scale and to slags high in iron oxide formed in various furnace operations. They are used successfully for lining some large and small electric steel furnaces, for the construction of hearths of forge furnaces, reheating furnaces, billet-heating furnaces, and parts of the linings of soaking pits and metal mixers in basic open-hearth steel plants. Other applications include calcium carbide furnaces, copper and silver refining furnaces, some aluminum-melting furnaces, and secondary lead, brass, and copper furnaces.

MAGNECON brick give excellent service in various operations where they are exposed to contact with lime, dolomite, or alkaline dust or fumes. They are used to advantage in the hot zone linings of shaft and rotary lime and dolomite kilns and in the walls and checkers of glass-tank regenerators.

BRC-60, a chemically-bonded magnesite-chrome brick, among various applications, is used in the copper and nickel industries in reverberatory and refining furnaces, and in the steel industry for the lining of metal mixers.

BRC-60 METALKASE is a chemically-bonded magnesite-chrome brick encased in steel. In service, the steel oxidizes at the hot ends of the brick and combines with the magnesia to form a bond consisting of the refractory mineral magnesioferrite. The spalling resistance of the brick is thereby increased. Over the cooler portion of the brick, the steel casings serve to add strength and stability. BRC-60 METALKASE is recommended for use in applications where basic refractories are required and where both high refractoriness and high resistance to spalling are important properties. The brick are used in sprung-arch or suspended roofs of open-hearth steel furnaces, in suspended roofs of copper and nickel reverberatory furnaces, in the linings of electric steelmelting furnaces above the slag line, and in bulkheads, end walls, back walls, front walls, skews, and roof shoulders of basic open-hearth steel furnaces.

CRB-20 is a chrome-magnesite brick which is burned at an extremely high temperature in modern tunnel kilns. It is made from blends of chrome ore and dead-burned magnesite with the optimum particle sizing for securing the most desirable physical properties. The fact that CRB-20 is formed under very high pressure contributes to its high strength and excellent load-carrying capacity at high temperatures. It is very resistant to thermal shock as compared with basic brick in general, and is unusually stable in volume at high temperatures.

CRB-20 chrome-magnesite brick are noted for excellent performance in bottoms, walls, and ports of open-hearth furnaces. They are used to advantage in the linings of electric steelmelting furnaces, soaking pits, and the bottoms of forge furnaces. They are making excellent records in nonferrous metallurgy, in copper refining furnaces, copper and copper-nickel converters, and as checkers in regenerators of open-hearth steel and glass-tank furnaces. A chemically-bonded modification of CRB-20 is available. The choice between the burned and the chemically-bonded brick depends on the particular application.

CRL CHROME brick are produced in both hard-burned and chemically-bonded brands. They are used in soaking pits, in the subhearths of various types of furnaces, in aluminum-remelting furnaces, in recovery units of kraft paper mills, and in the working hearths of forge furnaces where they must resist corrosion by molten iron oxide scale.

HIGH-ALUMINA BRICK

CRL's range of Canadian-made high-alumina brick include **CRL CORUNDUM** (99% alumina), **CRL KORUNDAL** (90% alumina), and **CRL SILLIMANITE** (60% alumina) adapted for extreme conditions of temperature and spalling. CRL SILLIMANITE is made essentially from Indian ores, and is outstanding in performance in furnace atmospheres containing soda and vanadium, which are common in industrial oils burned in eastern Canada. These brick are available in a wide range of shapes including burner blocks, electric furnace roof brick, and various shapes for the superstructure of glass and silicate of soda furnaces.

BONDING MORTARS

MAGSET is a refractory, plasticized magnesite mortar especially suited for laying all types of magnesite brick.

BRUCITE CEMENT has a magnesite base. It is applied to the surfaces of basic brick walls by spraying with an air gun to prolong the life of the walls.

CRL CHROME MORTAR, which is air-setting, is used in laying all types of magnesite and chrome brick, as a neutral layer between acid and basic brick, and for laying fireclay and high-alumina brick subjected to severe slagging conditions.

KYANEX is an air-setting high-temperature bonding mortar of premium quality used for laying all classes of fireclay and some high-alumina brick, particularly in metallurgical practice and in steam power and heating plants. It has a very high fusion point, and is free from shrinkage in drying and firing. Its workability is excellent both for troweling and for dipped joints.

KYANEX is regularly shipped in wet form with just the proper amount of water for troweling. It is also available in dry form, both air-setting and heat-setting. KYANEX is used satisfactorily for surfacing new and old firebrick construction and for laying ladle sleeves. It is also used in patching and repairing eroded areas in furnace linings by mixing with crushed fireclay brick and water to a good forming consistency.

KORUNDAL BONDING MORTAR and **CRL SILLIMANITE MORTAR** are other CRL high-alumina bonding mortars which are used for laying various high-alumina brick.

SILICA 40 is the pioneer in the class of special clay-free silica bonding mortars. Its noteworthy properties are excellent plasticity and water retention, and high refractoriness. Its use in laying both superduty and conventional silica brick contribute to the resistance of these brick to spalling and slagging in open-hearth steel furnaces, electric furnaces, other metallurgical furnaces, glass tanks, and lime kilns.

CRL SILICON CARBIDE MORTAR is a heat-setting bonding mortar, prepared from high-purity silicon carbide grains. It is especially suited for laying silicon carbide brick.

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MONOLITH-FORMING REFRACTORIES

CRL RAMIX is the original air-setting magnesite ramming mix for the bottoms of basic open-hearth and electric steelmelting furnaces. The major constituent is Kilmar magnesite, carefully sized to facilitate ramming, and to form monolithic hearths of high density. It requires only the addition of the proper amount of water and thorough mixing to prepare it for use.

It is possible to install the greater part of the hearth of an open-hearth furnace, and in many cases the entire hearth, merely by ramming the CRL RAMIX into place as a monolith of the desired thickness and contour. Because of its exceptional resistance to hydration, CRL RAMIX hearths do not slake during the drying period or during furnace shutdowns. Its high density and low porosity minimize metal and slag penetration, and reduce cost of maintenance as well as loss of operating time. When used in the installation of electric furnace bottoms, CRL RAMIX completely avoids the necessity of burning-in the bottoms with the arc.

CRL RAMIX is used also for the maintenance of bottoms and banks of open-hearth and electric steel furnaces. The rate at which it sets greatly exceeds that of conventional grain magnesite, and, by its use, hot or cold repairs can be made in a minimum of time. For use in copper and nickel reverberatory furnaces, CRL RAMIX is rammed into metal containers, which in service are supported in such manner that they form the upper part of the sidewalls. CRL RAMIX is used to form the tapholes of basic open-hearth furnaces and for various other applications, including the linings of furnaces used in the production of silver and cobalt.

695 PLASTIC is a highly refractory magnesite-chrome ramming and gunning mix. When mixed with water, it sets quickly to form a hard, dense mass, and when heated acquires a glassy surface which is highly impervious to attack by slag or metal.

695 PLASTIC was developed for use in forming the tapholes of basic open-hearth furnaces. When used on the slopes of open-hearth furnaces, it effectively protects them from silica drip and foamy slags. It is used for patching front and back walls, and floors and uptakes of the ports. It also serves well for repairing the bases of soaking pits, hearths of billet-heating furnaces, and sections of metal mixers. It is not wetted by molten aluminum.

695 PLASTIC has long been a standard refractory in many foundries for lining ladles up to five tons capacity employed for handling manganese and other alloy steels.

CRL PLASTIC CHROME ORE consists of carefully sized refractory chrome ore with added plasticizing and bonding agents. Upon drying it forms a strong highly impervious, monolithic mass having a bulk density of 200 pounds per cubic foot. Some of its important applications are in kraft recovery furnaces, studded water-wall boilers, steel rolling mill hearths, soaking pits, and open-hearth doors.

KROMECRETE is a highly refractory castable with an approximate service limit of 2900°F. Its use is especially beneficial in furnace linings subjected to attack by basic slags or fluxes.

CRB-20 GUNPATCH is specially prepared for gunning walls in open-hearth and electric steel furnaces, and in nonferrous metal furnaces.

MAGNIFRIT is a quick-setting furnace magnesite made from Kilmar magnesite and is especially suited for use in furnace hearths. Careful selection of the magnesite rock, and proper choice of materials added to facilitate dead-burning, insures the production of grains having high ultimate refractoriness and the proper composition for burning-in monolithic hearths. The rigidly controlled grain sizing of MAGNIFRIT contributes to high density of the hearths and to long life in service. MAGNIFRIT, used for many years for the permanent bottoms of open-hearth steel furnaces, is also a standard refractory for the resurfacing and daily maintenance of the bottoms and banks of open-hearth and electric steelmelting furnaces.

QX MAGNIFRIT is a fettling and patching refractory embodying a new principle. It is the result of combining with MAGNIFRIT a small proportion of low-melting basic minerals. Under even moderate furnace heat, these minerals melt, forming an appreciable proportion of liquid. On further heating, the liquid reacts with the granular MAGNIFRIT, again solidifies, and consolidates the refractory mass. This is a unique property of QX MAGNIFRIT. The products of this reaction are essentially crystalline magnesia (periclase), and dicalcium silicate, both of which are highly refractory. With continued heating and higher temperatures, the mass becomes harder, providing maximum resistance to erosion by molten metal and slag.

QX MAGNIFRIT is applied as a hot-patch material for basic open-hearth furnace bottoms and banks. It should not be mixed with basic slag or any other material for use. The furnace temperature should be approximately 2400°F. when QX MAGNIFRIT is applied. In any bottom or bank repair installed at 2400°F. or higher, QX MAGNIFRIT will thoroughly bond with the existing bottom material and form a hard, dense, and highly refractory hearth on which the succeeding heat of steel may be produced. QX MAGNIFRIT gives a marked reduction in setting time, as compared with most other refractory hearth materials, and thus permits earlier charging of the furnace.

MAGNIFRIT CEMENT is used for maintenance of nonferrous metallurgical furnaces, and for building and maintaining the tapholes.

KROMORE is ground chrome ore prepared to user's specifications for a wide variety of refractory applications, and for other uses, such as a colorant for glass.

CRL high-alumina ramming mixes include **KORUNDAL RAMMING MIX** and **CRL SILLIMANITE RAMMING MIX** which are used for extreme conditions, particularly in the presence of corrosive slags. **SILLCRETE** is a mullite-base castable for service at temperatures above those for which fireclay castables may be used.

DUROPATCH is a fireclay plastic refractory of proper consistency for use as shipped. It is made in slabs ready to pound into place with a mallet or pneumatic rammer. DUROPATCH is used in domestic, commercial, and industrial boiler settings, in oil burner installations, heating furnaces, forge furnaces, brass-melting furnaces, annealing ovens, cupolas, ladles, incinerators, and bake ovens, and to form burner blocks. It is ideally suited for monolithic construction of furnace walls, arches, and door sills, and is especially adapted for patching holes in boiler settings. Two grades are supplied: regular DUROPATCH for moderate and high-duty service, and **SUPER DUROPATCH** for severe high-temperature conditions which require superduty fireclay refractories.

DUROCRETE is a versatile fireclay refractory castable for use at temperatures up to a full 2600°F. It is only necessary to add water to bring to proper consistency before pouring and casting into special shapes. A modification known as DUROCRETE-10 is used for gun applications. A strong bond is developed in 12 hours. It has low thermal expansion and is resistant to spalling and abrasion. It does not shrink or crack upon drying.

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DUROCRETE is used for door linings, furnace ducts, covers and bottoms, burner blocks, arches, tiles, lintels, and baffles, and for casting small monolithic furnace linings. It is well adapted for incinerator linings of special designs. It is recommended for use in the chain sections of rotary cement kilns, and in the firing hoods of kilns and driers. DUROCRETE KR, a modification of DUROCRETE, is used for forming tunnel kiln car bottoms.

CRL SILICON CARBIDE RAMMING MIX serves as monolithic linings of small furnaces and troughs and for patching structures of compatible thermal expansions and compositions.

INSULATION

The Canadian Refractories Limited range of insulating materials produced in Canada includes those made from diatomaceous earth, vermiculite, and lightweight aggregates of fireclay base, and embraces insulating brick, insulating castables, and bulk insulation. Detailed information concerning these materials will be gladly furnished by any CRL representative.

SPECIAL PRODUCTS

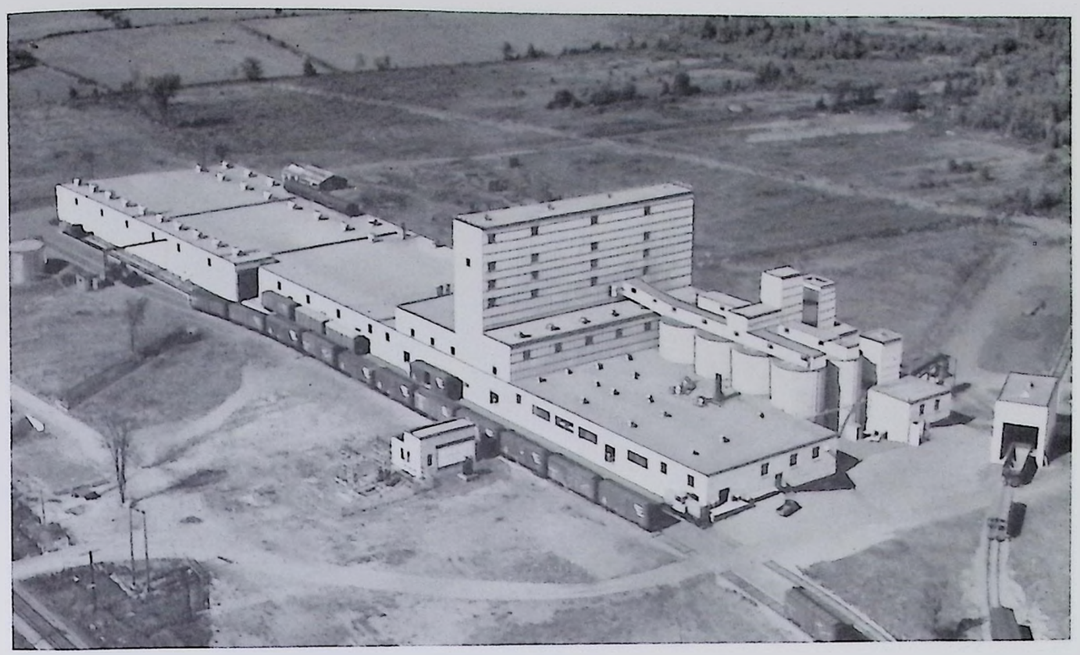
From its large supply of numerous raw materials, Canadian Refractories Limited is prepared to manufacture various Special Products to customers' specifications.

HARBISON-WALKER PRODUCTS

The services of Canadian Refractories Limited are available to every user of refractories in Canada in connection with all Harbison-Walker products. Stocks of various Harbison-Walker alumina-silica and silica refractories are carried in CRL and Clayburn-Harbison warehouses at Montreal, Toronto, Hamilton, Edmonton, and Vancouver.

H-W BRANDS EXTENSIVELY USED IN CANADA

QUALITY	BRANDS
High-Alumina Brick	ANCHOR, ALUSITE, CORALITE, and Others.
Superduty Fireclay Brick	ALAMO, VARNON, DEAN, H-W SUPER SAVAGE.
High-Duty Fireclay Brick	WALSH XX, H-W SAVAGE, WOODLAND, H-W 18, FRANKLIN CROWN.
Silica Brick	VEGA, VEGA HP, STAR.
Acid-Proof Brick	DURO.
Insulating Firebrick	H-W 23-LI, H-W 26, H-W 28, VEGALITE.



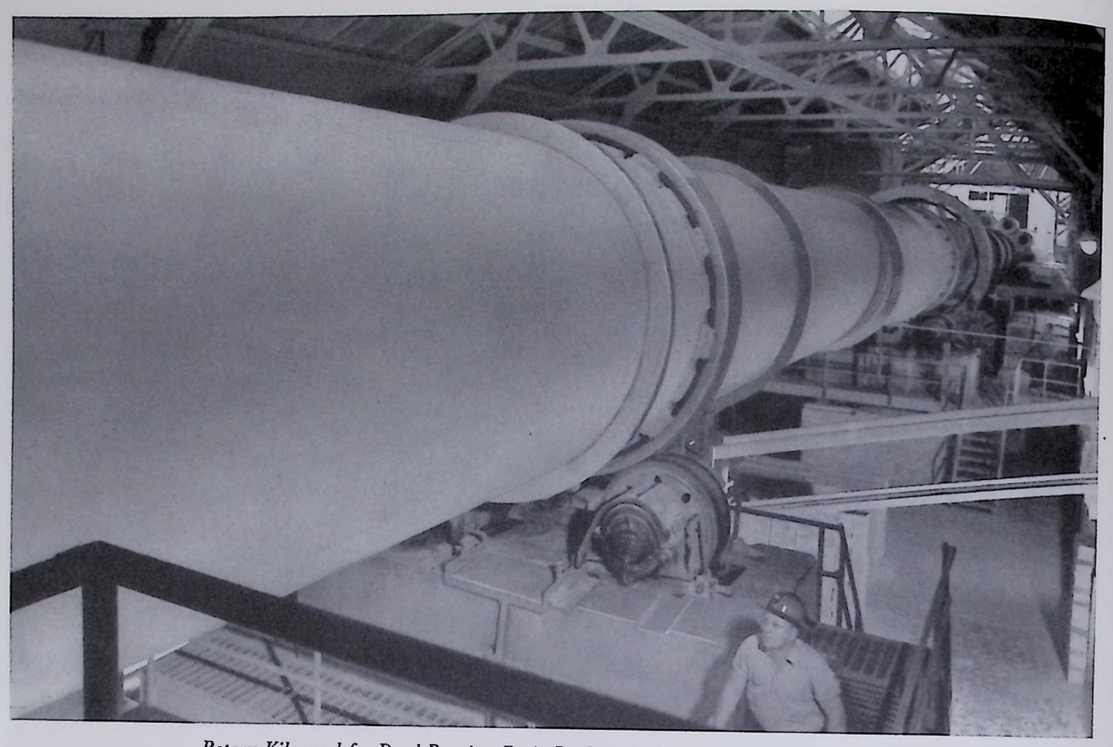
Manufacturing Plant of Canadian Refractories Limited at Marelan, Quebec.



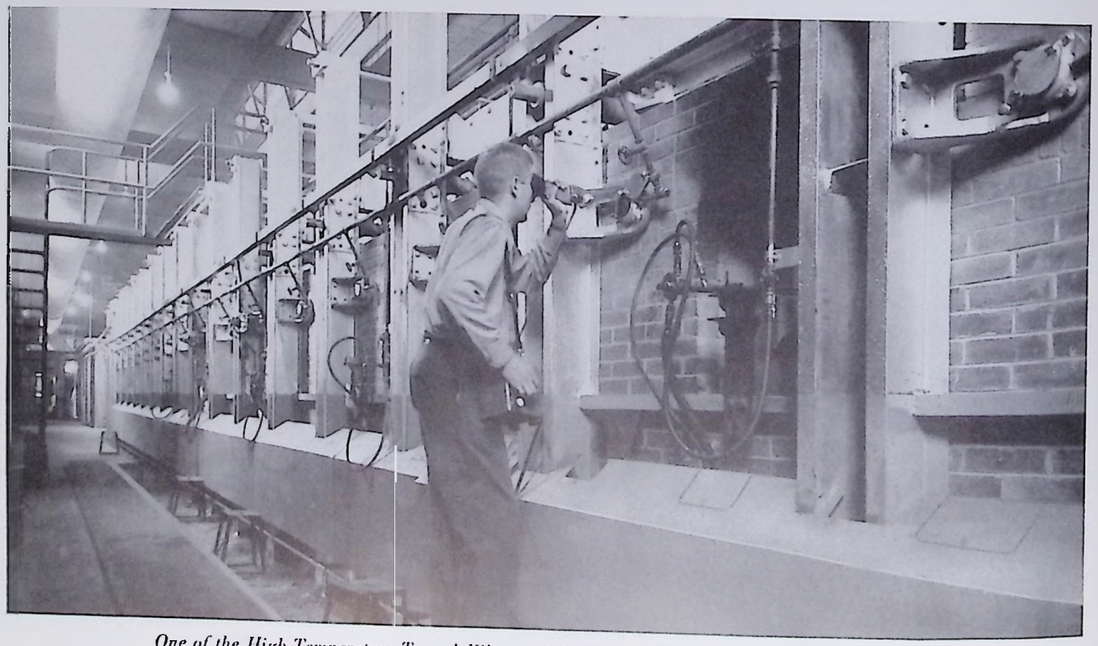
Research Laboratories of Canadian Refractories Limited at Marelan, Quebec.

HARBISON-WALKER REFRACTORIES COMPANY

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Rotary Kiln used for Dead-Burning Basic Products in the Plant at Kilmar, Quebec.



One of the High-Temperature Tunnel Kilns used for Firing Basic Brick at the Marelan Plant.

REFRACTORY PRODUCTS OF CLAYBURN-HARBISON LIMITED VANCOUVER, B. C., CANADA

Brand Name	Class	Process*	Remarks
FIRECLAY BRICK			
C-H SUPERDUTY	Superduty	P.P., H.M.	For general superduty service.
†SKAGIT	High-Duty	P.P., H.M.	For general high-duty service.
†SKAGIT-X	High-Duty	P.P., H.M.	For severe high-duty service, where high strength and density are important.
†CLAYBURN	Medium-Duty	P.P.	For general medium-duty service.
FLAME	Low-Duty	P.P.	For general low-duty service.
ACID-PROOF BRICK			
†KILGARD		P.P., Ext.	For chemical-resistant construction.

Brand Name	Base Material	Kind of Set	Form as Shipped	Maximum Service Temperature	Pounds Required Per Cubic Foot
MORTARS					
†KYANEX (Wet)	High-Alumina	Air	Wet	....	...
†KYANEX (Dry)	High-Alumina	Air	Dry	....	...
†SKAGIT	High-Duty Fire Clay	Heat	Dry	....	...
†CLAYBURN	Medium-Duty Fire Clay	Heat	Dry	....	...
PLASTIC REFRACTORIES					
†SUPER DUROPATCH	Superduty Fire Clay	Heat	Wet	3000°F.	137
†SUPER DUROPATCH	Superduty Fire Clay	Air	Wet	3000°F.	137
†DUROPATCH	High-Duty Fire Clay	Heat	Wet	2800°F.	133
CASTABLES					
†DUROCRETE	High-Duty Fire Clay	Hydraulic	Dry	2400°F.	115
†DUROLITE 24	Lightweight Aggregate	Hydraulic	Dry	2400°F.	85
†DUROLITE 22	Lightweight Aggregate	Hydraulic	Dry	2200°F.	56

* P.P. = Power Pressed, H.M. = Hand Molded, Ext. = Extruded.
† Trade-marks registered in Canada.

CLAYBURN-HARBISON LTD. is an affiliate of Canadian Refractories Limited, and operated as Clayburn Company Limited prior to 1957. The company operates two plants, one at Abbotsford, B. C., where fireclay refractories and building brick are made, and a second at Kilgard, B. C., which makes sewer tile and some other clay products.

Immediately after the formation of Clayburn-Harbison in 1957, an intensive program of research was carried out in cooperation with Harbison-Walker. Superduty fireclay brick were manufactured for the first time in Canada. Clayburn-Harbison now offers the most complete line of fireclay refractories made in Canada, including fireclay brick of all the standard classes, acid-proof brick, refractory mortars, plastic refractories, and refractory castables.

A product development laboratory is maintained at Abbotsford, B. C. Quality control laboratories maintained at each of the two plants are provided with all equipment necessary to conduct both standard and special tests. The company has established quality standards for its products which meet the requirements of the Canadian Standards Association where applicable, and the American Society for Testing Materials.

In the refractories plant at Abbotsford, brick

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are formed by both the power-press and the extrusion processes. Special shapes which cannot be formed by machine methods are molded by hand or by air-ramming. The brick are fired in continuous tunnel, shuttle, and round periodic kilns.

The company's products are widely used in the pulp and paper industry, oil refineries, the metallurgical industries, in chemical plants, power plants, and other applications.

Sales engineering and installation service is provided throughout western Canada. The company maintains sales offices and warehouses in Vancouver and Edmonton, and is represented by many dealers throughout British Columbia, Alberta, Saskatchewan, Manitoba, Washington, and Oregon.

Any product sold by Canadian Refractories Limited or Harbison-Walker Refractories Company can be obtained through Clayburn-Harbison Ltd.

C-H SUPERDUTY firebrick, the first fireclay brick of this class made in Canada, meet the requirements of A.S.T.M. specifications for superduty firebrick of the regular type. Their volume stability at high temperatures insures the maintenance of tight joints. They have applications in many high-temperature furnaces.

SKAGIT brand is recommended for general high-duty service, and **SKAGIT-X** for high-duty service where extra high strength and density are especially important. Both brands are used in cupola linings, boiler settings, oil refining furnaces, heat-treating and forge furnaces, Dutch ovens, annealing ovens, incinerators, and furnaces of other kinds.

CLAYBURN brand is a medium-duty fireclay brick, manufactured from the finest of Clayburn district clays, and has an outstanding record of performance. It has low porosity, good resistance to spalling, uniformity of composition, and excellent workmanship. It is used in moderate-duty boiler settings, waste-heat boilers, stacks and flues, incinerators and breachings, annealing furnaces, and as backing for more refractory brick in furnaces operated at extremely high temperatures.

FLAME low-duty fireclay brick, made from local clays, give excellent service in furnaces where brick of this quality are called for. They are used in flues and stacks, as a back-up brick, and in various other applications where the service conditions are not severe.

KILGARD acid-proof brick and tile are dense, vitreous, nonabsorbent, and resistant to the action of acid solvents. They are strong mechanically and resistant to abrasion. The serviceability of KILGARD brick has been proved in use in many large industrial plants in western Canada.

KYANEX air-setting mortar is recommended for laying C-H SUPERDUTY, SKAGIT, and SKAGIT-X brick, and for the same service conditions as KYANEX made by Canadian Refractories Limited (CRL) as described on page 185. For conditions under which a heat-setting mortar is preferable, **SKAGIT** high-duty fire clay is strongly recommended for laying SKAGIT and SKAGIT-X brick.

CLAYBURN medium-duty fire clay is used to advantage for laying CLAYBURN and FLAME brick.

SUPER DUROPATCH and **DUROPATCH** plastic refractories are equivalent in service to these brands as made by CRL. For further description, see page 187.

DUROCRETE castable is the service equivalent of DUROCRETE made by CRL, as described on page 187.

DUROLITE 24 and **DUROLITE 22** lightweight castables are the equivalent of CRL DUROLITE 24 and DUROLITE 22. Detailed information concerning these materials will be gladly furnished by any Clayburn-Harbison Ltd. representative.



REFRACTORIES MADE IN MEXICO AND PERU

PRODUCTS OF

FABRICA DE LADRILLOS INDUSTRIALES Y REFRACTARIOS HARBISON-WALKER-FLIR, S. A., *Monterrey, Nuevo Leon, Mexico*

HARBISON-WALKER-FLIR DE MEXICO, S. A., *Mexico, D. F., Mexico*
Both are subsidiaries of Compania Fundidora de Fierro y Acero de Monterrey, S. A., and affiliates of Harbison-Walker Refractories Company

REFRACTARIOS PERUANOS, S. A., *Lima, Peru*
subsidiary of Harbison-Walker Refractories Company

HARBISON-WALKER REFRACTORIES COMPANY

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PRODUCTS OF FABRICA DE LADRILLOS INDUSTRIALES Y REFRACTARIOS HARBISON-WALKER-FLIR, S.A., MONTERREY, N.L., MEXICO

Brand Name	Class	Process*	H-W Equivalent and Remarks
FIRECLAY BRICK			
ALAMO-M	Superduty	P.P., H.M.	For general superduty service.
ALAMO-MS	Superduty	P.P.	For general superduty service requiring highest density and strength.
VARNON-M	Superduty	P.P., H.M.	For special superduty service.
VARNON-MS	Superduty	P.P.	For special superduty service requiring high density and strength.
FLIR	High-Duty	P.P., H.M.	For general high-duty service.
FERRO FLIR	High-Duty	Ext.	Equivalent to WALSH T. (See page 67)
H-W-F	High-Duty	P.P., H.M.	Slag and spall resistant. (P.C.E. 32½—33) Meets Mexican requirements for superduty class.
PIRO-FLIR	Medium-Duty	P.P.	For medium-duty service. (P.C.E. 29)
VESTA	Medium-Duty	P.P.	Meets Mexican requirement for high-duty class. (P.C.E. 31—31½)
ALTOR	Blast Furnace High-Duty	P.P.	Equivalent to H-W KY BF. (See page 62)
ALTOR-18	Blast Furnace High-Duty	P.P.	Equivalent to H-W 18 KY. (See page 62)
HIGH-ALUMINA BRICK			
DIALITE-M	50% Alumina	P.P., H.M.	Equivalent to DIALITE. (See page 83)
ANCHOR-M	60% Alumina	P.P., H.M.	Equivalent to ANCHOR. (See page 83)
ANCHOR DASH-M	60% Alumina	P.P., H.M.	Equivalent to ANCHOR DASH. (See page 83)
ALUSITE-M	70% Alumina	P.P., H.M.	Equivalent to ALUSITE. (See page 84)
SILICA BRICK			
SILICA	Conventional	P.P.	Equivalent to STAR. (See page 93)
SILICA-E	Superduty	P.P.	Equivalent to VEGA. (See page 92)
SILICA-FR		P.P.	For soaking-pit service.
INSULATING FIREBRICK			
FLIR-16	1600°F.	P.P.	Made of fired diatomaceous earth.
FLIR-20	2000°F.	P.P.	Made of fired diatomaceous earth.
FLIR-23	2300°F.	P.P.	Made of fired diatomaceous earth.
FLIR-26	2600°F.	P.P.	Equivalent to H-W 26. (See page 127)
FLIR-28	2800°F.	P.P.	Equivalent to H-W 28. (See page 127)
LOTHERM-M	2400°F.**	P.P.	Equivalent to LOTHERM. (See page 127)

* P.P. = Power Pressed, H.M. = Hand Molded, Ext. = Extruded.
** In rotary kiln service, 2100°F.

Brand Name	Class	H-W Equivalent and Remarks
BASIC BRICK		
HW-MAGNESITE-M	Magnesite	Equivalent to H-W MAGNESITE. (See page 104)
MAGNEX-M	Magnesite-Chrome	Equivalent to MAGNEX. (See page 106)
MAGNEX-MCF	Magnesite	Equivalent to MAGNEX CF. (See page 104)
MAGNEX-MH	Magnesite-Chrome	Equivalent to MAGNEX H. (See page 106)
MAGNEX-MBH	Magnesite-Chrome	Equivalent to MAGNEX B. (See page 106)
METALKASE-M	Magnesite-Chrome	Equivalent to METALKASE MAGNEX. (See page 108)
METALKASE-MAGNEX-M-OHR	Magnesite-Chrome	Equivalent to METALKASE MAGNEX OHR. (See page 108)
METALKASE-MH	Magnesite-Chrome	Equivalent to METALKASE MAGNEX H. (See page 106)
CHROMEX-M	Chrome-Magnesite	Equivalent to CHROMEX. (See page 108)
CHROMEX-MS	Chrome-Magnesite	Equivalent to CHROMEX S. (See page 110)
HW-CHROME-M	Chrome	Equivalent to H-W CHROME. (See page 109)
REFRACTORY MORTARS		
MORTERO HW-FLIR		Equivalent to H-W SPECIAL MORTAR. (See page 141)
LIG-AER (Wet and Dry)		Equivalent to HARWACO BOND. (See page 144)
LIG-AER MASTIC		Equivalent to HARWACO MASTIC. (See page 144)
LIG-A-SIL		Equivalent to VEGA BOND. (See page 142)
MORTERO REFRACTARIO SILICA		Equivalent to H-W STAR SILICA FIRE CLAY. (See page 142)
ANKORITE-65-M		Equivalent to ANKORITE 65. (See page 142)
HW-SPECIAL FURNACE CHROME-M		Equivalent to H-W SPECIAL FURNACE CHROME. (See page 143)
PLASTIC REFRACTORIES		
PLASTICO HW-FLIR		Equivalent to H-W STANDARD PLASTIC FIREBRICK. (See page 157)
PLASTICO SUPERIOR, HW-FLIR		Equivalent to H-W SUPER PLASTIC FIREBRICK. (See page 157)
PLASTICO A-50		50% Alumina Plastic Refractory.
CASTABLE MATERIALS		
CONCRETO REFRACTARIO ALTA CALIDAD HW-FLIR		Equivalent to H-W STANDARD CASTABLE. (See page 163)
CONCRETO REFRACTARIO CALIDAD SUPERIOR HW-FLIR		Equivalent to H-W SUPER CASTABLE. (See page 164)
CONCRETO REFRACTARIO ALTA RESISTENCIA HW-FLIR		Equivalent to H-W EXTRA STRENGTH CASTABLE. (See page 164)
CONCRETO REFRACTARIO ALTA ALUMINA HW-FLIR		Equivalent to H-W HIGH-ALUMINA CASTABLE. (See page 164)
CONCRETO REFRACTARIO HW-FLIR-56		Equivalent to H-W LIGHTWEIGHT CASTABLE 22. (See page 166)
CONCRETO REFRACTARIO HW-FLIR-85		Equivalent to H-W LIGHTWEIGHT CASTABLE—EXTRA STRENGTH. (See page 167)
HW-KUPLOMIX-M		Equivalent to KUPLOMIX. (See page 161)

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Prior to 1955, Fabrica de Ladrillos Industriales y Refractarios, S.A., was operated as a subsidiary of Compania Fundidora de Fierro y Acero de Monterrey, S.A., and produced refractories to meet the needs of the growing industries of Mexico. In 1955, Harbison-Walker Refractories Company acquired a substantial minority interest in the former company, which then became known as Fabrica de Ladrillos Industriales y Refractarios Harbison-Walker-Flir, S.A. Since then Harbison-Walker Refractories Company has provided technical and engineering assistance on production methods, quality control, products, and product applications. Brands formerly made have been improved and many new brands added, so that today Flir (as the company name is abbreviated for convenience) manufactures a complete line of fireclay, silica, and basic brick, mortar materials, and monolithic refractories. The service given by these products under comparable furnace conditions is equivalent in every respect to that of the refractories made by Harbison-Walker in the United States.

The company obtains much of its raw materials from large deposits of refractory kaolins, plastic clays, and amorphous silica in central Mexico. Other raw materials needed for the manufacture of high-quality products are obtained largely from Harbison-Walker.

The products are manufactured in a large modern plant situated in Monterrey, N.L. The brick are formed mainly by the power-press method. Some are formed by the extrusion process, and special shapes not adapted to machine manufacture are made largely by hand. Some insulating firebrick and some special fireclay brick shapes are formed by slip-casting. The brick are fired in modern tunnel kilns and in periodic kilns.

The quality control laboratory maintains continuous control over all raw materials and all materials in process. Representative samples of finished products are analyzed and the more important physical properties are determined daily. Samples of the products are regularly submitted to the Harbison-Walker Central Control Laboratory at Hays, Pennsylvania, where all results are checked.

The laboratory is located at the plant site, and contains the most modern equipment for making both regular and special physical tests and complete chemical analyses. Research is continuously conducted on the processing of raw materials and the development of new products as needed by the industries. This work is done in cooperation with the Garber Research Center at Pittsburgh, Pennsylvania.

Harbison-Walker-Flir supplies the various refractories required by the completely integrated and rapidly growing steel industry of Mexico, with its blast furnaces, open hearths, electric steel furnaces, soaking pits, and heating furnaces. The company also produces the various kinds of refractories needed in iron and steel foundries, nonferrous metallurgical plants, glass plants, portland cement kilns, the ceramic industry, and other industries.

Harbison-Walker-Flir is in position to recommend and supply any Harbison-Walker product needed for specific purposes. Some Harbison-Walker brands widely used in Mexico include Thermolith, Korundal Bonding Mortar, H-W Periklase Bonding Mortar, Plastic Thermolith Batch, Thermolith Batch (Dry), Coralite Ramming Mix, and H-W Magnamix.

Harbison-Walker-Flir freely offers technical assistance in the selection of the refractories for every requirement, and frequently can help in supervision of installation. Upon request, a company representative will be glad to discuss all refractories problems.

PRODUCTS OF HARBISON-WALKER-FLIR DE MEXICO, MEXICO, D.F., MEXICO

Brand Name	Class	Process*	H-W Equivalent and Remarks
FIRECLAY BRICK			
Alamo-M-DF	Superduty	P.P., H.M.	For general superduty service. Equivalent to Alamo. (See page 66)
Alamo-MS-DF	Superduty	P.P.	For general superduty service requiring special high density and strength. Equivalent to Alamo S. (See page 66)
Flir-DF	High-Duty	P.P., H.M.	For general high-duty service.
Ferro-Flir-DF	High-Duty	Ext.	For general high-duty service requiring high density and strength. Equivalent to Walsh T. (See page 67)
H-W-F-DF	High-Duty	P.P., H.M.	Slag and spall resistant. (P.C.E. 32½—33)
Piro-DF	Medium-Duty	P.P.	For medium-duty service. (P.C.E. 29)
Vesta-DF	Medium-Duty	P.P.	For medium-duty service—also Mexican high-duty. (P.C.E. 31—31½)
Altor-DF	High-Duty	P.P.	For blast-furnace linings. Equivalent to H-W Ky BF. (See page 62)
Ladeo	Ladle Brick	P.P.	Expanding-type brick for steel plant ladles.
INSULATING FIREBRICK			
Flir-16-DF	1600°F.	P.P.	Made of fired diatomaceous earth.
Flir-20-DF	2000°F.	P.P.	Made of fired diatomaceous earth.
Flir-23-DF	2300°F.	P.P.	Made of fired diatomaceous earth.
Flir-26-DF	2600°F.	P.P.	Equivalent to H-W 26. (See page 127)
Flir-28-DF	2800°F.	P.P.	Equivalent to H-W 28. (See page 127)
REFRACTORY MORTARS, PLASTIC REFRACTORIES, and CASTABLES			
Mortero HW-Flir-DF			Equivalent to H-W Special Mortar. (See page 141)
Auro-Set (Wet)			Equivalent to Harwaco Bond. (See page 144)
Mortero Ladeo			For laying Ladeo brick.
Auro-Plast			Equivalent to H-W Standard Plastic Firebrick. (See page 157)
Auro-Plast-Superior			Equivalent to H-W Super Plastic Firebrick. (See page 157)
Auro-Plast-A-50			50% Alumina Plastic Refractory.
Auro-Kast			Equivalent to H-W Standard Castable. (See page 163)

* P.P. = Power Pressed, H.M. = Hand Molded, Ext. = Extruded.

HARBISON-WALKER REFRACTORIES COMPANY

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Harbison-Walker-Flir de Mexico operates a modern tunnel kiln plant at Mexico City for the production of fireclay brick and other refractories. It serves the consuming industries of central Mexico with a line of all the standard classes of fireclay brick and insulating firebrick, together with mortar materials, plastic refractories, and castables. These products give the same excellent service as the refractories of the affiliated companies Harbison-Walker Refractories Company of Pittsburgh, Pennsylvania, and Fabrica de Ladrillos Industriales y Refractarios Harbison-Walker-Flir, S.A. of Monterrey, N.L.

Most of the products of this plant are made from high-grade kaolins and plastic clays obtained from mines in central Mexico. These raw materials are made into refractory products of the best quality by the most modern methods of manufacture, in which strict control procedures are exercised in every step of processing, from the mining of the clays through to final inspection of finished products.

While brick are formed mainly by the power-press method, some are made by the extrusion process, and many special shapes are molded by hand. The slip-cast method is used for forming some special shapes and insulating firebrick. The brick are fired in continuous tunnel kilns.

The various products are extensively used by the petroleum and petrochemical industries, railroads, the sugar industry, iron and steel, and other metallurgical plants. Harbison-Walker-Flir de Mexico, S.A. is in position to render sales engineering and installation service as required. Any product of Harbison-Walker Refractories Company of Pittsburgh or of Fabrica de Ladrillos Industriales y Refractarios Harbison-Walker-Flir, S.A., can be obtained through Harbison-Walker-Flir de Mexico, S.A.



Refractories Plant of Harbison-Walker-Flir at Monterrey, Mexico.

PRODUCTS OF REFRACTARIOS PERUANOS, S.A. (REPSA), LIMA, PERU

Brand Name	Class	Process*	H-W Equivalent and Remarks
FIRECLAY BRICK			
Alamo	Superduty	P.P., A.R.	Equivalent to Alamo. (See page 66)
Varnon	Superduty	P.P., A.R.	Equivalent to Varnon. (See page 66)
Repsa	High-Duty	P.P., A.R.	General high-duty service.
Repsa Special	High-Duty	P.P., A.R.	For high-duty service requiring superior resistance to loads and to corrosion by slags.
Repsa 18	High-Duty	P.P., A.R.	For high-duty service requiring high resistance to abrasion.
HIGH-ALUMINA BRICK			
Dialite	50% Alumina	P.P., A.R.	Equivalent to Dialite. (See page 83)
Anchor	60% Alumina	P.P., A.R.	Equivalent to Anchor. (See page 83)
Alusite	70% Alumina	P.P., A.R., I.P.	Equivalent to Alusite. (See page 84)
SILICA BRICK			
Vega	Superduty	P.P., A.R., I.P.	Equivalent to Vega. (See page 92)
Star	Conventional	P.P., A.R., I.P.	Equivalent to Star. (See page 93)
BASIC BRICK			
Magnesite	Magnesite	P.P., A.R., I.P.	Equivalent to H-W Magnesite. (See page 104)
Magnex	Magnesite-Chrome	P.P., A.R.	Equivalent to Magnex. (See page 106)
Metalkase Magnex	Magnesite-Chrome	P.P., A.R.	Equivalent to Metalkase Magnex. (See page 108)
Chromex	Chrome-Magnesite	P.P., A.R.	Equivalent to Chromex. (See page 108)
CB-20	Chrome-Magnesite	P.P., A.R., I.P.	Equivalent to Chromex B. (See page 109)

Brand Name	Kind of Set	H-W Equivalent and Remarks
REFRACTORY MORTARS		
Superduty Fire Clay	Heat-Setting	Equivalent to H-W Superduty Mortar. (See page 141)
High-Duty Fire Clay	Heat-Setting	Equivalent to H-W High-Duty Fire Clay. (See page 140)
Harwaco Bond	Air-Setting	Equivalent to Harwaco Bond. (See page 144)
Ankorite 65	Heat-Setting	Equivalent to Ankorite 65. (See page 142)
Star Silica	Heat-Setting	Equivalent to H-W Star Silica Fire Clay. (See page 142)
Furnace Magnesite	Heat-Setting	Equivalent to H-W Washington Furnace Magnesite. (See page 142)
Furnace Chrome	Heat-Setting	Equivalent to H-W Special Furnace Chrome. (See page 143)
Thermolith	Air-Setting	Equivalent to Thermolith. (See page 146)
PLASTIC REFRACTORIES, CASTABLES, AND RAMMING MIXES		
Standard Plastic Firebrick		Equivalent to H-W Standard Plastic Firebrick. (See page 157)
Super Plastic Firebrick		Equivalent to H-W Super Plastic Firebrick. (See page 157)
Standard Castable		Equivalent to H-W Standard Castable. (See page 163)
Extra Strength Castable		Equivalent to H-W Extra Strength Castable. (See page 164)
Super Castable		Equivalent to H-W Super Castable. (See page 164)
Chrome Castable		Equivalent to H-W Chrome Castable. (See page 165)
Chrome Castable, E.S.		Equivalent to H-W Harchrome Castable. (See page 165)
Black Patch		Equivalent to H-W Black Patch. (See page 157)
Kuplomix		Equivalent to Kuplomix. (See page 161)
Magnamix		Equivalent to H-W Magnamix. (See page 113)

* P.P. = Power Pressed, A.R. = Air-Rammed, I.P. = Impact Pressed.

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Refractarios Peruanos, S.A. was formed in 1955 to serve the refractories requirements of Peru and the neighboring countries on the Pacific Coast of South America. The home office and modern plant are located at Calle Materiales 2828, five miles from the port of Callao and three miles from the center of Lima. The company's own siding on the Central Railway of Peru as well as direct access to the Central and Pan American Highways assures the prompt and economical distribution of REPSA products throughout the area.

The excellence and uniformity of REPSA products are firmly based on adequate reserves of high-quality raw materials. Large deposits of high-duty and superduty fire clays and refractory silica rock have been discovered, tested, and acquired by the company. A continuous program of development and further prospecting assures continuous supply of these essential raw materials for many years to come.

Production facilities include modern crushing, grinding, blending, tempering, and forming equipment. Brick are formed by the power-press, impact-press, and air-rammed processes. Burning is carried out in round, downdraft periodic kilns. Production capacity is adequate for handling the largest requirements with prompt deliveries.

The maintenance of strict quality standards is assured by constant control testing at each step of manufacture from raw material through finished product. REPSA has its own fully-equipped control laboratory whose results are checked and verified periodically by the central Quality Control organization in Pittsburgh. A.S.T.M. standards are the minimum requirements for REPSA products. Products which carry the Harbison-Walker brand names are fully equivalent in service to the same products as manufactured in the United States. Refractarios Peruanos is in position not only to supply the various standard brands, but also to provide modifications of these brands, as made in the United States, to meet specialized requirements.

Refractarios Peruanos has taken advantage of the unique qualities of its clays to develop an outstanding group of high-duty fireclay refractories under its own brand names.

REPSA brand is the general purpose high-duty brick, with a P.C.E. of 32½.

REPSA 18 is an extra high-fired modification of the standard REPSA composition with definitely enhanced resistance to abrasion and the harmful effects of carbon monoxide gas.

REPSA SPECIAL is a dense, low porosity brick with a P.C.E. of 31½ to 32, superior load-bearing properties, and excellent resistance to slag attack.

Basic research into the improvement of present refractories and the development of new ones is carried on through the Garber Research Center at Pittsburgh, Pennsylvania. REPSA cooperates fully in this research effort by carefully gathering data on its customers' refractories problems and providing pilot-plant facilities to work out the research solutions.

Major industries in the market area of REPSA include the nonferrous metals, particularly copper, lead, and zinc, together with steel, ceramic ware, portland cement, glass, foundries, food processing, and many types of heating furnaces. The diversity of the area's refractory needs is indicated by the wide range of products provided by the company. For specialized service beyond the scope of its own products, REPSA is in position to supply the proper refractories from Harbison-Walker.

Sales offices of Refractarios Peruanos, S.A. are maintained at the home office, Apartado 2828, Lima, Peru and at 307 Fifth Avenue, Pittsburgh 22, Pennsylvania.



EXPORT DEPARTMENT

HARBISON-WALKER REFRACTORIES COMPANY

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Loading Basic Brick on Shipboard at Baltimore for Shipment to Italy.



Part of a Large Shipment of Blast-Furnace Brick, Packed for Export to Sweden.

AGENCY OFFICES

OUTSIDE CONTINENTAL UNITED STATES

Territory	Agency Office Location
CANADA	
British Columbia	*Vancouver*
Alberta	*Calgary*
Manitoba	*Winnipeg*
Ontario	*Fort William, Hamilton Toronto*
Quebec	*Montreal*
MEXICO	
Northern	*Monterrey, N. L.*
Southern	*Mexico, D. F.*
CENTRAL AMERICA	
Costa Rica	*San Jose*
El Salvador	*San Salvador*
Panama	*Panama*
WEST INDIES	
British West Indies	*Kingston*
Dominican Republic	*San Juan, P.R.*
Puerto Rico	*San Juan*
Trinidad	*Georgetown, British Guiana*
SOUTH AMERICA	
Argentina	*Buenos Aires*
Bolivia	*La Paz*
British Guiana	*Georgetown*
Brazil	*Rio de Janeiro, Sao Paulo*
Chile	*Santiago*
Colombia	*Barranquilla, Bucaramanga, Bogota, Cali, Medellin*
Ecuador	*Quito*
Paraguay	*Asuncion*
Peru	*Lima*
Uruguay	*Montevideo*
Venezuela	*Caracas, Barinas, Maracaibo, Puerto La Cruz, Puerto Ordaz*
PACIFIC ISLANDS	
Hawaii, U.S.A.	*Honolulu*
Philippines	*Manila*
New Zealand	*Auckland*
EUROPE	
Austria	*Wanne-Eickel, Germany*
Belgium	*Brussels*
Denmark	*Copenhagen*
Finland	*Helsingfors*
France	*Paris*
Germany	*Wanne-Eickel*
Holland	*Brussels, Belgium*
Luxembourg	*Brussels, Belgium*
Greece	*Athens*
Italy	*Agra (Varese)*
Norway	*Oslo*
Portugal	*Brussels, Belgium*
Spain	*Madrid*
Sweden	*Goteborg*
Switzerland	*Basel*
Yugoslavia	*Paris, France*
ASIA	
Ceylon	*Colombo*
China	*Hong Kong, Taipei*
Israeli	*Haifa*
India	*Bombay, Calcutta, Madras*
Japan	*Kobe, Osaka, Nagoya, Tokyo, Yokohama*
Pakistan	*Chittagong, Karachi*
AFRICA	
Algeria	*Paris, France*
Egypt	*Cairo*
French W. Africa	*Paris, France*

HARBISON-WALKER REFRACTORIES COMPANY

EXPORT SALES OFFICE

307 Fifth Avenue Pittsburgh 22, Pennsylvania

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EXPORT DEPARTMENT

For over 50 years, Harbison-Walker has exported thousands of tons of refractory products annually to all parts of the world. Because of this experience, it is equipped to handle promptly and accurately the many details connected with export shipments, in accordance with the customs requirements of the various countries.

With refractories manufacturing plants in Alabama, California, Colorado, Indiana, Kentucky, Maryland, Michigan, Missouri, Ohio, Pennsylvania, and Texas, the company has exceptional facilities for making foreign shipments either by all-rail service to Canada and Mexico, or by combined rail and water service to foreign ports at minimum transportation expenditure to the purchaser.

Harbison-Walker products meet the requirements of every kind of service, as they include practically the entire range of commercial refractories—fireclay, high-alumina, silica, silicon carbide, zircon, and basic brick, insulating firebrick, acid-proof brick, mortar materials of all classes, special clays, block insulation, plastic refractories, castables, and ramming and hearth materials. The company's products are used extensively throughout the world in boiler furnaces, blast furnaces, open-hearth furnaces, coke ovens, electric steelmelting furnaces, and smelting and refining furnaces used in the metallurgy of copper, lead, tin, aluminum, and magnesium. They are also used in vertical shaft kilns and rotary kilns used for making cement, for burning lime, and for sintering or drying, and in many other types of furnaces.

SUGGESTIONS REGARDING ORDERS FOR REFRACTORIES

When ordering, it is well to anticipate requirements as much as possible to insure desired deliveries. Orders for standard sizes of brick will be most clearly expressed when they include both the name of the brick sizes desired and their complete dimensions as they are given on pages 478 to 510.

In determining the sizes and quantities desired, operators and engineers will find helpful the brick tables near the end of this volume, in chapters entitled "Brick Combinations for Rings," and "Brick Combinations for Arches."

With initial orders for special shapes, the purchaser is requested to send sketches or drawings. On subsequent orders for the same shapes, it is sufficient to give Harbison-Walker's shape and drawing numbers and to refer to the previous order for the same material. When ordering brick, sufficient mortar of the proper quality should be included for laying them.

The purchaser is requested also to supply the following information:

1. The kind of packing preferred for brick, whether skids, pallets, crates, or cartons.
2. Complete and accurate description of each item, in the form required by the customs regulations of the importing country. This information is necessary to secure proper consulated documents.
3. Full instructions regarding numbering and marking of all packages, including skids, pallets, crates, and cartons.
4. The kind and amount of insurance desired. Unless otherwise instructed, Harbison-Walker will arrange for insurance in accordance with its established practice.

PACKING H-W REFRACTORIES FOR EXPORT SHIPMENT

Refractory brick for export shipment must be well packed in strong containers to prevent damage en route. Shipments should be of the lowest possible tare weights consistent with safety, to avoid excessive costs for transportation. Based upon these considerations, the company has adopted four types of containers, including (1) strong wooden skids, (2) type "X" pallets, (3) strong wooden crates, and (4) heavy paper cartons. Illustrations of these containers are shown on pages 206, 207, 208, and 209.

The skids provide a means for safe shipment of large packages of heavy weight with the minimum amount of labor at economical packing expenditure. A single skid will hold 300 standard 9″ x 4½″ x 2½″ straight brick, or their equivalent, with gross weights of 2,050 pounds to 3,710 pounds, depending on the type of brick. Skids are adapted for ocean shipment when adequate mechanical lifting equipment is available at transfer points and at destination.

The type "X" pallet, a more recent development in export packaging, has met with great success. This type of package represents a means of transporting large packages of heavy weight with economy and safety. Handling requires the minimum amount of labor and the minimum expenditure for packing. The height of the pallets is not limited, but depends on the relative weight of the type of brick being shipped, as each pallet is generally loaded to an average gross weight of 3,500 pounds.

The crates are made in two standard sizes, one holding 54 standard 9″ x 4½″ x 2½″ straight brick each and the other holding 36 brick each. The larger crates serve for the shipment of fireclay, high-alumina, silica, and acid-proof brick; the smaller crates are used for the heavier magnesite, chrome, and forsterite brick. The gross weight per crate for the various types of brick will be from about 355 pounds to 590 pounds. Mechanical equipment which will handle the heavier skids and pallets is now available at practically all ports, and in the majority of customers' plants. Consequently, crates are now normally used only for small lots, or when local handling conditions make it preferable to use them.

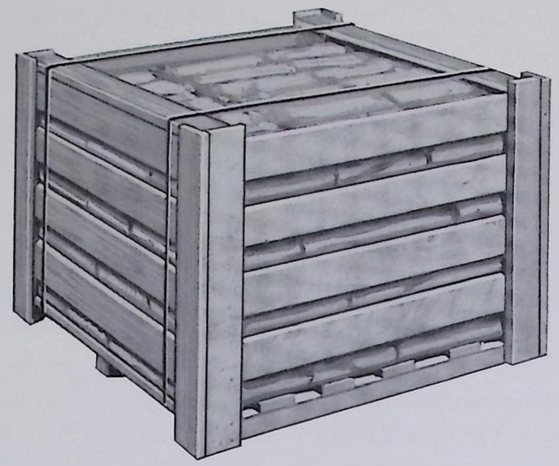
The cartons used for packing fireclay, high-alumina, silica, and basic brick are of such dimensions that they will contain 10 standard 9″ x 4½″ x 2½″ straight brick each, or approximately the same volume of other 9-inch sizes. They are securely bound with strap iron, to prevent damage in transit or through handling. The full carton weighs about 62 to 132 pounds, depending upon the type of brick which it contains. The tare is low, being only about 2 pounds per carton.

When required, brick are also packed in specially constructed wooden boxes. These boxes are used exclusively when shipping conditions are unusually severe. This is a custom-made package and the weight varies depending on the number and type of brick.

Most high-temperature bonding mortars and plastic refractories are shipped in steel drums. Bulk materials such as ground fire clay and other mortar materials, dead-burned magnesite, H-W Magnamix, special furnace chrome, and castables are shipped in special export paper sacks. When desired by the purchaser, sacked materials can be loaded on pallets. Each pallet carries about 30 sacks.

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VOLUMES AND WEIGHTS OF REFRACTORIES PACKED FOR SHIPMENT



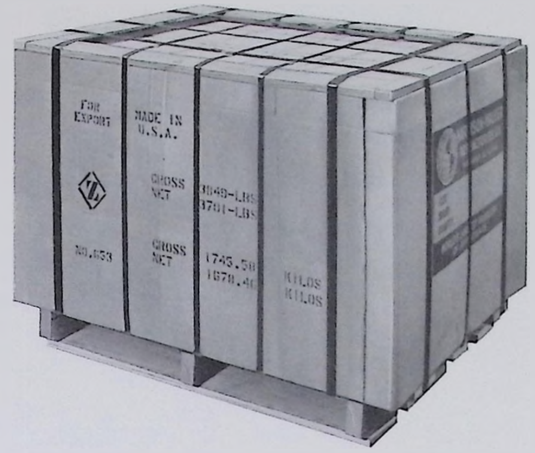
H-W STANDARD EXPORT SKID

H-W STANDARD EXPORT SKIDS

Approximate Size		Approximate Volume		Approximate Tare Weight	
Inches	Millimeters	Cubic Feet	Cubic Meters	Pounds	Kilos
42 x 41 x 30	1067 x 1041 x 767	29.9	0.85	200-270	91-122

Skids are designed to hold 300 Standard 9″ x 4½″ x 2½″ Straights or their equivalent.

Type of Brick	9″ x 4½″ x 2½″ Straights Per Skid	Approximate Net Weight Per Skid		Approximate Gross Weight Per Skid	
		Pounds	Kilos	Pounds	Kilos
FIRECLAY					
High-, medium-, and low-duty	300	2130-2520	965-1145	2380-2770	1080-1255
Superduty	300	2310-2550	1050-1155	2580-2820	1170-1280
Semi-silica	300	2100-2200	950-1000	2350-2450	1065-1110
HIGH-ALUMINA					
45-48, 50, 60, 70% Alumina, and Mullite	300	2430-2640	1100-1200	2700-2910	1224-1320
80, 85, 90% Alumina, and Corundum	300	2730-3120	1240-1415	3000-3390	1360-1540
SILICA	300	1800-2010	815-910	2050-2260	930-1025
BASIC					
Magnesite and Magnesite-Chrome	300	3060-3360	1390-1525	3260-3560	1480-1615
Metalkase	300	3360-3900	1525-1770	3580-4120	1625-1870
Chrome and Chrome-Magnesite	300	3300-3510	1500-1590	3500-3710	1590-1685
Forsterite	300	2820-2880	1280-1305	3020-3080	1370-1395



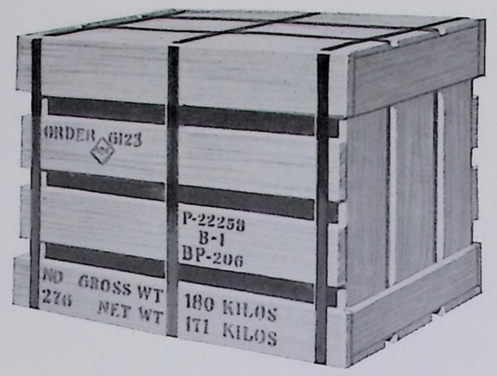
H-W STANDARD EXPORT PALLET

H-W STANDARD EXPORT PALLETS

	Approximate Size		Approximate Volume	
	Inches	Millimeters	Cubic Feet	Cubic Meters
H-W TYPE X PALLETS	48 x 36 x 32	1219 x 915 x 812	32	0.91
H-W BASIC TYPE X PALLETS	48 x 36 x 20	1219 x 915 x 508	20	0.57

Type of Brick	9-Inch Straights or Equivalent per Pallet	Approximate Net Weight Per Pallet		Approximate Gross Weight Per Pallet	
		Pounds	Kilos	Pounds	Kilos
FIRECLAY					
High-, medium-, and low-duty	456 or 532	3775-3830	1710-1735	3880-3935	1760-1785
Superduty	456	3510-3875	1590-1760	3615-3980	1640-1805
Semi-silica	456	3190-3330	1445-1510	3295-3435	1495-1560
HIGH-ALUMINA					
45-48, 50, 60, 70% Alumina, and Mullite	380 or 456	3345-3695	1515-1675	3450-3800	1565-1725
80, 85, 90% Alumina, and Corundum	380	3460-3950	1570-1790	3565-4055	1615-1840
SILICA	532	3190-3565	1445-1615	3295-3670	1495-1665
BASIC					
Magnesite and Magnesite-Chrome	304	3100-3405	1405-1545	3205-3510	1455-1590
Metalkase	304	3405-3950	1545-1780	3520-4055	1595-1830
Chrome and Chrome-Magnesite	304	3345-3555	1515-1615	3450-3660	1565-1660
Forsterite	380	3080-3345	1395-1515	3185-3450	1445-1565

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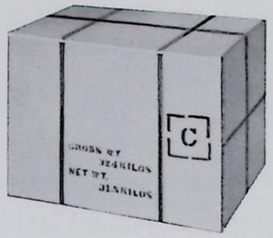


H-W STANDARD EXPORT CRATE
Made in Two Sizes
Size A holds 54 Standard 9″ x 4½″ x 2½″ Straights
Size B holds 36 Standard 9″ x 4½″ x 2½″ Straights

H-W STANDARD EXPORT CRATES

Crate	Approximate Size		Approximate Volume		Approximate Tare Weight	
	Inches	Millimeters	Cubic Feet	Cubic Meters	Pounds	Kilos
A	27 x 21 x 16	686 x 533 x 406	5.25	.15	30	13.6
B	27 x 20 x 11	686 x 508 x 279	3.44	.10	25	11.3

Type of Brick	9″ x 4½″ x 2½″ Straights Per Crate	Approximate Net Weight Per Crate		Approximate Gross Weight Per Crate		Crate to be Used
		Pounds	Kilos	Pounds	Kilos	
FIRECLAY						
High-, medium-, and low-duty	54	380-455	172-206	410-485	186-220	A
Superduty	54	415-460	188-209	445-490	202-222	A
Semi-silica	54	375-400	170-181	405-430	184-195	A
HIGH-ALUMINA						
45-48, 50, 60, 70% Alumina, and Mullite	54	435-475	197-215	465-505	211-229	A
80, 85, 90% Alumina, and Corundum	54	490-560	222-254	520-590	236-268	A
SILICA	54	325-360	147-163	355-390	161-177	A
BASIC						
Magnesite and Magnesite-Chrome	36	365-405	166-184	390-430	177-195	B
Metalkase	36	415-470	190-215	440-495	200-225	B
Chrome and Chrome-Magnesite	36	395-425	179-193	420-450	190-204	B
Forsterite	36	335-350	152-159	360-375	163-170	B



H-W STANDARD EXPORT CARTON

Contains 10 Standard 9″ x 4½″ x 2½″ Refractory Brick

H-W STANDARD EXPORT CARTONS

	Approximate Size		Approximate Volume		Approximate Tare Weight	
	Inches	Millimeters	Cubic Feet	Cubic Meters	Pounds	Kilos
	13 x 9 x 9	330 x 229 x 229	0.61	.017	2.0	0.91

Type of Brick	9″ x 4½″ x 2½″ Straights Per Carton	Approximate Net Weight Per Carton		Approximate Gross Weight Per Carton	
		Pounds	Kilos	Pounds	Kilos
FIRECLAY					
High-, medium-, and low-duty	10	70-85	32-39	72-87	33-40
Superduty	10	75-85	34-39	77-87	35-40
Semi-silica	10	70-75	32-34	72-77	33-35
HIGH-ALUMINA					
45-48, 50, 60, 70% Alumina, and Mullite	10	80-90	36-41	82-92	37-42
80, 85, 90% Alumina, and Corundum	10	90-105	41-48	92-107	42-49
SILICA	10	60-67	27-30	62-69	28-31
BASIC					
Magnesite and Magnesite-Chrome	10	100-115	45-52	102-117	46-53
Metalkase	10	115-130	52-59	117-132	53-60
Chrome and Chrome-Magnesite	10	110-120	50-54	112-122	51-55
Forsterite	10	93-97	42-44	95-99	43-45

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H-W STANDARD EXPORT DRUMS

Drum	Approximate Size				Approximate Shipping Volume		Approximate Tare Weight	
	Outside Diameter		Height					
	Inches	Millimeters	Inches	Millimeters	Cubic Feet	Cubic Meters	Pounds	Kilos
A	15	381	19½	495	2.00	.056	11	5.00
B	15	381	14½	368	1.48	.042	10	4.54
C	17	431	9	229	1.18	.033	7	3.18
D	17	431	24	610	3.15	.89	15	6.80



H-W Standard Export Drums are made in Four Sizes, A, B, C, and D.

Material	Approximate Net Weight Per Drum		Approximate Gross Weight Per Drum		Drum
	Pounds	Kilos	Pounds	Kilos	
BONDING MORTARS					
Firebond	200	90.7	215	97.5	D
Harwaco Bond	200	90.7	211	95.7	A
Thermolith	200	90.7	211	95.7	A
Coralite Bonding Mortar	200	90.7	211	95.7	A
Korundal Bonding Mortar	100	45.4	107	48.5	C
H-W Corundum Bonding Mortar	100	45.4	107	48.5	C
H-W Periklase Bonding Mortar	175	79.4	186	84.4	A
Forsterite Bonding Mortar	175	79.4	186	84.4	A
RAMMING MIXES					
Plastic Thermolith Batch	200	90.7	210	95.2	B
Coralite Ramming Mix	200	90.7	211	95.7	A
Korundal Ramming Mix	200	90.7	211	95.7	A
H-W Corundum Ramming Mix	200	90.7	211	95.7	A



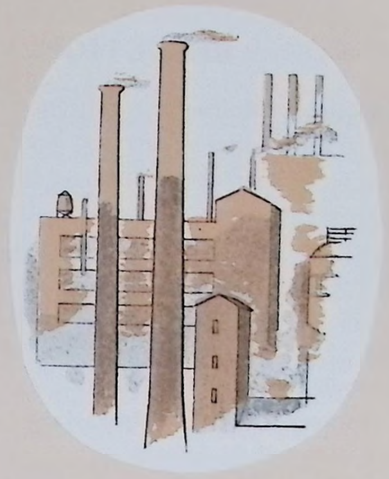
H-W Standard Export Sack for Fire Clay.

This is a strong six-ply waterproof sack.

H-W STANDARD EXPORT SACK

Approximate Size		Approximate Shipping Volume		Approximate Tare Weight	
Inches	Millimeters	Cubic Feet	Cubic Meters	Pounds	Kilos
22 x 15 x 8	559 x 381 x 204	1.53	.043	1.00	.45

Material	Net Weight Per Sack		Gross Weight Per Sack	
	Pounds	Kilos	Pounds	Kilos
Fire Clay and Silica Fire Clay	100	45.4	101	45.8
Castables	100	45.4	101	45.8



SELECTION AND USE OF REFRACTORIES

HARBISON-WALKER REFRACTORIES COMPANY

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SELECTION AND USE OF REFRACTORIES

Selection of Refractories: Economy in the use of refractories is governed largely by selection of the kinds best suited for the particular purposes intended. A careful study of furnace design and operating conditions will greatly aid in this selection.

The type and class of refractories most suitable in any particular case will be determined by such factors as the following:

1. Factors Related to Operation:
- Function of the furnace.
- Nature of the material, if any, to be processed.
- Rate of operation.
- Continuity of operation.
- Temperatures in different parts of the furnace.
- Rapidity and range of temperature changes.
- Source of heat:
  - Kind of fuel.
  - Electric—arc, resistance, or induction.
- Heat release per unit of volume.
- Rate of heat dissipation.
- Chemical attack by oxides of metals, by slags, fuel ash, or other corrosive material.
- Chemical attack by dust, fumes, or gases.
- Fluidity of molten metal or slag.
- Velocity of gases in contact with the linings.
- Abrasion resulting from moving charges.
- Abrasion from dust in rapidly moving gases.
- Impact from charging of cold stock.
- Erosion by molten metals.
- Impinging flames or hot spots.
- The effects of pulsating flames, explosions, or machinery vibration.

2. Factors Related to Furnace Design and Construction:
- Type of furnace.
- Furnace volume for maximum fuel input.
- Design and dimensions of walls and arches.
- Loads imposed upon the lining materials.
- Conditions of heating:
  - From one side, as in an outside wall.
  - From more than one side, as in a pier.
  - From beneath, as in a furnace roof.
- Degree of insulation.
- Ventilations of furnace parts.
- Air or water cooling.
- Type of construction:
  - Brick or monolith-forming materials.
- Methods of bonding and support.
- Type of bond.
- Thickness of joints.
- Nature of bonding mortar.
- Provision for thermal expansion.
- Mechanics of moving parts, such as rotary kilns or tunnel kiln cars.

3. Factors Related to Refractories:

A. Properties at atmospheric temperatures (brick only):
- Workmanship, uniformity in size, freedom from warpage.
- Ability to withstand normal handling.
- Density, porosity, permeability.
- Chemical and mineral composition.
- Uniformity in composition and texture.
- Size of brick.
- Design of brick shapes.

B. Properties at high temperatures (all refractories):
- Refractoriness.
- Temperature of vitrification.
- Reversible thermal expansion.
- Resistance to thermal shock.
- Resistance to chemical attack.
- Resistance to mechanical stress and impact.
- Resistance to abrasion and erosion.
- Permeability to gases and liquids.
- Stability of volume, porosity, and permeability, as affected by furnace conditions.
- Stability of mineral constitution.
- Resistance to gases and fumes.
- Thermal conductivity.
- Heat capacity.
- Electrical resistivity.
- Dielectric strength.

C. Economic factors:
- Delivered cost.
- Cost of installation.
- Standard sizes vs. special shapes.
- Service life.
- Salvage value.

From the multiplicity of factors which may have a bearing upon the choice of refractories, it might appear that the choice of the most suitable material for any particular installation would be exceedingly difficult. Sometimes this is true. Yet there is usually a wealth of data from past experience in the use of refractories under similar operating conditions. Moreover, the best refractory for any particular purpose often depends upon a few requirements so important that by comparison other factors play a minor role. For example, in some cases, high refractoriness alone may be the deciding factor; in others, high refractoriness together with resistance to thermal shock. In still others, resistance to slags or to disintegration by gases may govern the selection. In some cases, high thermal conductivity of the refractories is desired; in others, high insulating value.

The true cost of refractories is not measured by their costs per piece or per ton. The proper criterion for the value of a refractory material is its effect upon the over-all cost of production per unit of output—per ton of steel, per pound of copper, or per unit of any other product. In many cases, the furnace operator has been able to decrease the over-all costs of production by making changes which shorten the life of the refractories but result in greater furnace output. In other cases, savings have been effected by changing to refractories which cost more but which lengthen the furnace campaign.

The costs per ton of handling and installation and generally the cost of transportation amount to as much for inferior products as for those of high quality. In addition, the use of refractories not best suited to the operating conditions will cause loss of output due to down-time for repairs, and additional expense for making the repairs. Not infrequently, materials of lowest first cost are the most expensive in the long run.

When the user must select refractories for a type of furnace or for conditions of operation with which he has had little past experience, he will find it good policy to obtain competent advice. The wide experience of Harbison-Walker, in the selection of refractories for every type of industrial furnace, is at the disposal of all users of refractories. To take complete advantage of this experience, the user should supply all pertinent information regarding the service to which the refractories will be subjected, including the kind of furnace, type of fuel, and operating conditions.

HANDLING, SHIPMENT, AND STORAGE

At all Harbison-Walker plants, the brick are handled with utmost care throughout the different stages of manufacturing, and in moving them to and from storage prior to shipment. Drier and kiln car tracks are kept smooth and level. Brick are carefully inspected and placed on pallets as they are removed from the kilns. They are transported to stock sheds, or directly to motor trucks or railroad cars, on rubber-tired fork trucks.

Generally, shipments—whether by rail or truck—are made on the pallets. However, if desired, the brick may be shipped loose, well packed in straw or other packaging material and properly braced or secured in the carrier.

The standard pallet is a single-deck type, 36 by 48 inches, with three runners, 2½ to 4 inches high, parallel with the 36-inch dimension. The typical pallet load amounts to approximately 4000 pounds net weight.

Pallet loads may be shipped with or without special wrappings to secure the brick to the pallets and protect them from damage. The form of pallet protection is governed by the natural

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stability of the particular load, as well as upon the customer's desires. Internal protection, as well as external, is provided as necessary. The standard pallet quantities, pallet protective patterns, carloading arrangements, and complete details of palletized shipments are described in the "Refractories Industry Palletizing Manual," a copy of which can be obtained from any Harbison-Walker representative.

Drums, sacks, and cartons also are shipped on pallets. Patterns for shipment of these materials may also be found in the "Palletizing Manual." This method of shipment greatly facilitates the handling of refractories.

Brick should be handled as carefully by the user as by the manufacturer. Care in handling, smooth runways, and smooth shed floors will minimize abrasion, chipped corners, and breakage, and deliver the brick in best condition to their ultimate destination.

Refractories should be kept dry during transportation and storage. Stock sheds should be waterproof with smooth, dry floors. Wet bonding mortars and ramming mixes should not be stored where cold weather may cause them to freeze, nor near hot furnaces where temperatures above 120°F. may cause their plasticity to deteriorate.

ORDERING

When standard sizes of brick are ordered, it is not necessary to send drawings, but complete descriptions and dimensions should be given exactly as they are stated on pages 478 to 510.

A drawing should be sent with an initial order for special shapes. Moreover, prints showing assemblies of the special shapes are helpful in securing the best results. On subsequent orders Harbison-Walker's drawing number or the purchaser's drawing and shape numbers should be shown, and when convenient a reference should be made to the order previously placed for the same material.

To facilitate prompt and efficient handling in accordance with the user's wishes and best interests, the following information should be given on all orders:

Whether truck or rail shipments are desired.

Whether the materials are to be shipped on pallets or loose. If on pallets, the quantities of each item should be specified either in multiples of standard pallet quantities, or in terms of the number of pallet loads desired.

When there is preference, state the type of pallet protection preferred, and the arrangements desired for stowing and bracing, as described in the "Palletizing Manual."

When ordering standard circle brick or other brick of the radial type, such as cupola or rotary kiln blocks, it is best to give both the inside and the outside diameter of the lining.

Orders for brick should include sufficient mortar materials of the proper kinds and qualities for laying them.

Ground fire clays and various other ground or crushed refractory materials, ordered in carload quantities, can be shipped either in bulk or in sacks, as preferred, and the order should specify which method of shipment is desired. Less than carload shipments are made in sacks.

If an order calls for more than one carload of material, it is best to specify the rate at which shipments are desired.

It is advisable to anticipate requirements as far in advance as possible in order to provide for the desired delivery.

FURNACE DESIGN AND CONSTRUCTION

Foundations: The foundations provided for industrial furnaces are commonly made of portland cement concrete, and in many instances, are subjected to temperatures of 500°F. or even higher. The concrete has three components—an aggregate of crushed stone, sand, and a binder of hydrated portland cement.

The usual aggregates include quartz pebbles, silica gravel, crushed silica rock, and crushed limestone. An aggregate made of silica rock in any form will expand sufficiently at temperatures up to 1000°F. to set up stresses within the concrete and cause appreciable weakening. Limestone or dolomite rock used as the aggregate will become calcined at somewhat higher temperatures and may weaken considerably if overheated. Calcined refractory fire clay, in the form of lumps up to 1-inch size, may be used to provide an insurance against the shortcomings of some of the conventional aggregate materials. Its thermal expansion is low, and it does not shrink at the highest temperature to which the concrete will be subjected.

Under average conditions, concrete made of the usual portland cement has been used safely for furnace foundations up to a temperature of 700°F. At 900°F., dehydration of the cement progresses to such an extent that the concrete has little mechanical strength. For temperatures higher than 700° to 900°F., it is best practice to build the foundations of "refractory concrete," made of refractory castable material. This is used without the addition of an aggregate. In general, refractory concrete made of standard castables may be used at temperatures up to 2400°F., and superduty castables up to 3200°F., within their load limits.

For high-temperature furnace operation it is often advisable to ventilate the lower courses of the brickwork or the upper part of the concrete foundation. This may be done by designing the furnace so that it rests on plates or girders or on low brick piers between which air can circulate. The piers and separating flues may be of any convenient dimensions; frequently 9-inch piers 5 to 10 inches high, separated by 4½-inch flues, are most practicable. Sometimes, cross flues for ventilation are formed in the top of the concrete foundation. Another means of ventilation is obtained by embedding, in the foundation, pipes 3 inches in diameter or larger, which are kept open to the air. Some furnaces are built with adequate space beneath the bottoms for effective cooling. Air blasts may be used for additional cooling.

Furnace Hearths: The hearths of many furnaces are built of refractory brick usually superimposed on a monolithic refractory foundation. Other furnace hearths have subbottoms built of brick, with working bottoms composed entirely of monolithic refractories, such as dead-burned magnesite or refractory ramming mixes. Some metallurgical furnaces are built with invert-arch bottoms, similar to that illustrated in Figure 1.

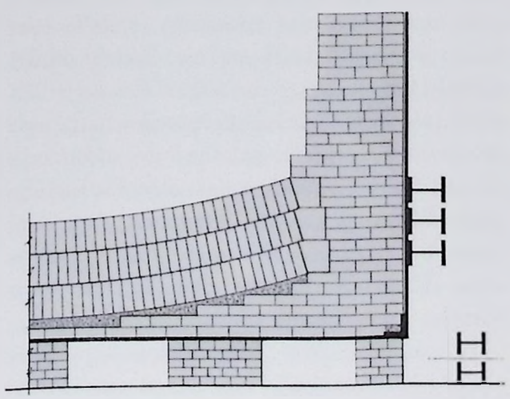


Fig. 1. Typical Invert-Arch Bottom for Metallurgical Furnaces.

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Conditions which may affect the durability of hearths are impact and abrasion, penetration by metal or slag accompanied by corrosion, floating of the brick by liquid pressure, and loosening by movement of the charge over the hearth.

In the construction of many furnaces, the brick in the hearths should be laid with expansion joints. In some cases it is advisable to provide additional expansion space for the hearth under the walls. Hearths of large furnaces may become overheated unless they are ventilated by means of open cross-flues, located in the lowest courses of brick in the furnace bottom, or in the top of the foundation.

Solid hearths of rammed granular material are often used, since with this construction penetration is kept to a minimum and the hearths may be maintained by hot patching. Ramming mixtures of various compositions and dead-burned grain magnesite are excellent materials for the construction of furnace hearths. H-W C-Mix and H-W Magnamix are basic monolith-forming materials which are rammed to the working contours of open-hearth and electric steel furnaces. By their use the building of bottoms by sintering, in thin layers, is avoided with great saving in time and without damage to the refractory structures.

In the hearths of reheating furnaces, the lower courses of brick are usually laid on flat and the top courses on edge. The brick are often laid with their lengths parallel to the axis of the furnace. However, the rows of brick in the top course are sometimes set with a herring-bone pattern. During construction, expansion joints are made by the insertion of wooden laths. These are removed after construction is completed and before the furnace is heated.

In some pipe-welding furnaces, the slightly sloping hearth usually consists of sand placed above crushed ganister or pebbles, forming a "French drain" through which the liquid slag can readily escape.

Bonding of Refractory Walls: The building of furnaces is a specialized branch of masonry, and should be entrusted only to bricklayers who have had experience in furnace construction. Walls, arches, and other furnace parts should be so designed and constructed that structural stability is assured, and that full advantage is taken of the desirable properties of the refractories.

The horizontal layers of brick in a wall are called "courses." Those in which the lengths of the brick are parallel to the face of the wall are known as "stretchers," and those in which the lengths of the brick are at right angles to the face of the wall are termed "headers." In rowlock courses, the brick are set on edge; in soldier courses, they are set on end.

Header courses on the hot face of a wall are likely to spall less than stretchers, on account of the smaller area of the exposed sections. However, stretcher courses expose fewer joints than do headers. This is an advantage in any service where the joints tend to wear back more rapidly than the body of the brick. In walls built of standard 9-inch brick, the number of horizontal joints can be held to a minimum by the use of brick 3 inches thick.

The Types of Bond: Strength and stability are imparted to a wall by bonding or tying-in the brick through the use of various combinations of header and stretcher courses, and by off-setting or "breaking" the vertical joints. In brick masonry, the pattern obtained by the arrangement used to cause overlapping of the brick is called the "bond" of the brickwork.

The type of bond selected for any particular furnace construction will depend upon such factors as the design of the furnace, the thickness of the wall, the degree of necessity for gas-tight construction, the severity of operating conditions, and the ease of maintenance.

One of the most important considerations, in deciding upon the method of bonding, is the fact that the resistance of brick to crushing or deformation under load is less at high temperatures than at low temperatures. For example, any part of a high-duty fireclay brick which is heated above approximately 2250°F. has relatively low load-bearing capacity. The wall should be so bonded that stresses resulting from loads are transferred to the outer, cooler part of the wall when the inner, hotter portion loses its ability to sustain pressure.

Among the types of bond employed for laying the brick in furnace walls are the following:

1. All Brick are Stretchers. Brick walls one stretcher thick usually have least structural stability. Their chief use is in small furnaces, and in furnaces where the maximum amount of heat must pass through the walls.

Thin walls of excellent stability are built with double tongue and groove brick. (See page 507.)

2. Header and Stretcher Courses Alternate. This is probably the most common arrangement in industrial furnaces. Alternate header and stretcher construction, for walls of various thicknesses, and built with standard 9-inch brick, is illustrated by Figures 2, 3, and 4. Large 9-inch brick (9″ x 6¾″ x 2½″ or 9″ x 6¾″ x 3″) are used for breaking joints, for starting ends of walls, and for turning corners.

3. Most Courses Consist of Headers. This arrangement is often used advantageously in 9-inch and 13½-inch walls subjected to high temperatures and heavy loads and to slag attack, and is usually preferred for walls built of basic brick. Walls with this bond have the advantage of stability and of easy replacement, and the disadvantage, in 9-inch walls, that most of the expansion joints pass entirely through the wall.

4. The Courses Consist Mainly or Entirely of Headers on the Inner Face of the Wall and Mainly of Stretchers on the Outer Face. This bond is sometimes considered desirable when spalling conditions are severe. (See Figures 5 and 7.)

5. The Inner Face of the Wall Has Three or Four Stretcher Courses to One Header Course. (See Figure 6.) This arrangement is sometimes favored because the interior face of the wall can be repaired when necessary by tying-in a "skin wall" 4½ inches thick, but should not be used where there is danger of the stretcher courses falling into the furnace.

6. Composite Wall Construction, Consisting of Two or More Kinds of Brick, with Inner and Outer Courses Tied Together. (See Figures 7 and 8.) In various types of furnaces, it is common practice to build the enclosing walls of two or even three kinds of brick. Many such combinations are in common use. As examples, high-alumina brick may be backed up by high-duty fireclay brick; superduty or high-duty fireclay brick may be backed up by medium- or low-duty fireclay brick, or by insulating fire-brick. Usually, the more refractory brick of a combination should be used for tying-in courses.

7. Composite Wall Construction with Back-Up Courses not Tied to Inner Courses. This type of bond is desirable when the wall is constructed of different kinds of brick having marked differences in their rates of thermal expansion, and is especially desirable when the temperature gradient through the wall is such as to make an appreciable difference in the total amounts of expansion. (See Figure 9.)

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BONDING OF WALLS BUILT WITH BRICK OF STANDARD SIZES

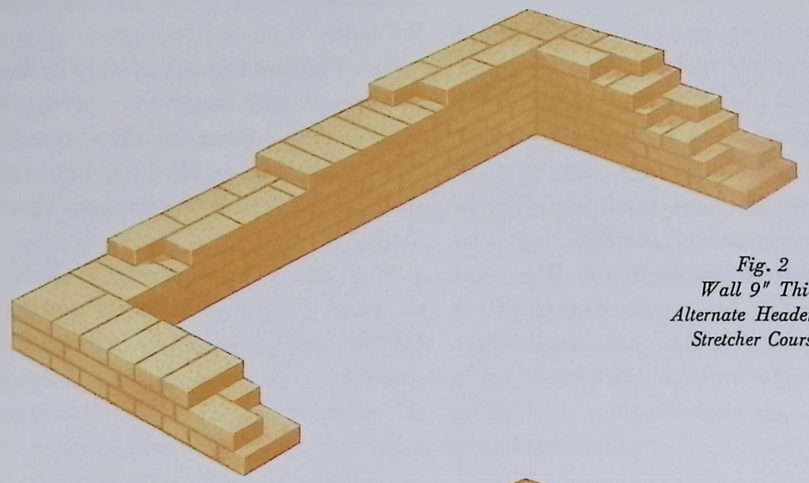


Fig. 2
Wall 9" Thick
Alternate Header and
Stretcher Courses.

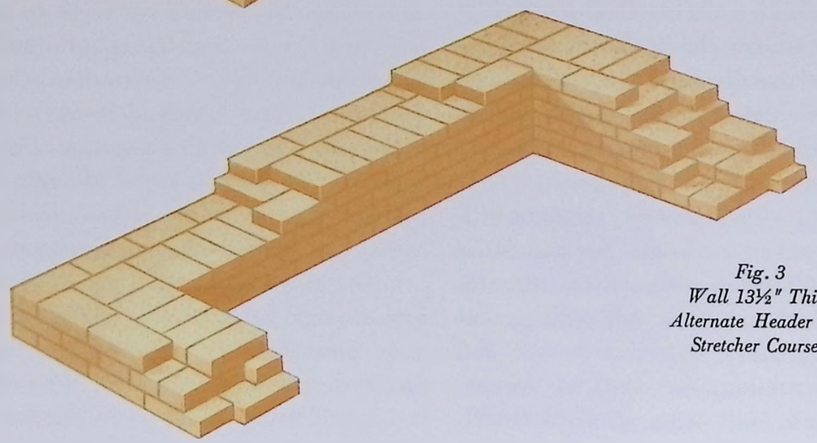


Fig. 3
Wall 13½" Thick
Alternate Header and
Stretcher Courses.

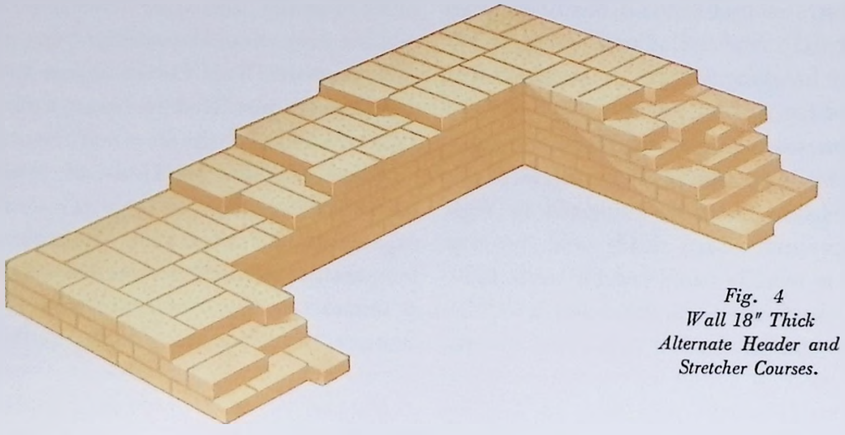


Fig. 4
Wall 18" Thick
Alternate Header and
Stretcher Courses.

BONDING OF WALLS BUILT WITH BRICK OF STANDARD SIZES

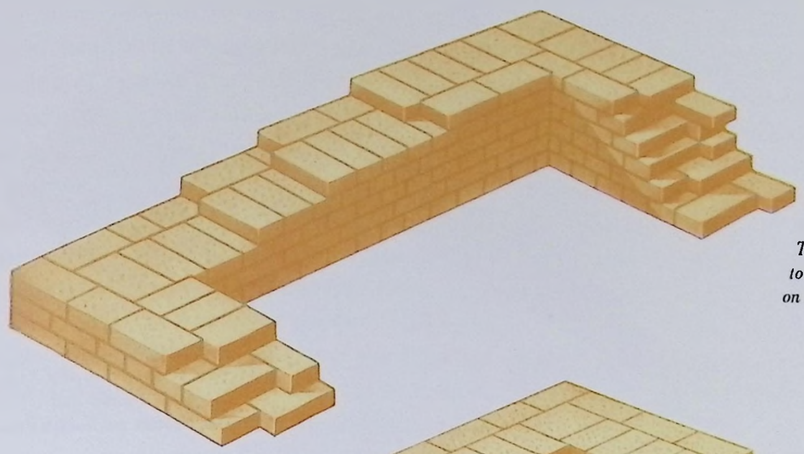


Fig. 5
Wall 13½" Thick
Three Header Courses
to One Stretcher Course
on Exposed or Hot Face.

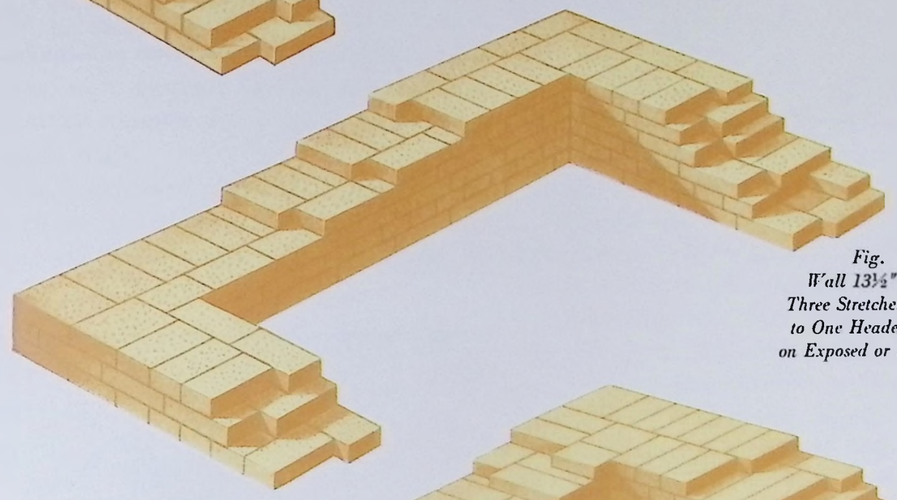


Fig. 6
Wall 13½" Thick
Three Stretcher Courses
to One Header Course
on Exposed or Hot Face.

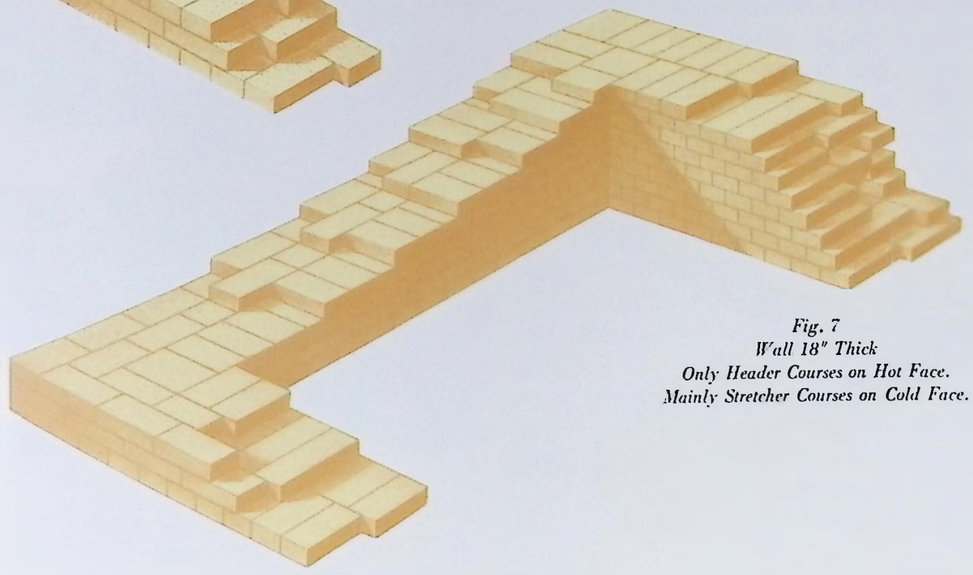


Fig. 7
Wall 18" Thick
Only Header Courses on Hot Face.
Mainly Stretcher Courses on Cold Face.

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BONDING OF WALLS BUILT WITH BRICK OF STANDARD SIZES

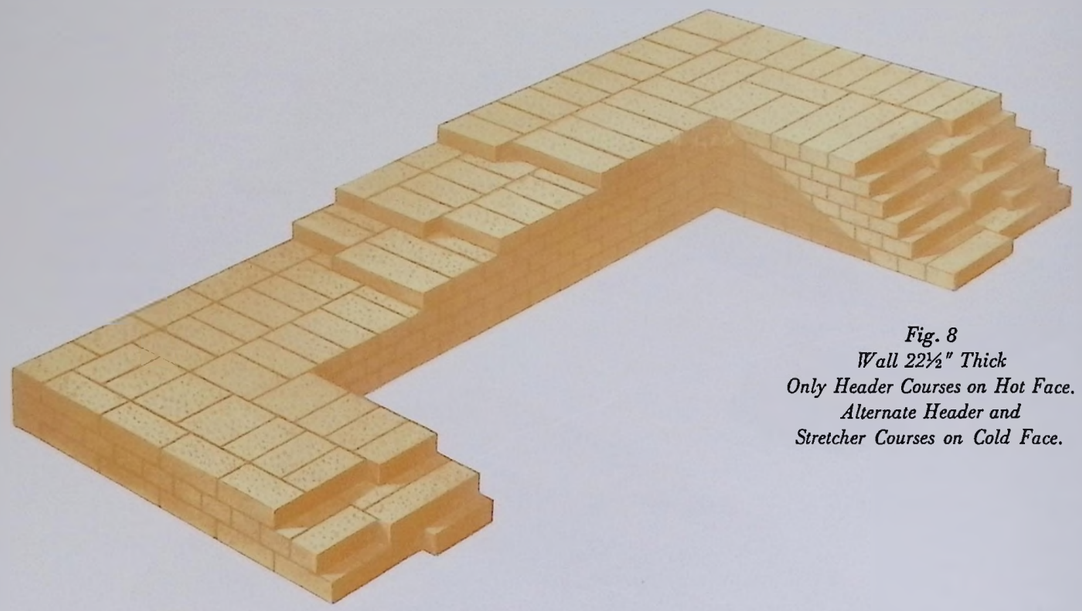


Fig. 8
Wall 22½" Thick
Only Header Courses on Hot Face.
Alternate Header and
Stretcher Courses on Cold Face.

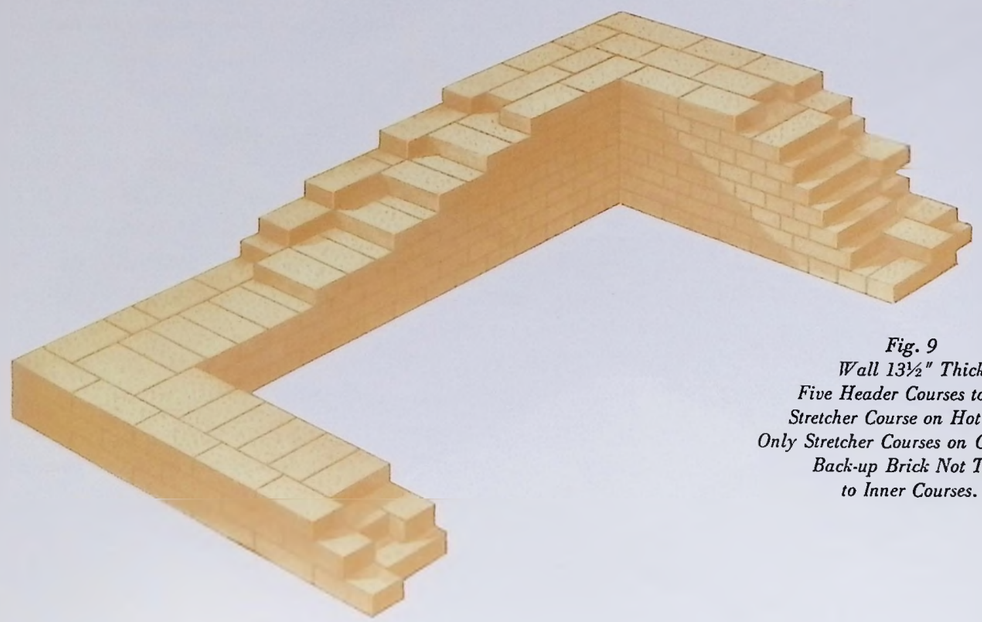
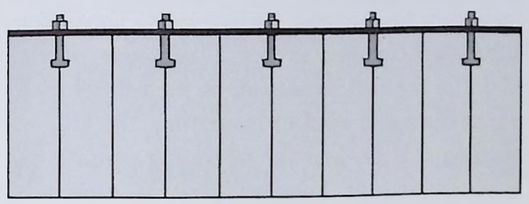


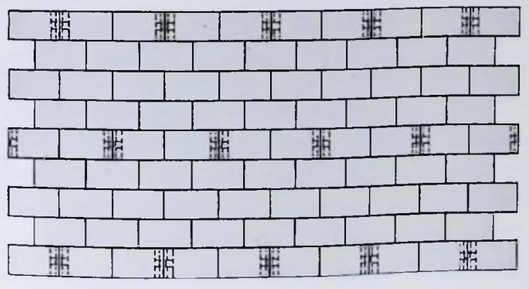
Fig. 9
Wall 13½" Thick
Five Header Courses to One
Stretcher Course on Hot Face.
Only Stretcher Courses on Cold Face.
Back-up Brick Not Tied
to Inner Courses.

Thickness of Walls: While great latitude is permissible in the thickness of walls, it should bear some relation to the height and unsupported length. In straight walls not tied to the binding at vertical intervals or otherwise supported, a 4½-inch thickness will serve for heights up to 3 feet; 9-inch thickness from 3 to 8 feet; 13½-inch thickness from 8 to 12 feet, and 18-inch or greater thickness for walls higher than 12 feet. Walls with an unsupported length more than one and one-half times their height should be somewhat thicker. Additional thickness may be desirable also if the brick are subjected to conditions which cause thermal spalling. The walls of cylindrical furnaces and stacks, with adequate backing, may safely be somewhat thinner for a given height than straight walls.

The thickness of suspended walls, or of walls which are tied to the binding at vertical intervals, will be determined by the method of support. If adequately supported, walls 30 feet or more in height may not need to be more than 9 or 13½ inches thick.



Plan View



Side View

Fig. 10. Reinforcement of Walls With Bonding Tile—Typical Construction.

Thickness of Joints: The thickness of joints depends on the character of both the brick and the bonding mortar and the necessity for preventing gas leakage, air infiltration, or slag penetration. The thickness of joints is influenced also by the kind of bond employed, and by the manner in which provision is made for the thermal expansion of the brick.

When there is no necessity for guarding against gas leakage or slag penetration, or for bonding the brick strongly together, they are sometimes laid without mortar. However, the use of mortar is generally desirable to level courses and to provide smooth bedding for the brick, or wherever gas leakage through the walls is to be kept to a minimum.

Brickwork laid with a heat-setting bonding mortar, such as finely ground fire clay, preferably should have thin joints. Mortars of this kind offer little resistance to penetration by slag and fumes. Fireclay mortar should be mixed to a creamy consistency and the brick should be laid with either dipped or poured joints, and rubbed or tapped into place to secure joints with as nearly brick-to-brick contact as possible. Joints which are made with an air-setting mortar of ample refractoriness and strong bonding properties, generally can be made somewhat thicker. Such joints should be completely filled.

A peculiar manner of fluxing in glass-tank caps, commonly referred to as "boring," can be avoided by using thin full-bedded mortar joints, except where provision must be made for expansion. The mortar material prevents the infiltration of volatile alkalies into the roofs of tanks operated under positive pressure. Unless the joint is completely filled with the mortar,

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the fluxing agent has access to the refractories in zones back of the exposed face.

Thermal Expansion Allowance: In the construction of a furnace, proper consideration should be given to the thermal expansion of the refractories, and allowance for expansion should be made as needed. Usually, the vertical expansion in walls is provided for by allowing them to move freely upward. Horizontal expansion of walls is provided for by means of vertical expansion joints. Compensation for transverse expansion of furnace roofs and bottoms under certain conditions may be made by release of tie rods.

The provision for expansion must be adequate, as insufficient allowance in some cases will cause pinch spalling. However, too great an allowance is undesirable, as it may cause structural weakness, as well as excessive leakage of gases or air infiltration.

Customary maximum allowances for thermal expansion of refractories used at high temperatures are given in Table I. As may be seen from the charts on page 302, the figures in Table I are based upon an assumed furnace temperature of 2600°F. or higher. The amount of expansion allowance for any particular case, is usually fixed by past experience. Frequently it may be lower than the figures given in the table because of lower operating temperatures, the bedding-in of joints, shrinkage of mortar in the joints, thermal expansion of furnace binding, stretching or letting out of the rods, or other causes.

In order to provide most advantageously for the thermal expansion of the refractories, it is frequently necessary to estimate the expansion of the steel binding of the furnaces. As shown in Figure 11, the expansion of steel over its usable temperature range is about three times that of fireclay brick.

TABLE I.

Thermal Expansion Allowances For Refractory Brick

In High-Temperature Service.

Type of Brick	Approximate Expansion Per Foot
Fireclay	3/32"
High-Alumina 50 to 80% Alumina	3/32"
90% Alumina	1/8"
99% Alumina	5/32"
Silica	5/32" to 3/16"
Magnesite and Magnesite-Chrome, Fired	1/4"
Magnesite-Chrome, Chemically Bonded	3/16"
Spinel-Bonded Magnesite-Chrome	3/16"
Chrome and Chrome-Magnesite, Fired	1/8"
Chrome-Magnesite, Chemically Bonded	7/32"
Forsterite	3/16"

Expansion Joints in Walls: The methods of making allowance for thermal expansion of refractory brick differ considerably, depending upon such factors as the dimensions of the wall, the thermal expansion of the refractories, the amount and kind of insulation, the kind of bonding mortar, and the operating conditions.

With high or long walls, it is especially important that sufficient provision for expansion be made. The thickness of the wall and the amount of insulation determine the temperature drop from the hot to the cold face and the corresponding difference in amount of thermal expansion. With most refractories, the expansion at the hot face is considerably greater than in the cooler parts of the wall. Silica brick actually attain nearly their full expansion at any point in a wall where the temperature is 1000°F. or higher, and about two-thirds of their expansion at any point where the temperature has reached 500°F.

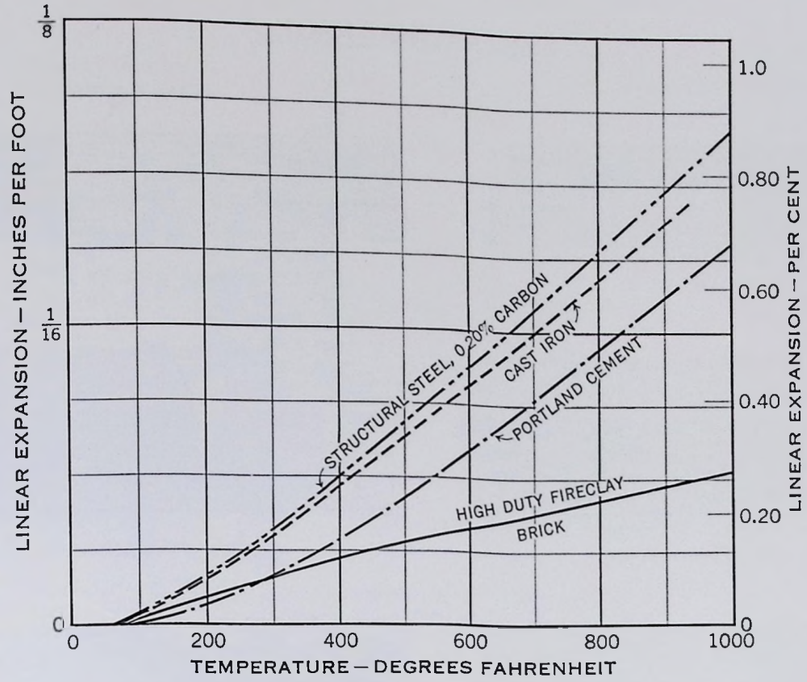


Fig. 11. Thermal Expansion of Steel, Iron, Portland Cement, and High-Duty Fireclay Brick.

The horizontal expansion joints through a wall which has a thickness of two or more brick may be staggered. In thin walls, expansion joints extending through from the inner to the outer face cannot always be avoided. For such cases, leakage of gas can be reduced to a minimum by packing the outside ends of open joints with a compressible inorganic packing material or by covering them temporarily with a loose course of brick.

When the mortar used is of the heat-setting type, the vertical expansion joints may be staggered as desired. However, if the brick are laid with an air-setting mortar, the expansion joints will not function properly unless those in successive courses are in vertical alignment. Brick which are required to move with respect to each other, as the material expands and contracts on heating and cooling should not be bonded together with an air-setting mortar.

Types of Expansion Joints: Individual preferences generally govern the choice of the kind of expansion joints. The types illustrated in Figures 12 to 16 are in common use and are regarded as satisfactory.

Expansion joints in basic brick walls of all-header construction on the hot face are sometimes made as shown in Figure 12.

For walls with header-and-stretcher bond, expansion allowance may be made as shown in Figures 13 to 15. The construction with staggered joints shown in Figure 13 may be used when the brick are laid either dry or with a heat-setting bonding mortar. Expansion joints at corners may be made as shown in Figures 14 and 15. When the brick are laid with an air-setting bonding mortar, vertical alignment of the expansion joints in successive courses is good practice. In the construction of a bridge wall, expansion spaces should always be pro-

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EXPANSION JOINTS

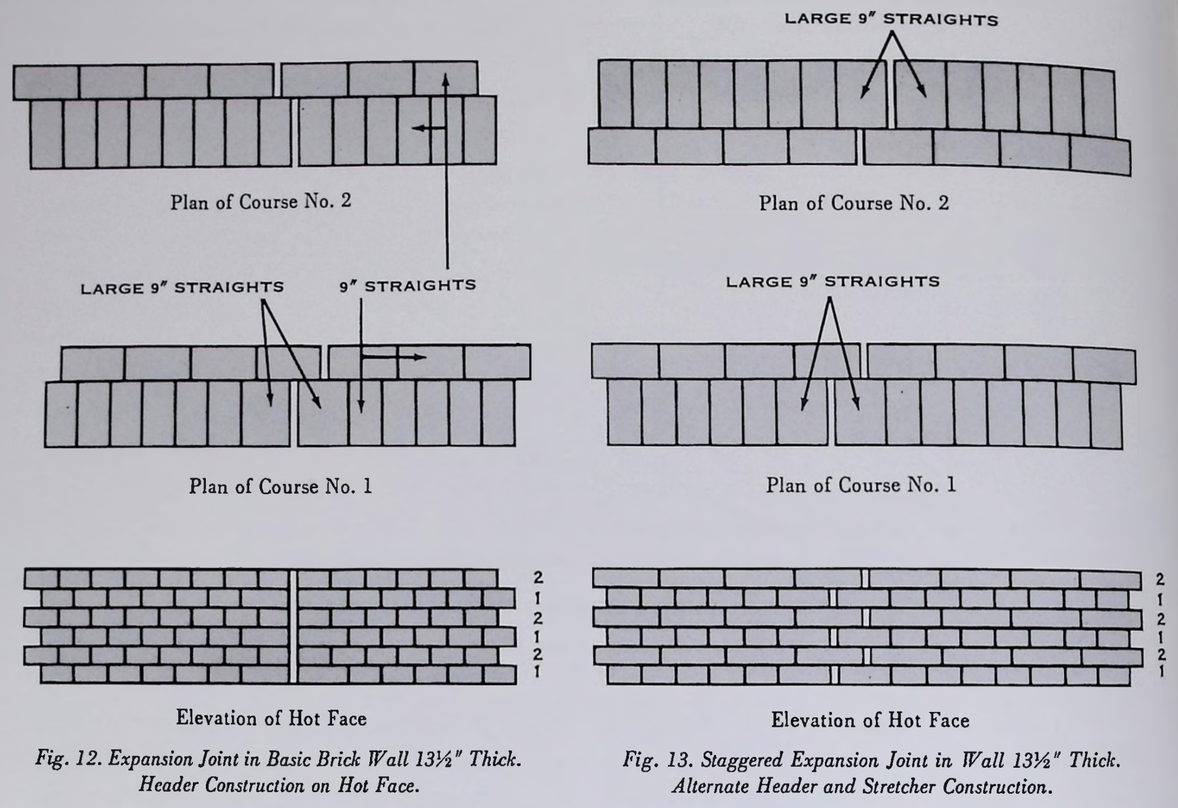


Fig. 12. Expansion Joint in Basic Brick Wall 13½″ Thick. Header Construction on Hot Face.

Fig. 13. Staggered Expansion Joint in Wall 13½″ Thick. Alternate Header and Stretcher Construction.

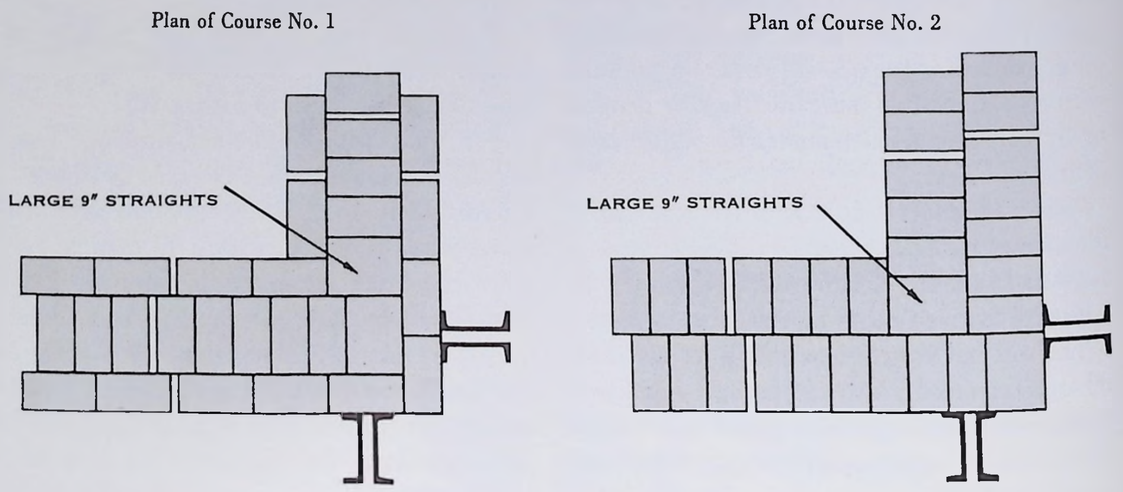


Fig. 14. Double Expansion Joint Near Corner of Wall 18½″ Thick. Alternate Courses Showing Header and Stretcher Construction.

EXPANSION JOINTS

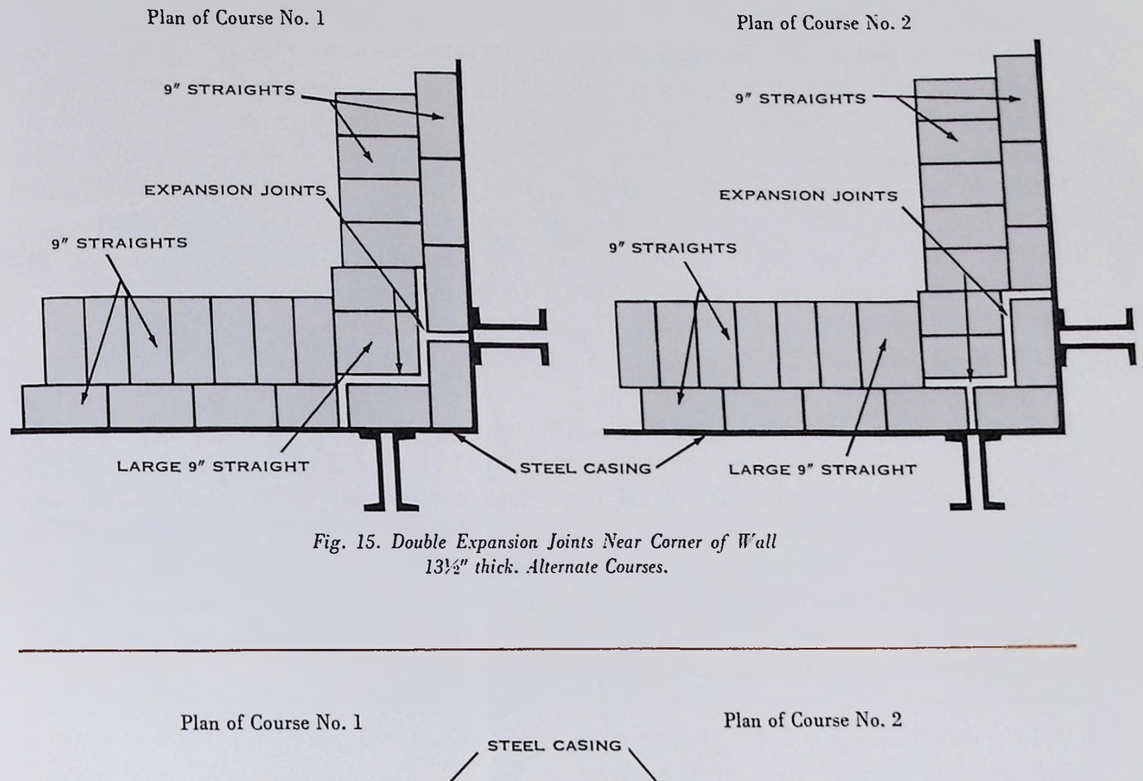


Fig. 15. Double Expansion Joints Near Corner of Wall 13½″ thick. Alternate Courses.

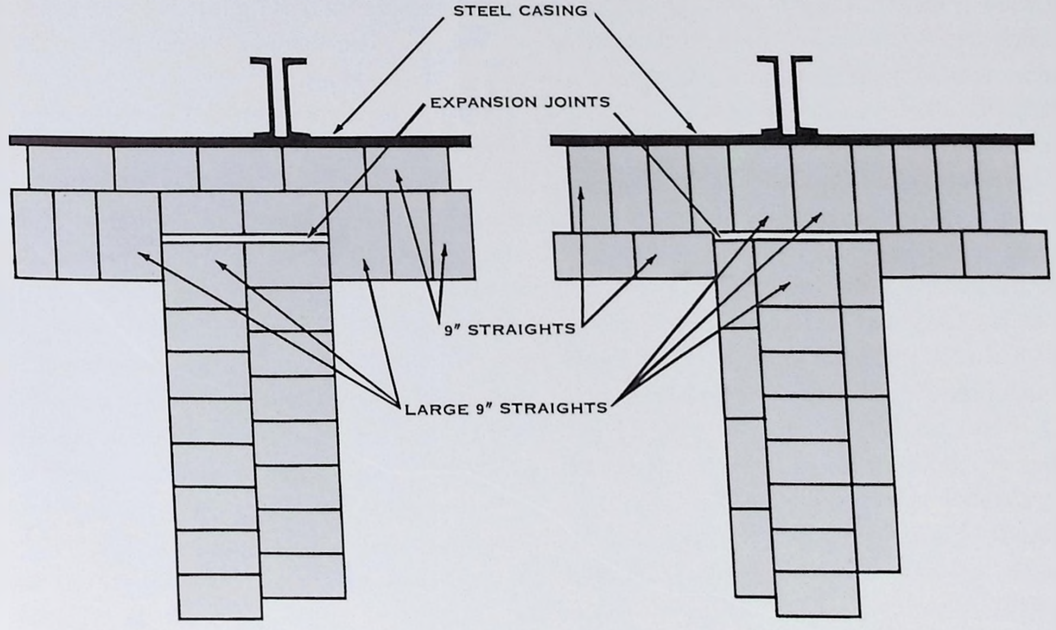


Fig. 16. Expansion Joint for Bridge Wall. Alternate Courses.

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vided at the ends of the wall. Typical construction is shown in Figure 16.

Expansion Joints for Fireclay Brick: In boiler settings having walls 15 feet or more in length, it is customary to provide staggered vertical expansion joints 4 to 6 feet apart. In other types of furnaces built of fireclay brick, the expansion joints are usually somewhat farther apart, especially if the walls are low. In tunnel kiln construction, for example, the expansion joints are usually 10 to 15 feet apart in the high-temperature section and 15 to 20 feet apart in the low-temperature section.

Expansion Joints for Silica Brick: In the silica brick walls of copper reverberatory furnaces, vertical expansion joints which consist of open spaces or slots extending from top to bottom of the walls are usually spaced 10 to 16 feet apart. In glass-tank construction it is customary to provide expansion joints in silica brick walls midway between the ports. In open-hearth furnace walls, probably the most common method consists in merely laying the brick somewhat loosely without definite expansion joints. Some operators prefer to make positive allowance for expansion at suitable intervals.

Expansion Joints for Basic Brick: Magnesite, chrome, and forsterite brick in straight walls are usually laid according to one of the following methods:

a. The brick may be laid dry, with sufficient space at each vertical joint or at 18- to 27-inch or wider intervals to take care of the expansion.

b. The brick may be laid dry with a heavy paper or cardboard filler in each vertical joint.

c. A method commonly used is shown in Figure 12. Expansion space is provided at 18- to 27-inch or wider intervals throughout the length of the wall, by means of joints filled with heavy corrugated paper or with cardboard. All other joints between brick are thin and are filled with mortar.

Relatively thin walls, particularly of basic brick, having both high thermal expansions and high thermal conductivities, can expand greatly out of proportion from the hot face to the outside. Except by a very slow rate of heating this can cause destructive distortion. By means of insulation, the excessive expansion differential between the two faces can be avoided.

In accordance with best practice, the expansion of basic brick in checker work is allowed for at the full rate, usually by means of a space at each joint between brick.

In lining horizontal cylindrical furnaces, such as copper converters, provision for expansion generally is made by means of a loose fill of grain magnesite between the brick lining and the shell; and in addition, expansion joints are made longitudinally between the brick at suitable intervals.

In rotary kilns, basic brick linings are laid with steel sheets in all joints between brick in a ring, and expansion joints ordinarily are made only between rings.

Provision for Expansion in Electric Furnace Roofs: In building a domed electric furnace roof with silica brick, adequate allowance for expansion is necessary. The amount of allowance for expansion varies from about 1/16 inch to 1/8 inch per foot. Proper functioning of the expansion joints is dependent largely upon the way in which they are made. They should be uniformly spaced, and preferably not over 1/16 inch to 1/8 inch thick. It is common practice to use soft wooden strips or heavy paper to form the expansion joints.

Where Expansion Joints are not Needed: In some furnaces, the brick are laid loosely enough to provide sufficient expansion space in the individual joints. In certain other furnaces no expansion allowance is made within the walls, but the brick are laid tightly against each other and the lining is allowed to expand as a whole. In such cases, the binding should be so designed that expansion of the brickwork can take place without the development of excessive stresses. In portable furnaces enclosed in rigid cast iron or structural steel casings, usually at least 1/2 inch of bulk insulation is placed between the brickwork and the shell, to take up the expansion. However, skewbacks in such furnaces should be placed against the casing.

In rotary kiln service, thermal expansion of the steel shell normally compensates sufficiently for the expansion of fireclay or high-alumina brick linings, even though they are laid tightly against the shell, without expansion allowance. Vertical cylindrical linings may be provided with a compressible backing to compensate for the horizontal thermal expansion of the annular rings of brick.

Filler Materials for Expansion Joints: Filler materials are used both to keep expansion joints free from mortar or other undesired materials, and to reduce gas leakage or air infiltration. The materials used are of two general types:

a. Combustible materials which usually are somewhat compressible.

b. Inorganic materials which are not combustible, but which are very compressible.

Combustible materials in common use include softwood strips, shavings, excelsior, sawdust, cardboard, corrugated paper, and other heavy paper. When wood strips are used, they should be removed if possible before the furnace is heated, especially with silica brick construction. Wood strips do not burn out at a low enough temperature to provide space for the expanding brick and are not easily compressed. When heated, wood does not begin to char below about 525°F. At this temperature, about two-thirds of the thermal expansion of silica brick has already taken place. Corrugated paper is extremely compressible.

Noncombustible filler materials include inorganic materials such as asbestos fiber, asbestos rope, rock wool, and diatomaceous earth powder. These materials have relatively low refractoriness, and should therefore be used only in outside joints. If used in parts of a furnace where the temperatures are high, they will melt and may damage the brickwork.

FACTORS AFFECTING THE LIFE OF REFRACTORIES

The behavior of refractories in service is governed by details of furnace design and construction, operating conditions, and the physical and chemical properties of the refractories.

When the life of a furnace lining is shorter than is regarded as normal, a study should be made of the governing factors, including furnace design and construction, selection of refractories, and operating practice.

Furnace Design: A change in furnace design, in some instances, will be the most effective means of securing longer life from the refractories. This may be the case, for example, when the volume of a combustion chamber is insufficient or the heat is too confined, when the walls are too thin or inadequately supported, when the amount of insulation is excessive, when hot brickwork is subjected to heavy load, or when ventilation or cooling of parts of the furnace obviously is desirable.

The combustion temperature of most fuels exceeds 3000°F. when they are burned rapidly with the amount of air theoretically required or with a slight excess. If the heat is liberated within an enclosed space, and if it is not utilized but is confined because of insufficient

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conduction and radiation, the refractories may be exposed to a temperature almost as high as the temperature of combustion. Under such service conditions, it may be possible to lengthen the life of the refractories appreciably by a change in furnace design which will prevent excessive confinement of the heat.

Brickwork exposed to high temperatures on two sides, without provision for ventilation, cannot be expected to give as long life as that which is heated from one side only.

The life of a brick wall or roof exposed to the action of an impinging flame may often be increased by a redesign of the furnace, by adjustment and control of the burners to secure a longer flame and avoid localized overheating, or by the use of brick of higher refractoriness and greater resistance to the prevailing destructive factors.

Proper size and placement of burners is important. When burners are placed too close to sidewalls, the refractories in the walls are subjected to localized high temperatures, and usually to the fluxing action of fuel ash. Back walls opposite burners should be placed far enough from the burners that they are beyond the zone in which heat is liberated most rapidly, and also beyond the range of flame impingement. A thin coating of high-temperature bonding mortar which will adhere strongly to the brick will reduce penetration by gases and by molten ash at least temporarily.

Ash deposited upon the openings of powdered-coal burners may deflect the flame and cause it to impinge upon portions of the brickwork with resultant fluxing and erosion.

The height of combustion chambers is often of great importance, as a small difference in roof elevation may cause a considerable difference in roof life. For example, the life of the combustion arch in a boiler setting has sometimes been lengthened by increasing its height above the grate.

High walls should always be supported with metal anchors, even when 18 or 22½ inches thick. Anchors prevent buckling and permit the use of thinner walls. Various methods of anchoring and suspending walls are in use.

Operating Conditions: Operation at greatly increased furnace output will necessarily impose more severe service upon the refractories. A lining material which is capable of withstanding the normal furnace temperature without fusion or appreciable softening may be badly damaged at higher operating temperatures. Refractories in intensely heated localized areas, even though the heating be of short duration, may be damaged considerably. At times when a greater output must be secured from a furnace than that for which it was designed, it may be necessary to rebuild the most vulnerable portions of the construction with materials which have higher refractoriness.

A change in the kind of fuel or in the nature of the charge will often cause a marked difference in the behavior of the refractory linings.

Rapid changes in temperature may cause spalling. This is particularly true in heating or cooling silica brick below 1200°F.

Effects of Stresses: In most cases, refractories can withstand relatively high compressive stresses up to a critical temperature, which varies for different types of refractories; above that temperature, their strength rapidly decreases. They have much lower resistance to transverse, shearing, and tensile stresses than to compression.

In spanning a wall opening or flue, a sprung arch is generally better than a flat tile, for the arch brick are under compression, while the lower face of the tile is under tension. Moreover, a tile spanning an opening between

parallel walls may break or spall, if the two walls are heated and cooled at different rates.

In a wall built of fireclay refractories, the hot ends of the brick may be somewhat pyroplastic, and unable to support a load, while at the same time the cooler portions of the brick may have many times the strength necessary to sustain the entire weight of the superimposed brickwork. The strength of most high-duty fireclay brick begins to decrease at about 1800° to 2000°F. Superduty fireclay brick retain their strength at somewhat higher temperatures.

The effect of the temperature gradient upon the strength of walls built of fireclay brick and subjected to high furnace temperatures is illustrated in Figures 17A, 17B, and 17C. In the cooler portion of the walls the brick are strong and rigid, while in the hottest portion they are pyroplastic and will deform if subjected to heavy pressure. In the figures, the temperatures which mark the limits of these portions or zones of the brickwork are approximate mean values, used merely as illustrations.

Figure 17A shows a section through a high-duty fireclay brick wall 13½ inches thick with a hot-face temperature of 2700°F. It is assumed that the pressure of the gas inside the furnace and that of the air outside the furnace are equal. Under these conditions the brickwork would be strong and rigid for a distance of about 10¾ inches from the cold face, while the remainder of the wall would be hot enough to deform under heavy pressure. However, the hot ends of the brick would not deform appreciably, since this slight softening of the wall would transfer the load to the cooler, stronger portion.

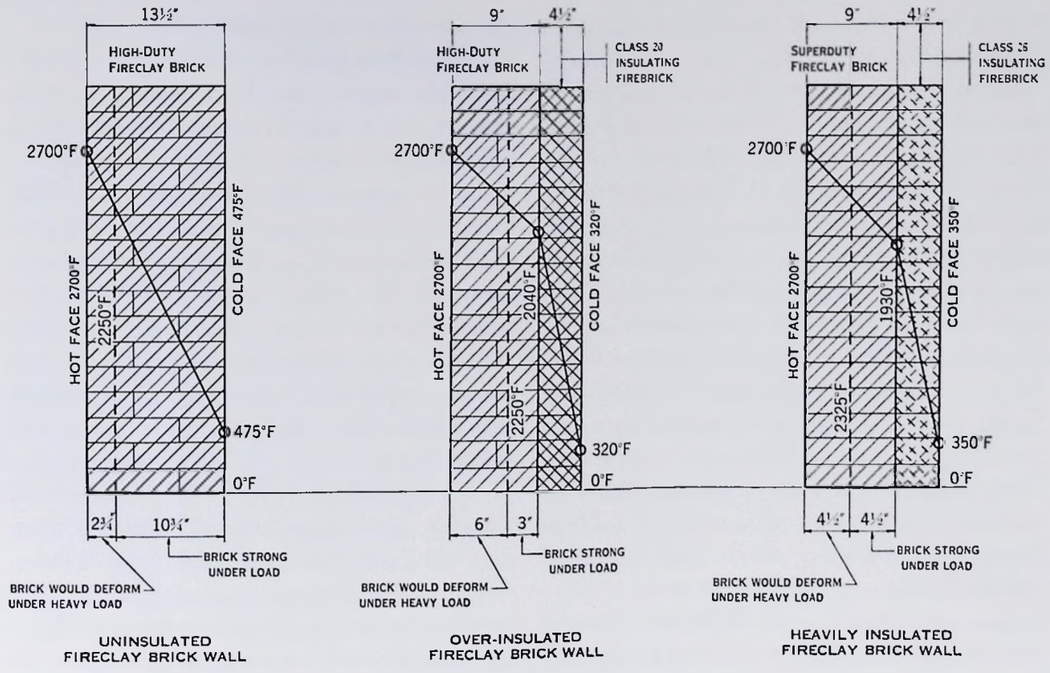


Fig. 17A *Fig. 17B* *Fig. 17C*

Fig. 17. Temperature Gradients Through Furnace Walls.

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Effects of Insulation: The loss of heat from the wall illustrated in Figure 17A would be about 1570 Btu per hour per square foot. A considerable proportion of this heat could be saved by insulating the wall. However, insulation can be excessive, as illustrated by Figure 17B, in which the fireclay brick in the outer 4½ inches of the wall are represented as having been replaced by insulating brick of class 20 (maximum working temperature 2000°F.). Under these conditions, the temperature at the interface between the insulating firebrick and the high-duty fireclay brick would be about 2040°F. The fireclay brick in this wall would be overheated, since they would be hot enough to deform under pressure for a distance of about 6 inches from the hot face, and would remain rigid for only about 3 inches of the 9-inch thickness. The wall might have insufficient structural stability, and could not be expected to give maximum service.

A considerable degree of insulation could be obtained by the method illustrated in Figure 17C, in which high-fired superduty fireclay brick are used instead of high-duty fireclay brick, and insulating brick of class 26 (maximum working temperature 2600°F.). The heat loss would be about 890 Btu per hour per square foot of wall. With this construction the interface temperature would be about 1930°F. About 4½ inches of the length of the superduty fireclay brick would remain rigid, and about 4½ inches would tend to deform under pressure. These conditions represent a heavy degree of insulation. A factor of safety could be provided by the use of high-alumina brick instead of high-fired superduty fireclay brick.

How can the safe maximum degree of insulation be determined for any particular installation? No definite answer of general applicability can be given to this question, because the answer depends upon various furnace operating conditions, as well as upon the properties of the particular refractory and insulating materials chosen. The following figures provide a rough guide to the maximum permissible temperatures in furnace walls which are not subjected to spalling, slagging, or abrasion, and into which hot gases are not forced by positive pressure. To provide a good margin of safety, the data are based on the assumption that the load upon brick may be as great as 25 pounds per square inch. Under these conditions, the *mean temperature* between the hot and the cold face of the refractory portion of the wall usually will not exceed approximately 2100°F. for hard-burned high-duty fireclay brick, 2200°F. for normally fired superduty fireclay brick, or 2250°F. for high-fired superduty fireclay brick. For lower pressure than 25 psi, these temperatures would be somewhat higher.

For mean temperatures higher than 2250°F., the brick which might be used include high-alumina, silica, silicon carbide, and some basic. High-alumina brick in walls may be subjected to a mean temperature of about 2300° to 3000° F. or a little higher depending on their compositions and strengths at high temperatures; conventional silica brick to about 2800°F., and superduty silica brick to about 2875°F. For long and high walls which are insulated, the use of suspended construction is generally good practice.

In most cases, an insulated furnace wall should be so designed that the insulating firebrick will not be subjected initially to its maximum working temperature, since the interface temperature rises as a wall wears thinner. Conservative practice suggests limiting the interface temperature to 100°F. or more below the maximum safe working temperature of the insulating firebrick, especially if the dense refractory portion of the wall is subject to wear.

This is not done under the conditions illustrated by Figure 17B, in which insulating firebrick of class 20 are shown exposed to an interface temperature of 2040°F. This temperature allows no margin of safety for the insulating firebrick. Should the fireclay brick portion of the wall wear thinner in service, the temperature at the interface would rise, possibly with detrimental effects upon the insulation. In the construction shown in Figure 17C, using insulating firebrick of class 26, the calculated interface temperature is 1930°F., which would not have a damaging effect upon insulating firebrick of class 26.

Insulation to Avoid Critical Temperatures: In addition to their other functions, insulating refractories under some conditions can be used to control the temperature gradient through furnace walls to avoid critical harmful temperature ranges.

(1) The critical temperature range for the decomposition of carbon monoxide gas into solid carbon and carbon dioxide gas is approximately 700° to 1100°F. Use of the proper insulation will move this temperature range out of the refractory brick and into the insulating firebrick. The latter must then be of a type which resists carbon disintegration.

(2) In certain metal chloride furnaces, the refractory linings may chlorinate and disintegrate at critical temperatures below or above that of the reaction temperature of the process. This effect may be largely avoided by using insulation to control the temperature gradient through the walls.

(3) "Boring" in glass-tank crowns can be reduced by insulating the silica brick with VEGALITE silica insulating brick. When this is done, the temperature of the silica brick crown throughout its entire thickness is higher than the condensation temperature of the volatile alkalies.

(4) The condensation of acid vapors, such as hydrogen chloride, on refractory-lined steel shells may corrode the shell very rapidly. By careful selection of the kind of insulation and application of the correct thickness to the outside of the shell, the temperature on the inside can be maintained above the critical dew point.

(5) In an oxidizing atmosphere, the presence of sulfur trioxide may combine or react with alumina in the refractory lining to form aluminum sulfate within a low critical temperature range. The formation of aluminum sulfate is usually accompanied by a volume increase and a subsequent loss in strength of the refractory lining. "Sulfating" can be avoided to a large extent by the use of insulation to reduce the temperature gradient through the lining, or to raise the temperature of the lining above that at which aluminum sulfate will form.

Charging Conditions: The lining materials of a furnace are subject to damage during charging operation as a result of excessive temperature change, mechanical abuse, impact and abrasion by the charge, and the washing action of any hot metal in the charge. Damage to furnace walls and hearths is often caused by tools used for manipulation of material placed in the furnace for heat treatment. Other frequent causes of damage to the linings are vibration from nearby hammers or other machinery, pulsating flames, and gas explosions.

Cleaning: Cleaning operations are sometimes very severe, as for example when a furnace is quenched with water to loosen scale, slag, or clinker. The necessity for quenching sometimes can be avoided by the use of a refractory to which these materials do not readily adhere.

Water Cooling: In a furnace with water-cooled parts, any water leaks which develop should be given prompt attention because of their harmful effects upon the refractories.

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SUGGESTIONS REGARDING DETAILS OF CONSTRUCTIONS

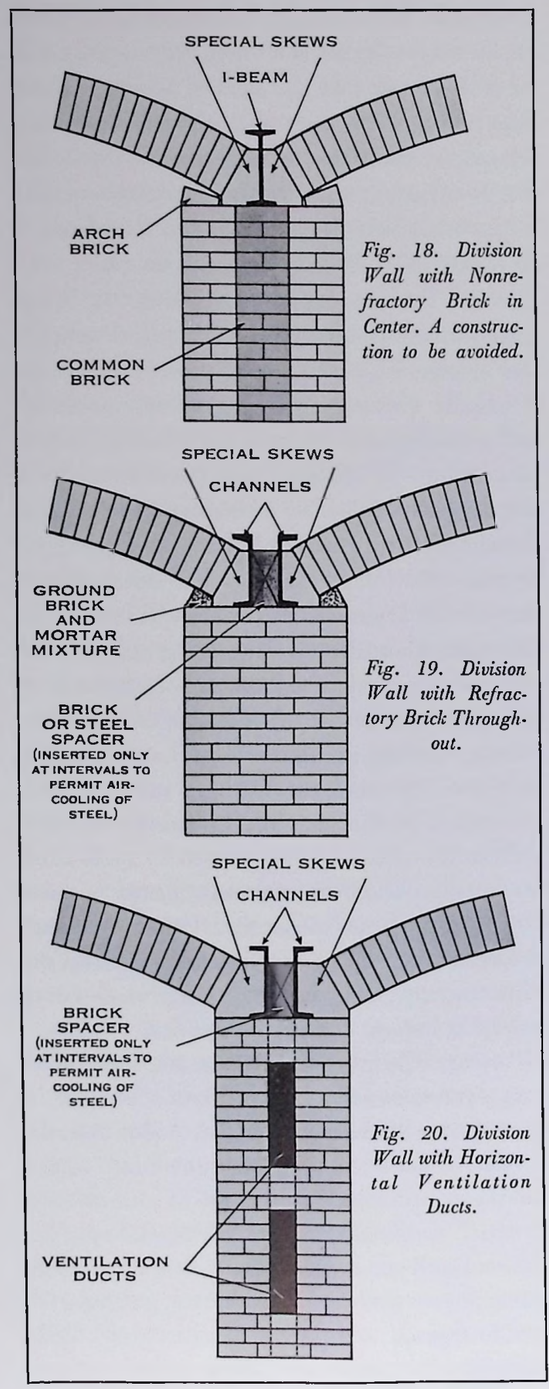


Fig. 18. Division Wall with Nonrefractory Brick in Center. A construction to be avoided.

Fig. 19. Division Wall with Refractory Brick Throughout.

Fig. 20. Division Wall with Horizontal Ventilation Ducts.

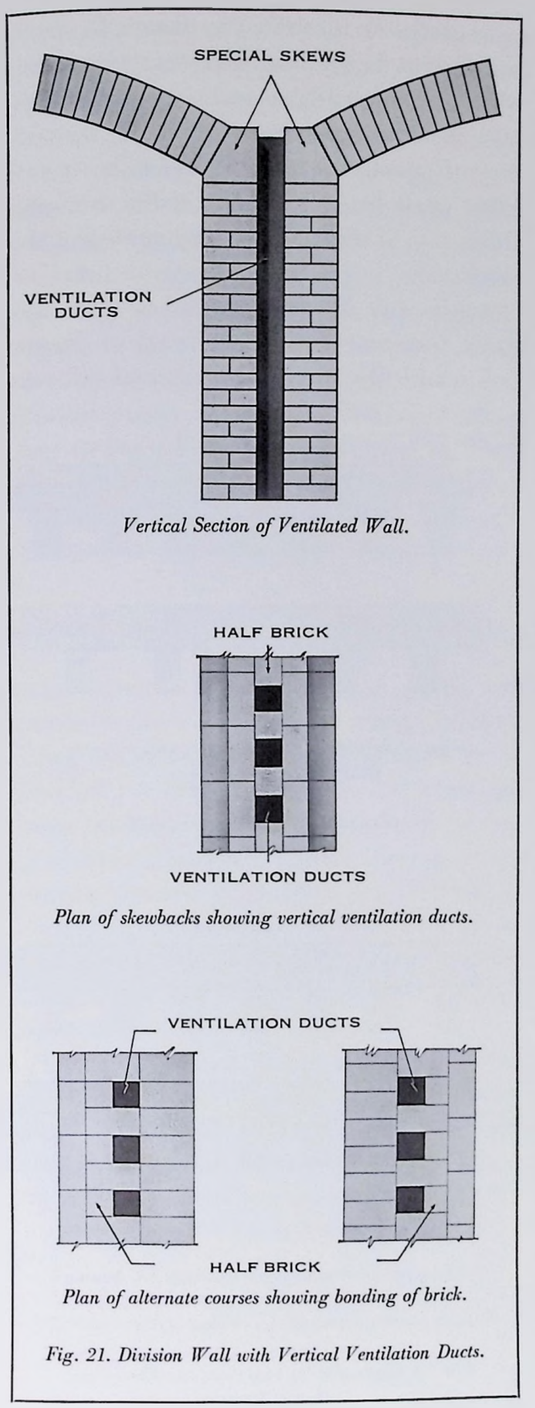
Division Walls: For high-temperature service, it usually is best practice to build all furnaces as individual units. For less severe temperature conditions, however, it may be advantageous to build two or more adjoining furnaces of certain types as a composite structure divided into two or more parts by division walls. The composite structure requires less space, costs less for brickwork and metal binding, and has lower heat loss by radiation and convection.

The mean temperature of the sidewalls of a furnace is normally much lower than the temperature at which the furnace is operated. However, division walls are heated on both sides and if not ventilated, attain practically the full furnace operating temperature throughout.

At high operating temperatures, such walls may deform unless built of material having higher refractoriness than that which is adequate for uninsulated outside walls. For example, solid division walls, supporting appreciable weight between furnaces operated at about 2200°F., should preferably be built of superduty fireclay brick, even if high-duty brick function satisfactorily in the outside walls of the furnaces.

If brick of inadequate refractoriness are used in the center of a division wall such as that shown in Figure 18, they may soften or completely melt at relatively low temperatures. The construction illustrated in Figure 19, in which the wall is built of refractory brick throughout, permits operation at higher temperatures.

In the construction illustrated by Figure 18, the skewbacks rest against an I-beam. With this construction, repairs can be made to one arch independently of the other; however, there is danger that the I-beam may become overheated. In the wall shown in Figure 19, the skewbacks are supported by two channels



Vertical Section of Ventilated Wall.

Plan of skewbacks showing vertical ventilation ducts.

Plan of alternate courses showing bonding of brick.

Fig. 21. Division Wall with Vertical Ventilation Ducts.

separated by brick or steel spacers. The steelwork will not become overheated since the spacers between the channels are inserted only at required intervals, and for the greater portion of their length the channels are exposed to the air on one side.

Figure 20 shows a ventilated center wall, which is cooled to some extent by means of air circulating through horizontal ducts. Continuous flow of cooling air is insured by the stack action of a short vertical flue which connects the horizontal ducts at one end. The other end of each of the ducts is wholly or partly open to the outside air.

Figure 21 shows a ventilated wall with vertical air ducts which are interconnected at the bottom.

Suspended Walls and Arches: For many kinds of service, the use of suspended arches and walls is highly economical although the first cost is greater than that of sprung arches and solid walls. Various types of suspended constructions are available from the designs of several engineering companies.

Suspended construction affords certain definite advantages. Repair costs are generally lower, both because of the ease with which brick can be removed and replaced, and because replacement can be limited to the brick which are actually damaged. In some cases there is the further advantage in that hot repairs can be made without loss of production.

In suspended construction, the refractories carry relatively light loads, and therefore have less tendency to deform at high temperatures than in other arch and wall structures. Definite allowance can be made conveniently to take care of thermal expansion, both horizontally and vertically, to avoid stresses which can cause breaking. Provision can easily be made for ventilation, for water-cooling, or for insula-

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tion, as conditions may require. Suspended construction permits a latitude in design of furnaces which otherwise would not be possible. One example of this is the greatly increased spans of many suspended arches, as compared with the spans of sprung arches.

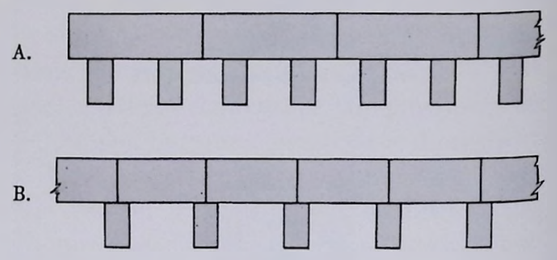
If the weight of the roof is supported by suspended construction, the top courses of the walls may necessarily be tied to the furnace binding by metal hangers or clips to keep the walls from bowing inward.

Checker Settings: Among the chief requirements of refractory brick in checker settings are uniformity in size, low porosity, high mechanical strength, resistance to deformation under load, and resistance to attack or build-up by carry-over in the furnace gases, such as alkali fumes and dust, iron oxide, or other materials. Also important for maximum efficiency are resistance to wetting and glaze formation, and durability. The heat capacities of checker brick are directly proportional to their bulk densities and specific heats. The rates of heat absorption and release involve these two factors, together with the thermal conductivity and emissivity.

Numerous designs of checker settings are in general use. Some of these are constructed of standard sizes of brick, while others employ special shapes. Among the designs of checker settings which require only standard sizes are those illustrated by Figures 23 to 28.

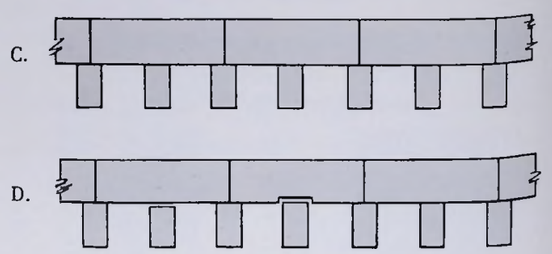
In designing a checker setting with standard sizes, as for example 9 x 4½ x 3-inch or 13½ x 4½ x 3-inch straights, it is not always possible to obtain full bearing as shown in Figures 25 and 26. In most cases, the best arrangement is the two-point support, as illustrated by sketches A and B, Figure 22. An undesirable feature of the three-point setting is the practical difficulty of placing the three supports on precisely the same plane. As illustrated by sketch D, if the mid-support is too low, it has no supporting effect and results in an actual two-point support of wider span than desired. If the mid-support should prove to be too high, it will either cause bending stresses in the overlying checker, or it will require some cutting of the checker.

Regenerator checker systems of glass furnaces commonly comprise a range of designs and involve the use of a number of different



A and B illustrate settings with two-point supports. Recommended constructions.

In setting A the span is less than in B—a desirable feature.



C and D illustrate settings with three-point supports.

C. All supports on same plane and have full bearing.

D. Supports not on same plane, causing defective bearings.

Fig. 22. Illustrations of Two-Point and Three-Point Checker Support.

kinds of refractories, even in a single setting. For example, the checkers opposite the hottest ports may consist entirely of one kind of basic brick or of a combination of superduty fireclay or high-alumina brick in the lower courses with the basic brick above. Under adjoining ports, basic brick may not be needed. In the coolest part of the regenerator, superduty fireclay brick may be adequate and provide an appreciable margin of durability in relation to the rest of the checkers.

Recuperators: Another important method of heat-saving is by means of recuperators. These are refractory brick structures in which are set rectangular or round hollow tile with thin walls. The tile are aligned in either a horizontal or a vertical position in such manner as to form a series of parallel flues or tubes. The hot waste gases flow in one direction in flues between or within the hollow tile. In doing so, they give up a portion of their heat by conduction through the refractory walls of the tile, to air flowing through or around them. The air being heated flows constantly and always in the same direction through the recuperator to the place where it is needed for combustion.

The important physical properties of recuperator tile are good thermal conductivity, close tolerance workmanship, adequate refractoriness, and durability on exposure to various factors such as fluxing agents, surface accretions, and detrimental actions of gases.

HEATING UP THE FURNACE

A new furnace should be heated slowly, with provision for a considerable volume of circulating air, since the formation of steam in the pores of the brick or in the mortar joints may cause damage to the brickwork. It is best practice to dry out the furnace thoroughly at a temperature not over 250°F. for 24 hours or longer, depending upon the size of the structure, and to avoid raising the furnace temperature above 400° to 600°F. until all steaming has ceased.

Careful drying of linings built of refractory brick containing magnesia and some of its compounds is especially important in order to prevent the formation of entrapped steam. These refractories generally are susceptible to hydration of the magnesia by water vapor or steam under pressure.

A flame which impinges upon the brickwork during the heating-up period may cause rapid local expansion with consequent spalling. Special care should be exercised in the heating of silica brick and basic brick because of their tendency to spall when subjected to rapid changes in temperature.

In low-temperature furnaces, it is often good practice to subject the structure to an initial heating, for a short period at a higher temperature than that required for operation. This preliminary heating develops the ceramic bond of the mortar material in the joints, and increases their mechanical strength.

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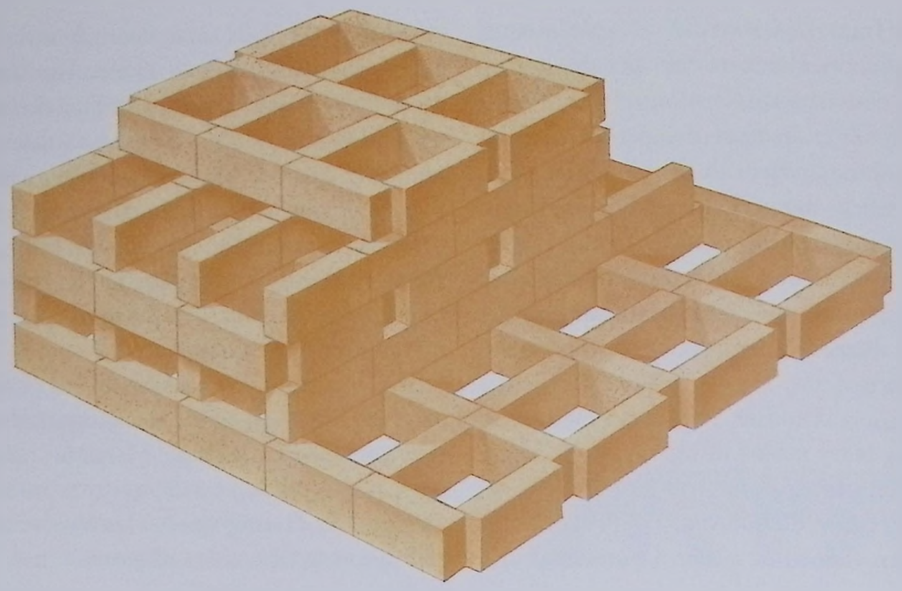


Fig. 23. Alternate Chimney and Open-Flue Checker Assembly—9" x 4½" x 2½" or 3" Straights.
Vertical Openings for 2½" Brick, 9" x 6½"
Vertical Openings for 3" Brick, 9" x 6"

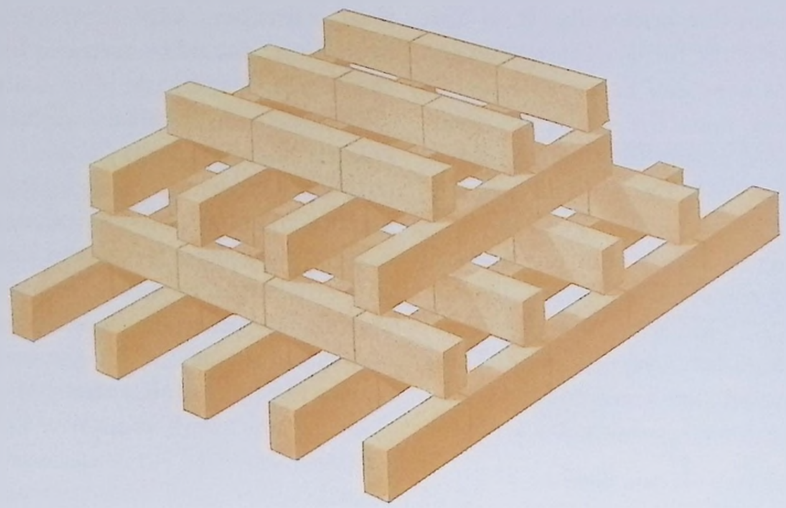


Fig. 24. Open-Flue Checker Assembly—9" x 4½" x 2½" or 3" Straights.
Vertical Openings for 2½" Brick, 6½" x 6½"
Vertical Openings for 3" Brick, 6" x 6"

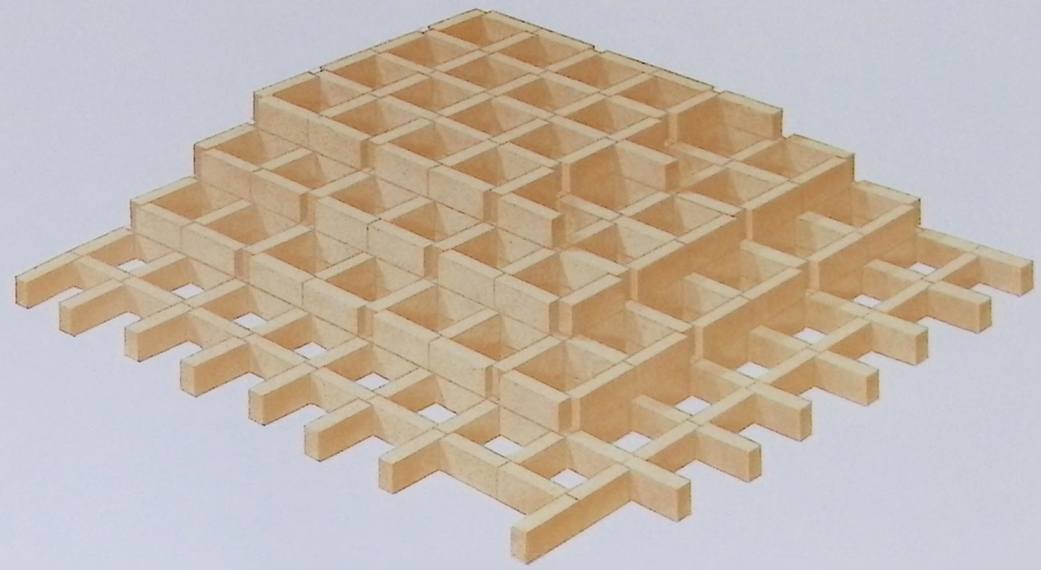


Fig. 25. Chimney Flue Checker Assembly—9" x 4½" x 2½" or 3" Straights.
Vertical Openings for 2½" Brick, 7¾" x 7¾"
Vertical Openings for 3" Brick, 7½" x 7½"

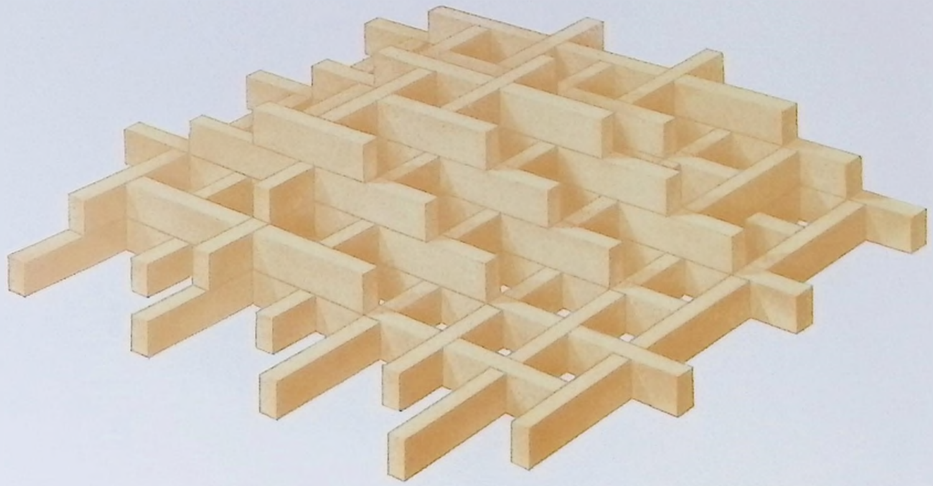


Fig. 26. Basket Weave Checker Assembly—18" x 6" x 3" Straights.
Vertical Openings, 7½" x 7½"

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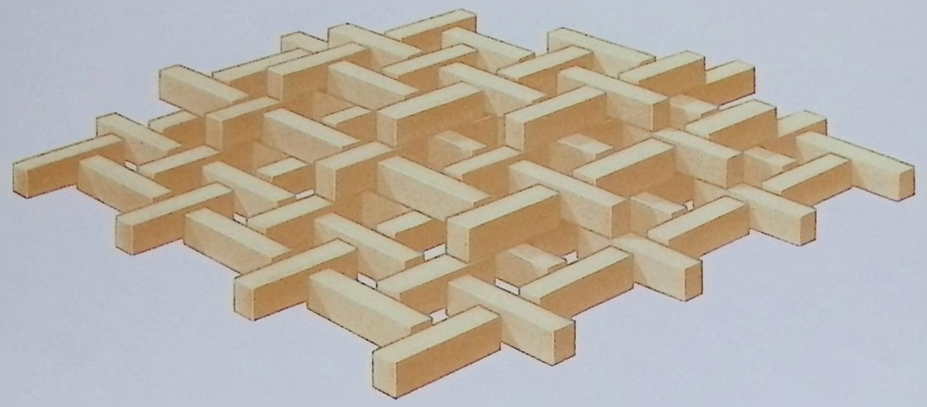


Fig. 27. Open Basket Weave Checker Assembly Using 13½" x 4½" x 3" Straights. Vertical Openings 5½" x 5½" to about 8½" x 8½"

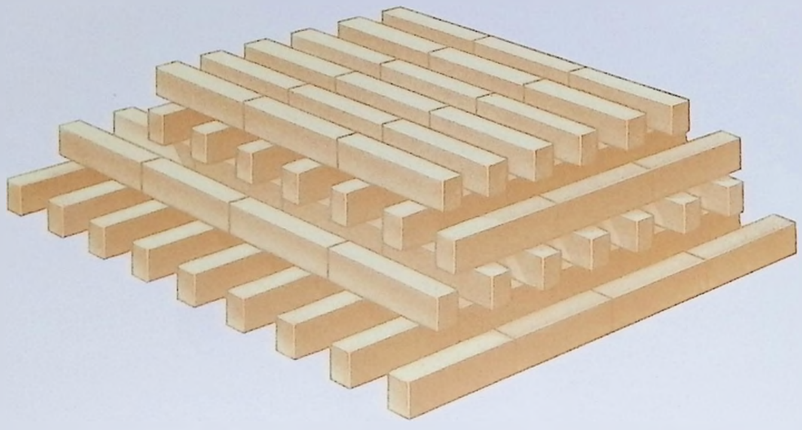
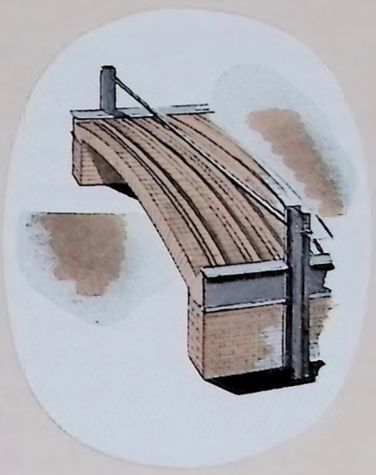


Fig. 28. Open Flue Checker Assembly Using 13½" x 4½" x 2¼" Straights. Vertical Openings 4¼" x 4¼"



SPRUNG ARCHES

FOR FURNACES

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FURNACE ARCHES

Arches form the roofs of furnaces, of combustion chambers, and of flues; they span wall openings; and they are sometimes used to support the weight of superstructures such as walls and checkerwork. In furnace construction, most arches are built of refractory brick; some are built of monolithic material.

In a true arch, each block or structural unit has a shape which is determined by the design of the whole. The arch is not self-supporting until all the structural units required to bridge the span between supports have been fitted together. The joints between brick are radial. At each end of an arch there are masonry units known as skewbacks, with sloping faces from which the arch rises or "springs."

An arch supported entirely by skewbacks is known as a "sprung arch," in contrast to "suspended arches" which are held in place by overhead supporting members and may be arched, flat, or corbeled. Suspended construction is not discussed in this chapter; it is commented upon briefly on page 233.

A sprung arch exerts upon its skewbacks not only the downward vertical force of its own weight and the weight of any loads carried by it, but also an outward or horizontal force. The vertical stress may be carried by steel beams; sometimes it is carried by the furnace walls, although usually this is not the best construction for furnace roofs.

The horizontal component of the arch stress also must be resisted, as otherwise the skewbacks would slide outward and deprive the arch of its support. The horizontal thrust of a roof arch is transmitted through the skewbacks to a steel supporting system known as the furnace "binding." The outward thrust of flue arches below ground is frequently supported by concrete outer walls backed up by earth or rock. In arches spanning wall openings, the stresses are supported by resistances within the wall.

SPRUNG ROOF ARCHES

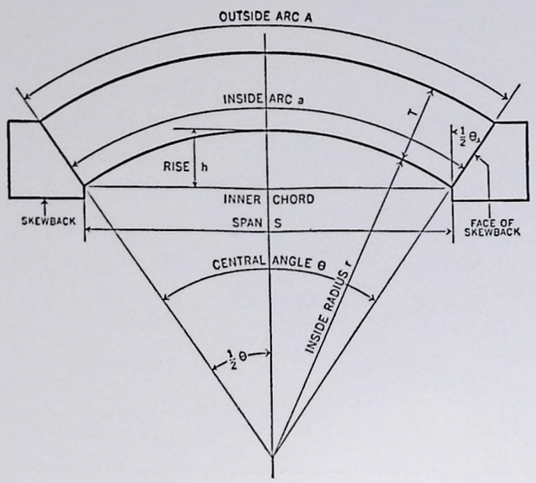


Fig. 29. Elements of Simple Sprung Arch.

Sprung-arch roofs of furnaces are most commonly formed by combinations of refractory brick shapes supported by skewbacks. As shown in Figure 29, a cross-section taken at right angles to the axis of the arch usually consists of a segment of a circular ring in which the outer and inner arch surfaces are represented by arcs of concentric circles, and in which the inner chord is horizontal.

The furnace binding consists of (1) horizontal buttress beams placed lengthwise of the furnace directly back of the skewbacks; (2) vertical beams known as "buckstays," spaced at intervals along the furnace walls, and generally with their lower ends set in a concrete foundation; and (3) horizontal members consisting of tie rods, I-beams, or channels, which extend across the furnace above the roof, and connect the upper ends of opposite buckstays.

The sloping surface of a skewback brick is termed its "face." The deviation of the face from a vertical plane is known as the "slope" of the skewback. The "rise" of an arch is the distance between the inner chord and the inner arc of the arch at their centers.

The stability of the arch depends upon its rise and thickness, upon the weight, strength, and thermal properties of the material of which it is composed, and upon the strength, placement, and structural support of the skewbacks.

Usually, in the design of a furnace arch, the span and the thickness are established first. When, in addition, the rise has been decided upon, all the other arch dimensions, as well as the slope of the skewback, are definitely fixed and can be calculated. The arch dimensions may be calculated in simple manner by use of the "arch constants" given in the table in the later chapter on page 529.

RISE OF A ROOF ARCH

The rise is commonly expressed either directly in inches per foot of span, or indirectly in terms of the central or included angle. In a simple sprung arch, when either of these two values is known, the other is definitely fixed.

Experience has shown that a simple roof arch should have a rise of not less than about 1 inch nor more than about 3 inches per foot of span. For any particular furnace, the rise will depend upon the operating conditions, the furnace design, and the type and class of refractories used. A roof which is too flat will be subject to excessive stresses; one which is too steep will tend to buckle.

A roof built of fireclay brick will usually be given a rise of not less than 1½ inches nor more than 3 inches per foot of span. The higher figure is to be preferred for roofs which are subjected to extremely high temperatures or to conditions of soaking heat.

Silica brick roofs, in furnaces of wide span operated at high temperatures, rarely have a rise of less than 1 inch or more than 2 inches per foot of span. They usually have a somewhat lower rise than fireclay brick roofs. Basic brick roofs of open-hearth steelmaking furnaces usually are given a rise ranging from 2¼ to 3 inches per foot of span.

Insulating firebrick have much lower resistance to compression than fireclay or silica brick; therefore, roofs built of insulating firebrick are given a rise of 2 to 3 inches per foot of span. Conditions of stability, however, require that the rise should be not more than 3 inches per foot of span.

A logical standard for many applications is the arch with a central angle of 60 degrees, corresponding to a rise of about 1⅝ inches per foot of span. This 60-degree arch meets all the normal requirements for strength and stability. The number of brick required for such arches can be calculated easily and quickly, since the inside radius is equal to the span, and the arch includes exactly one-sixth of a circle.

When the skewbacks are built with standard 9-inch featheredge brick of the 2½-inch series, a rise of 1½ inches per foot of span is obtained; and when standard 9-inch side-skew and end-skew brick of the 2½-inch series are used, the rise is 2⅝ inches per foot of span. Both these constructions are illustrated in a later chapter entitled "Sizes and Shapes," on page 508.

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ROOF THICKNESS

Factors which determine the most desirable thickness of a roof arch are the span, stability considerations, the type of refractory, the strength of the brick at operating temperatures, the kind of service, the permissible heat loss, and the normal life of the roof as related to that of the rest of the furnace structure.

In general, the thickness of a roof arch should be not less than 4½ inches for spans up to 5 feet, 9 inches for spans between 5 and 12 feet, and 12 or 13½ inches for spans from 12 to about 20 feet. For low-temperature operation the thickness may be somewhat less, and for roof arches subjected to severe corrosive action the thickness may be somewhat greater.

The thickness of a silica roof arch over a high-temperature furnace of wide span usually ranges from 12 to 22½ inches, depending upon the particular application. The thickness is rarely less than 0.05S, and generally not less than 0.06S, where S represents the span. Stress considerations suggest that such roofs should preferably be not thicker than about 0.06S for a rise of 1 inch per foot of span, about 0.085S for a rise of 1.25 inches per foot of span, or about 0.10S for a rise of 1.5 inches. For rises greater than 1.5 inches per foot of span, the maximum practical limit is about 0.10S.

If a roof arch is relatively thick and its rise is low, excessive stresses may develop unless care is taken to compensate in some manner for the expansion of the brick which occurs on heating. In some constructions, the abutments are so designed that they yield sufficiently to compensate for this expansion or the skews can be adjusted by loosening tie rods.

Table II.

TYPICAL DIMENSIONS OF BRICK FURNACE ROOFS

Kind of Furnace	Kind of Brick	Type of Roof	Typical Span	Typical Rise	Typical Rise Per Foot of Span	Typical Thickness	
						Roof	Ribs
Copper							
Reverberatory Smelting	Silica	Bonded	29′ 0″	36½″	1.26″	20″	..
Anode and Wirebar	Silica	Bonded	16′ 0″	18″	1.12″	15″ to 20″	..
Glass Tanks							
Container Glass	Silica	Bonded	21′ 0″	33½″	1.61″	12″ and 13½″	..
Flat Glass	Silica	Bonded	30′ 0″	48¼″	1.61″	13½″ and 18″	..
Steel							
Basic Open-Hearth	Silica	Ribbed Ring	20′ 6″	33″	1.61″	15″	18*
	Silica	Bonded	20′ 6″	36″	1.75″	13½″ to 18″	..
	Basic	Ring	20′ 6″	46½″	2.25″	12″	..
	Basic	Ribbed Ring	20′ 6″	46½″	2.25″	12″	15*

* Typical number of courses between ribs, 4.

SELECTION OF BRICK SIZES FOR THE ARCH

Furnace arches formed of brick consist either of tapered brick only, or of tapered brick used in combination with straights. The tapered brick employed are standard sizes or special shapes of wedge, arch, or key design. Wedge brick and sometimes key brick are used for wide spans; wedge brick or arch brick for spans which are relatively narrow.

Construction of an arch with units all of the same size and shape generally would require the use of special shapes. In order to obtain a required radius with standard brick sizes, it is usually necessary to use a combination of tapered and straight brick, or of two tapered brick having different slopes. If the proportion of straight brick in an arch is too high, the arch cannot be properly keyed, and lacks stability. In arches having relatively wide spans, a more desirable ratio of straight to tapered brick is obtained with standard sizes 3 inches thick than with those of 2½-inch thickness.

Tables showing the quantities and kinds of brick for arches of various rises and spans are given on pages 561 to 576.

ABUTMENTS

The supports or abutments of a roof arch consist of two parts: first, the brick skewback, and second, a horizontal steel member or "buttress" which supports the skewback. The buttress may be either a channel, an angle, or an I-beam. It is protected from the effects of excessive temperature by the brickwork. The abutments must not only support the cold thrust of the arch, but they must also withstand additional horizontal stresses due to thermal expansion of the brick. The vertical load may be supported either by the abutments or the walls, depending on the design.

Solid support for the skewbacks, to withstand the arch stresses, is very important. Movement of the skewbacks may result from insufficient strength or rigidity of the metal binding, or from overheating of the binding. Skewbacks resting upon sidewalls may sag because of softening or wearing away of the sidewalls, or because of defective or inadequate foundations.

SKEWBACKS

The skewbacks may be built-up combinations of standard brick sizes, as illustrated on page 508, or they may be one-piece special shapes. The built-up skewbacks can be used satisfactorily for roofs of narrow spans. The sizes used in their construction are available as needed from stocks regularly carried by manufacturers.

The one-piece skewback is generally to be preferred for furnace arches having spans greater than 4 feet. It is stronger than the built-up skewback because of its freedom from joints, and it can be supported more completely by the metal buttress.

It is important that the face of a skewback be given the proper slope, as determined by the rise and the span of the arch. When the skewback is carried on a channel or an angle, it is preferably designed and placed so that the line

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of thrust will pass through or slightly above the corner of the supporting channel or angle. If a one-piece skewback is so designed that its face forms an acute angle with the base, the sharp edge formed may crack or shear off. It is best practice therefore to design the skewback with a square toe, as shown in Figure 30.

In most cases, the dimension of a skewback brick lengthwise of the wall beneath it may advantageously be 9 inches for arches 4½ inches thick, and 3 or 4½ inches for arches 9, 12, and 13½ inches thick.

The skewbacks of ribbed arches should be high enough to support the ribs over the entire thickness of the arch.

The slope of the skewback, or angle between its face and a vertical plane, is equal to one-half the central angle of the arch. In plants where it is possible to standardize on the 60-degree central angle for the roofs of all furnaces, there will be no necessity for carrying in stock skewback shapes other than those which fit the 60-degree central angle. Skewbacks for 60-degree arches are shown on page 509. One series shown has no cutouts; a second series has cutouts to fit angles; and a third is designed to fit channels. From the illustrations, skewbacks can be selected for arches which are 4½, 9, 12, and 13½ inches thick.

The skewbacks without cutouts are suitable for roof arches when the supporting angle or channel can be placed with its flange outward, or when a buttress block of brick separates the skewback brick from the metal buttress. They may be used also for arches over openings in walls, and for some arches of flues.

The skewback brick illustrated are designed to fit the heaviest angles and channels which are likely to be used. When thinner angles are employed, proper bonding of the skewback brick may be secured by the use of ground brick or of mortar material.

PLACEMENT OF SKEWBACK BRICK

Protection of skewback brick from the destructive influences of furnace conditions is important, since wearing away of the skewbacks may cause failure of the roof. Water-cooled skews sometimes are used to advantage. Skewbacks set flush with the inner faces of walls will be deprived of their support, if these inner faces soften or wear away. Any sagging of the face of a wall which causes the skewbacks to tilt will impose severe stresses upon the arch brick, and may cause the roof to buckle. Skewback brick should not be separated from the metal buttresses by compressible material such as insulating firebrick, as these may crush through inability to support the arch stresses.

In the construction shown in Figure 30, the wall is thicker than the arch, the skewback is in a protected position, and damage to the interior face of the wall will not affect the skewback. For constructions in which the walls are 4½ inches thicker than the roofs, the special skewbacks shown on page 508 may be used. When this is done, a 4½-inch roof will rest on 9-inch sidewalls, a 9-inch roof on 13½-inch walls, and 13½-inch roof on 18-inch walls.

Figures 31 and 32 illustrate a 9-inch arch resting on a 13½-inch wall and supported by a built-up skewback formed of standard brick. In Figure 31, the better arrangement, the skewback is placed on the outer or cooler portion of the wall in such a manner that softening or wearing away of the inner 4½ inches of the hot face of the wall would not deprive the arch of its support. Repairs can be made to the

DESIGN AND PLACEMENT OF SKEWBACK BRICK

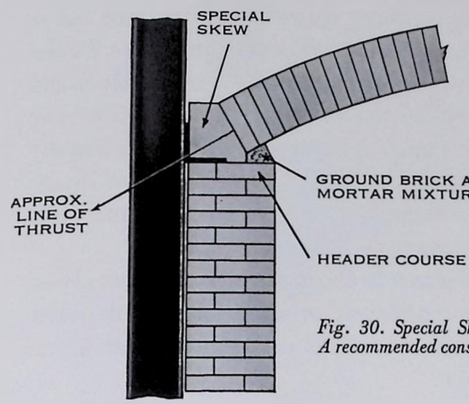


Fig. 30. Special Skewback. A recommended construction.

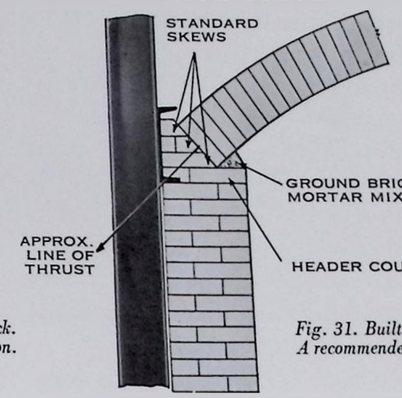


Fig. 31. Built-up Skewback. A recommended construction.

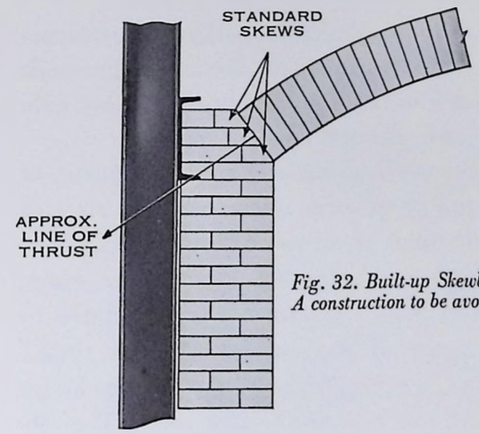


Fig. 32. Built-up Skewback. A construction to be avoided.

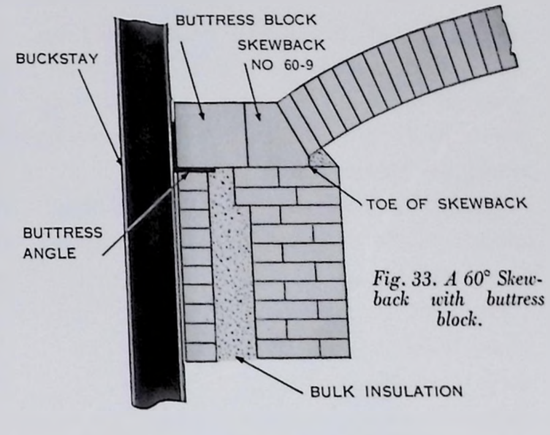


Fig. 33. A 60° Skewback with buttress block.

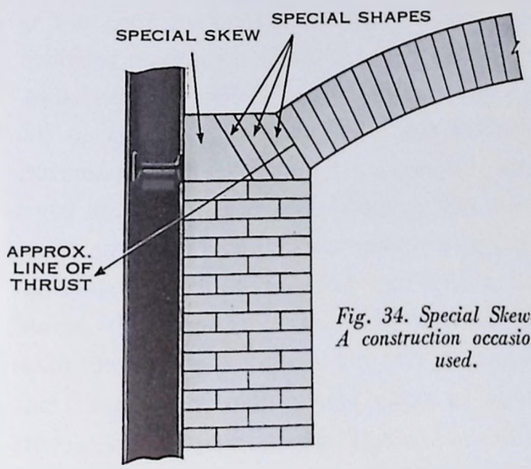


Fig. 34. Special Skewback. A construction occasionally used.

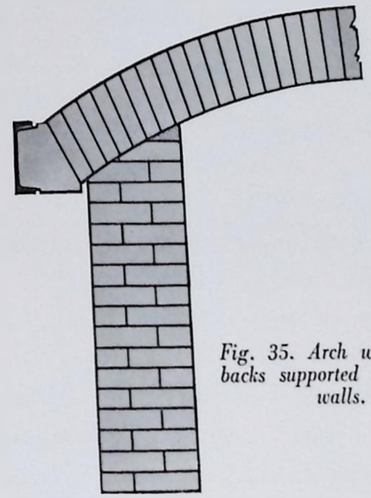


Fig. 35. Arch with Skewbacks supported outside of walls.

A stretcher course should never be used immediately below the skewback.

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inner 4½ inches of the wall without disturbing the arch. With a skewback placed as in Figure 32, damage to the hot face of the wall will weaken the support of the skewback brick and affect the stability of the roof.

When there is a narrow ledge on top of the sidewalls, as shown in Figures 30 and 31, the space between it and the arch sometimes is filled with featheredge or other thin brick. Since these may fall off, it is usually better practice to fill the space with plastic refractory material or a refractory ramming mixture.

In Figures 30, 33, 34, and 35, special skewbacks are employed. In each case, the skewback is placed on the cooler part of the wall and is thereby protected. However, in Figure 34 the special shapes between the skewback block and the ends of the arch may be damaged by any wearing away of the wall and the arch thereby weakened. The construction shown in Figure 35 is sometimes used when there are relatively large openings in the roof.

In Figures 30 and 31 the line of thrust comes within the channel or angle. This is a desirable condition, since it is conducive to stability of the arch.

TYPES OF BRICK SPRUNG ARCHES

Arches formed of separate courses or rings, not bonded together, are called "ring arches"; those in which the transverse joints are staggered, to tie the construction together, are known as "bonded arches."

Among the relative advantages and disadvantages of the two types of arches are these:

Ring Arch (Figure 36)

Somewhat less labor for initial construction.

Ease of cold repairs.

Less stress longitudinally.

Better resistance to spalling conditions.

Requires support at end of furnace to prevent outward displacement.

A ring may fall in if it is worn thin in spots.

Bonded Arch (Figure 37)

Stronger construction.

Better adapted to hot repairs.

Requires greater uniformity of brick, greater skill in construction.

More chance of single brick falling in.

Bearings of brick less positive.

Bonded roof arches of wide span are frequently built of brick 6 inches wide. Breaking of joints is accomplished by the use of brick 9 inches wide in the first and last courses. In a somewhat less desirable method of construction sometimes followed, the arches are built of brick 9 inches wide, and brick 6 inches wide are used in the first and last courses.

In the usual sprung-arch roof, all courses or rings are of uniform thickness. In a rib ring arch the rings are of two different thicknesses, as shown in Figure 38. The thicker rings, generally called "rib rings," are separated by three to six of the thinner or "valley rings." The rib brick usually are 3 to 4½ inches longer than the brick in the valley rings. The ribs project above the outer surfaces of the other rings, and the inner surface of the roof is smooth. Bonded arches are sometimes provided with ribs constructed of special wedge shapes.

Ribbed ring arches are used mainly in the roofs of open-hearth steel furnaces. In service, as the roof gradually wears thinner, the brick in the ribs remain strong even after the intervening rings have become too thin for stability. The stability of the ribs is especially advantageous if the roof wears away much more rapidly in some places than in others. Their additional strength is very helpful when roofs must be patched.

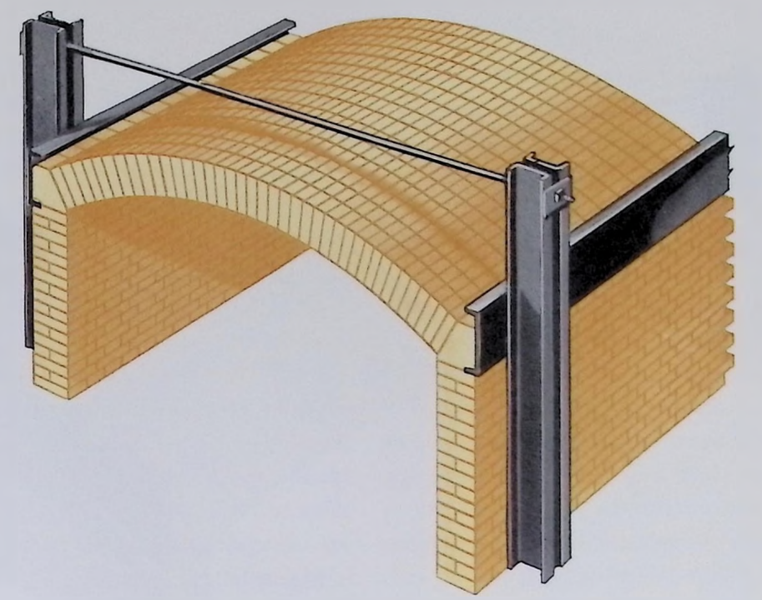


Fig. 36. Ring Arch Roof.

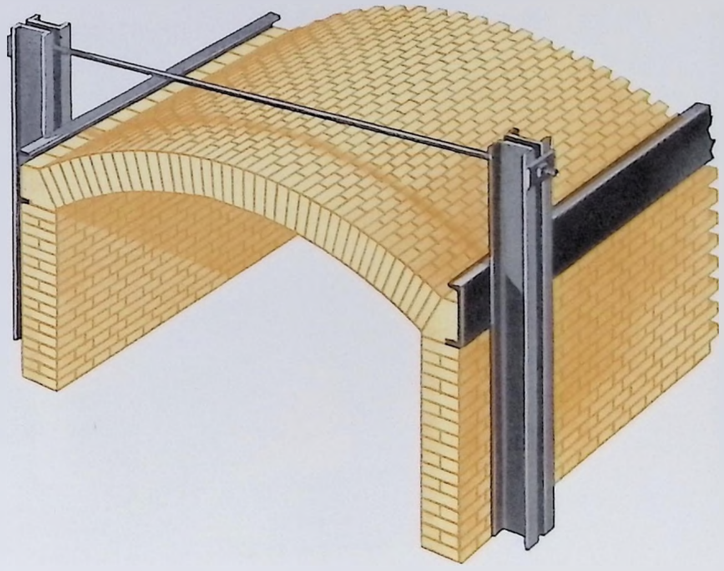


Fig. 37. Bonded Arch Roof.

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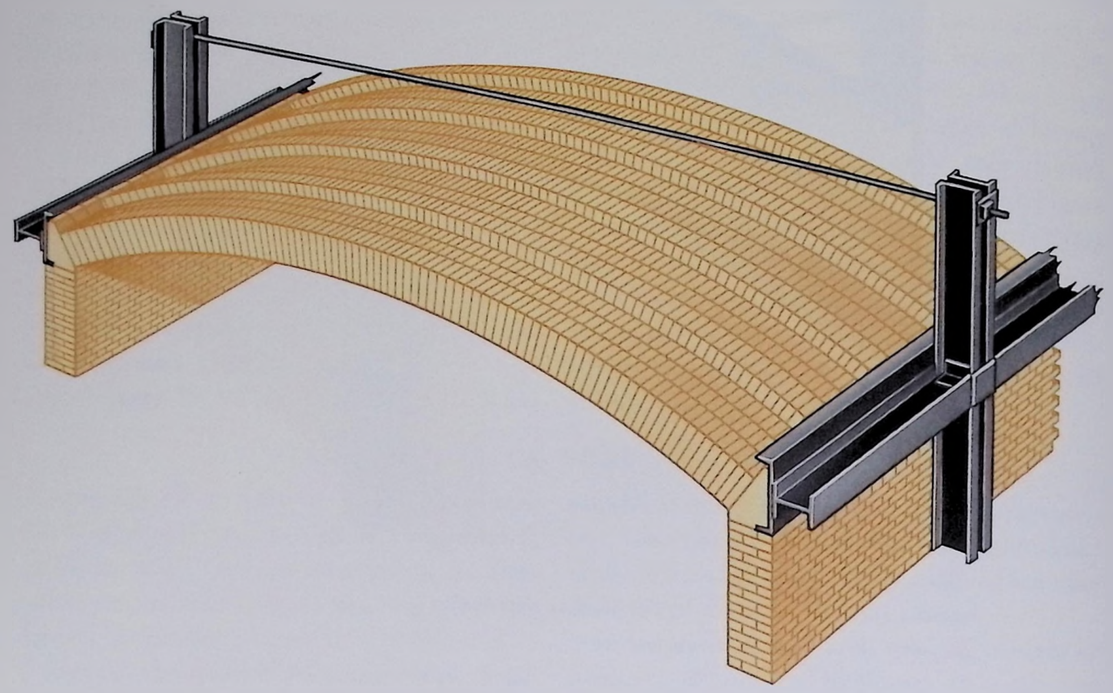


Fig. 38. Ribbed Arch Roof.

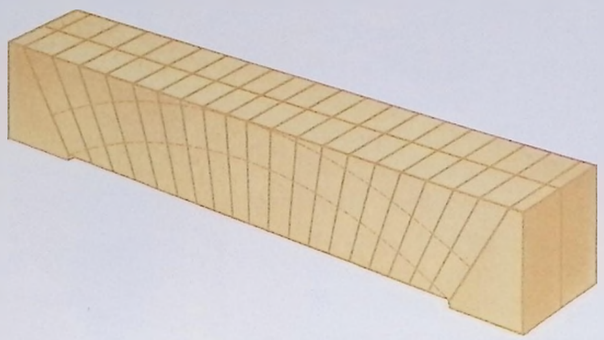


Fig. 39. Flat or Jack Arch.

JACK ARCH

The flat or jack arch is formed by special wedge shapes, which may be designed by first laying out a radial sprung arch of proper rise and thickness for the given span; then extending all lines representing joints between brick upward to the level of the highest part of the arch and downward to the level of the spring line. This construction is shown in Figure 39.

A wall opening spanned by a flat arch has a rectangular cross-section, which is desirable for certain purposes. Arches of this design sometimes are used to conserve space. A jack arch such as illustrated is structurally weak and should be used only for narrow spans. For best construction, a large number of special shapes is required.

WALL ARCHES

The term "wall arches" may be used to designate relieving arches, and arches over firing door and charging door openings, ports, and the like. The rise of wall arches can safely be made higher than that of roof arches, because the tendency to buckle is resisted by the weight of the overlying brickwork. Consequently wall arches are sometimes made semi-circular.

In furnaces operated at high temperatures, it is often advantageous to span an opening through a wall with two or more sprung arches one above the other. The lower arches serve to withstand the brunt of the severe furnace conditions, while the upper or relieving arch thus protected supports the weight of the wall, and also facilitates repairs and renewals to the lower arches. This construction is illustrated in Figure 40.

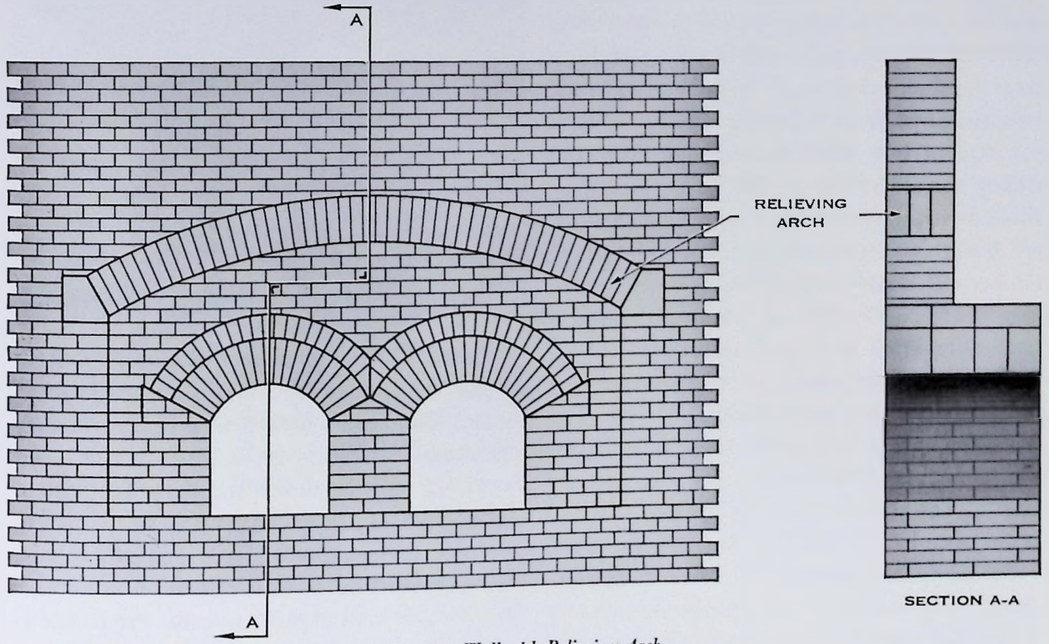


Fig. 40. Wall with Relieving Arch.

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MATERIALS OF ARCH CONSTRUCTION

Fireclay and silica brick are the materials most commonly used for furnace arch construction; insulating firebrick, high-alumina, and basic brick of various classes also find application. Monolithic refractories of some types are employed for special conditions.

Fireclay Brick Arches: The fireclay brick most commonly employed in roof service are those of the high-duty and superduty classes. They are used in the roofs of tunnel kilns, heating furnaces, malleable iron air furnaces, and the like. They are indispensable for service in which there are rapid fluctuations of temperature, and in many furnaces which are heated up and cooled down daily, or at other frequent intervals.

Silica Brick Arches: In metallurgical furnaces operated continuously at high temperatures, sprung-arch roofs of wide span usually are built of silica brick. The properties which make these brick valuable for arch construction are their great mechanical strength and rigidity at high temperatures, their lightness of weight, with consequent low arch stresses, and their constancy in volume above 1200°F.

Basic Brick Arches: Some types of basic brick are available which have high strength at high temperatures and adequate resistance to spalling. Forsterite brick and high-fired chrome-magnesite brick give good results in sprung-arch roofs of furnaces operated at high but relatively constant temperatures.

In the steel industry, one of the outstanding developments of the late 1950's was the adaptation of basic brick for complete roofs of the basic open-hearth furnace. Most of the basic roofs of open-hearth furnaces are of a modified sprung-arch type. In the copper industry suspended basic roofs are used on matte-smelting reverberatory furnaces, and both suspended and sprung roofs on refining furnaces.

Arches Built of Castable Refractories: Under some circumstances, true sprung arches for furnaces may be formed of castable refractory material. The castable may be used instead of brick for the purpose of saving time, or of securing good workmanship in constructions where bricklaying is difficult. Examples of such constructions are sloping arches, intersecting arches, and arches over flues which join a furnace at either a horizontal or a vertical angle. An illustration of a castable arch is given in Figure 41.

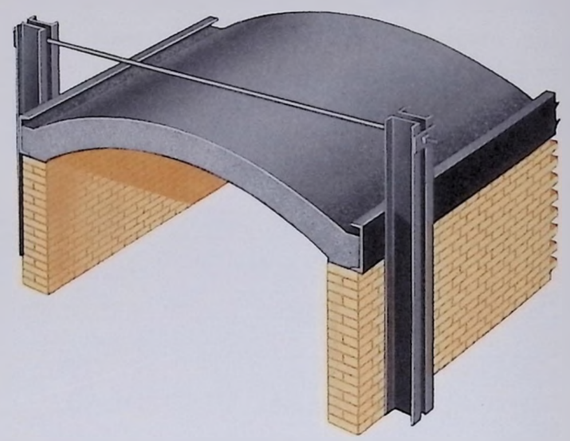


Fig. 41. Typical Castable Construction For Sprung Arch.

The rises and thicknesses of the monolithic arches are similar to those of arches built of brick. Monolithic arches are in satisfactory operation with spans up to 13 feet. The skewbacks are built as an integral part of the arch. The weight and horizontal thrust of a monolithic arch is supported by horizontal beams, independently of the sidewalls. Both transverse and longitudinal expansion joints are provided at appropriate intervals.

BRICK ROOF-CONSTRUCTION

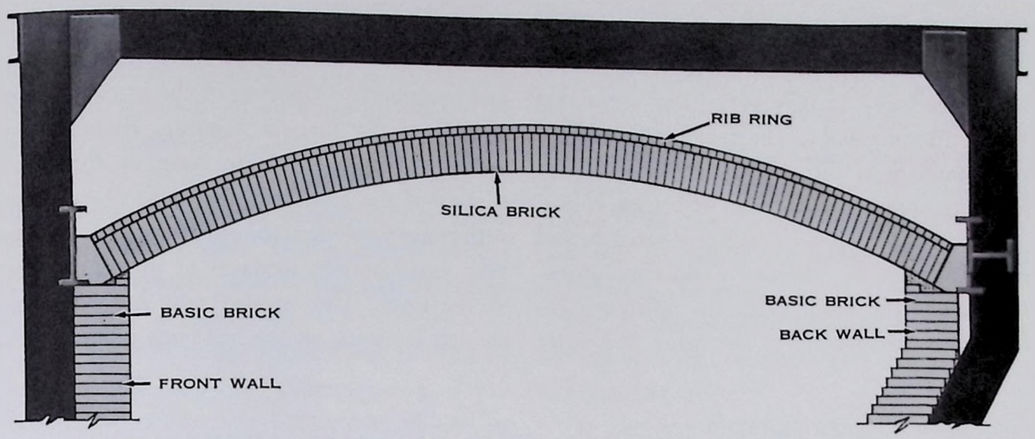


Fig. 42. Cross-Section of Silica Brick Roof of Basic Open-Hearth Steelmaking Furnace.

During the time a sprung-arch roof is being built, the brick are supported by a temporary structure or form called a "center." This usually consists of a number of wooden segments or "ribs" set vertically a few feet apart at right angles to the length of the furnace, and covered with wood lagging. The span of the "center" is slightly less than that of the arch, as otherwise the form could not be readily removed after the roof is built.

In the construction of an arch, the laying of brick begins at the skewbacks and progresses toward the middle. The operation of closing the space at the middle is known as "keying the arch." This is done by driving one or more brick into place. Wooden blocks held on top of these brick protect them from damage while being keyed. If the arch is keyed too tightly, it will be subjected to high compressive stresses; later, when the furnace is heated, and thermal expansion of the brick imposes additional stresses, there may be a tendency toward pinch spalling at the inner arch surface. All arch rings should be keyed uniformly; otherwise, some rings will rise higher than others when the furnace is heated. In building a roof arch, it is considered good practice to use two or three brick for keying. It is best not to drive them too tight.

Roofs built of silica brick frequently are laid without mortar, and grouted with a silica cement after the furnace is heated. However, there is a trend toward the more extensive use of highly refractory silica mortar for laying the silica brick, particularly on glass tanks.

Sprung-arch roofs constructed of fireclay or high-alumina brick are almost always laid with dipped mortar joints, which give an even bedding. For high-temperature arches, a heat-setting bonding mortar is usually satisfactory. In some arch constructions air-setting mortar is preferable, as for example in many flues, muffle-type arches, thin arches, or in other constructions where the arch is not subjected to a temperature high enough to develop a strong ceramic bond in the mortar.

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DIFFERENTIAL THERMAL EXPANSION OF ROOF BRICK

During the operation of a furnace, the temperature of the inner surface of the roof arch is relatively high—usually very little below that of the furnace gases. The temperature of the outer surface of the roof arch is much lower and consequently its thermal expansion is less.

The distance an arch will rise when heated depends upon the thermal expansion characteristics of the brick used, the difference between the expansions of the inner and outer surfaces of the arch, the arch dimensions, the closeness of fit of the brick surfaces, the elastic and pyroplastic properties of the brick, and the rigidity of the furnace binding. Rising of an arch may cause joints to open at the outer surface of the arch near the point of midspan, with concentration of the entire arch stress upon very small bearing surfaces at the inner ends of the brick. The stresses may become great enough to break off the hot ends of the brick.

PROVISION FOR EXPANSION IN BRICK ARCHES

In building a roof arch, provision may be made for longitudinal expansion by the use of strips of combustible material such as cardboard in each transverse joint, by leaving an open space at each joint, or by leaving open joints or slots across the roof at desired intervals. Usually, provision for the transverse thermal expansion is not made in the arch itself. This expansion generally is compensated for by rising of the arch, by slight compression of the hot ends of the brick, or by adjustment of tie rods. In the case of silica or basic brick arches, compensation for expansion is sometimes made by the use of steel springs at the ends of the tie rods. The usual allowances for thermal expansion of various types and classes of refractory brick are given on page 222.

At high temperatures, slight softening of the heated ends of fireclay roof brick will transfer the arch stresses to the cooler ends of the brick, which will provide solid bearing surfaces of ample strength to withstand the stresses. Usually sufficient compensation for the transverse expansion of a fireclay brick arch is provided automatically by bedding-in of brick surfaces, elongation of tie rods, rising of the arch, and compression of hot ends of the brick.

In some roof arches of wide span, such as those of glass-melting tanks and copper reverberatory furnaces, compensation for thermal expansion of silica roof brick is made by manual adjustment of tie rods.

In open-hearth steel furnaces, buckstays often are tied together rigidly with channels, and outward movement of skewbacks is usually prevented. In some cases, provision for transverse thermal expansion of the roof is made by the insertion of cardboard in the joints; in others, by the insertion of thin narrow strips of soft wood at the inner ends of the joints at appropriate intervals. In still other cases, compensation for transverse thermal expansion of silica brick arches is provided by driving the key brick just hard enough to permit the roof to drop slightly when the forms are removed, with the opening of small gaps between brick along the inner surface. If the brick have been laid properly, thermal expansion will close the gaps between brick and cause the arch to rise until it has assumed the contour desired.

ARCH STRESSES

Every brick in an arch is subjected to stresses resulting from the weight of the brick. In a section taken across an arch, the point through which the resultant of all outer forces acts at each surface of contact between adjacent brick is known as the "center of pressure," and the line joining the centers of pressure is called the "line of thrust." The positions of the centers of pressure and of the line of thrust are indicated in Figure 43.

In an arch of uniform thickness, the line of thrust would follow a catenary curve, if the curved line connecting the centers of gravity of the individual brick were also a catenary. In the usual simple sprung arch, however, the line through the centers of gravity is an arc of a circle. Nevertheless, the actual line of thrust coincides so closely with a catenary curve that the latter may be assumed to be correct for practical purposes.

Although the shape of the line of thrust in a simple sprung arch is known, its position is indeterminate, since various positions are possible. In order to make a solution of arch problems possible, various hypotheses have been advanced. The one which seems to be accepted most generally is known as Winkler's Theorem, which leads to the conclusion that for arches in which contact occurs over the whole face of each brick, the line of thrust in nearly every case will lie within the middle third of the thickness of the arch.

The conditions which must be met in order that an arch will be stable and that no joints will open are these:

1. a. The line of thrust must lie within the brickwork which makes up the arch ring; if not, the arch will collapse.
   b. The line of thrust should lie within the middle third of the thickness of the arch ring, or joints may open.
2. The angle between the line of thrust at any joint and the normal to that joint must not be greater than the angle of repose of brick upon brick, or of brick upon mortar, otherwise brick will slide past each other.

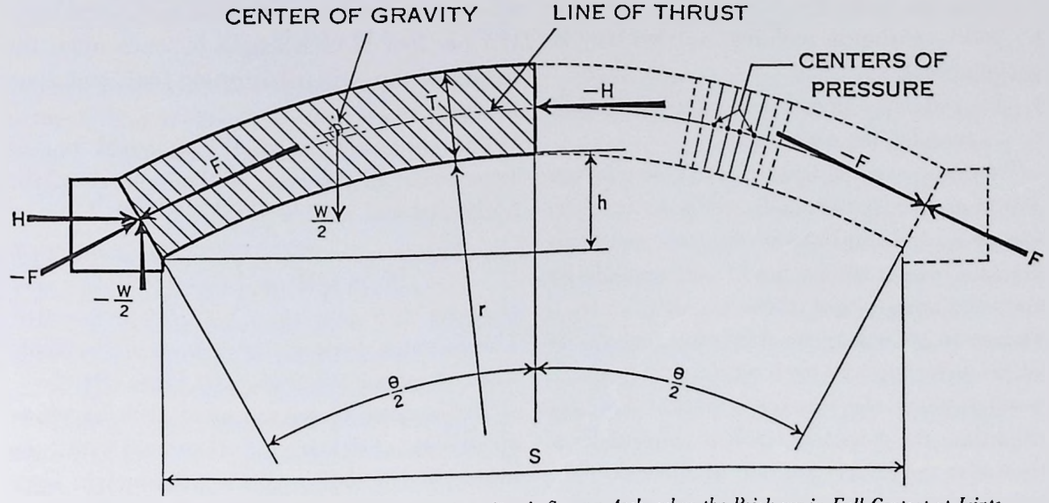


Fig. 43. Hypothetical Position of Line of Thrust in a Simple Sprung Arch, when the Brick are in Full Contact at Joints.

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The maximum resultant force occurs when the line of thrust is the flattest one possible through the arch ring; the minimum resultant force occurs when the line of thrust is the steepest one possible.

Pinch spalling, shearing, or deformation will occur if the pressure at any point in the arch exceeds the stress which the arch materials will withstand at furnace operating temperatures.

At atmospheric temperatures the angle of repose of brick on brick varies from 31 degrees to 38 degrees; the corresponding coefficients of friction are 0.60 to 0.68. These values are so high that normally there is little danger of brick in a roof arch sliding past each other. However, the coefficient of friction may vary to some extent with the pressure, and in some cases will be reduced by mortar between brick. Moreover, vibration caused by machinery or resulting from pulsating flames may cause brick to slip past each other, with damage to the arch.

Arch stresses are increased by the weight of material which adheres to the surface of the brick in service, and also by that which is absorbed by the brick. In open-hearth practice for example, it has been found that silica roof brick may increase in weight as much as 20 pounds per square foot of exposed surface.

Severe localized erosion or melting of the under side of an arch may cause it to buckle.

CALCULATION OF ARCH STRESSES

The amount of stress in a furnace arch can be determined only approximately for the following reasons:

1. The exact position of the line of thrust, even when the arch is cold, is not known.
2. The position of the line of thrust is altered when the furnace is heated.
3. Workmanship in building the arch may be imperfect.
4. Tie rods may stretch and supporting walls or foundations may settle.

The force exerted against the skewbacks per unit of arch length depends primarily upon the span, rise, and thickness of the arch, and upon the unit weight of the brick; and secondarily upon the temperature of the furnace.

Thrust in a Cold Arch: Adjoining surfaces of all brick forming an arch ring may be in full contact before the furnace is heated. For this condition, the thrust in a cold arch of uniform thickness and having opposite skewbacks at the same level can be calculated closely enough for most practical engineering purposes.

As shown in Figure 43, the resultant thrust of an arch at the skewback can be resolved into horizontal and vertical components. The vertical force at each skewback per foot of arch length is equal to one-half the weight (W) of the arch per running foot. The horizontal force (H) per foot of arch length depends upon the weight of the arch per running foot, and upon the span and rise.

The resultant thrust (F) is equal to the square root of the sum of the squares of the horizontal and vertical forces; that is,

$$F = \sqrt{H^2 + \left(\frac{W}{2}\right)^2}.$$

The thrust is least at the center of the span, where it equals the horizontal force (H).

The stresses in an unheated arch in which all adjoining brick are in full contact with each other may be determined approximately from the constants given in Table III.

MAXIMUM THRUST IN A HEATED ARCH

When a furnace is heated, the arch brick expand. The amount of expansion is greatest at the hotter inner surface and least at the cooler outer surface of the arch. Unless full compensation is made in some manner for the expansion, changes will occur both in the position of the line of thrust and in the magnitude of the thrust. The arch will rise, and the outer ends of some of the joints near the middle of the span will open.

At the instant when joints are just about to open, if the skewbacks do not tilt the line of thrust will pass from a point near the outside arch surface at each skewback, to a point near the inside arch surface at midspan. The arch stresses at this instant will assume the maximum values which are possible. Later, as the arch rises, the amount of stress will decrease slightly. However, even when the line of thrust comes so near the ends of the joints that the ends of the brick are sheared off, the stability of the arch is not necessarily endangered.

If the rise of the arch is low, and if no compensation for thermal expansion is made, the line of thrust may become almost a straight horizontal line when the furnace is heated. Under these conditions, the horizontal stress may become so great that one of two things must happen: (1) either plastic flow or pinch spalling must occur at the inner ends of the brick, automatically moving the line of thrust to a higher position and giving it greater curvature; or (2) the binding must yield.

The value of H_{max} (the limiting value which the horizontal thrust approaches) can be determined approximately from Table IV.

The factor of safety used in designing furnace binding ordinarily is higher than that used in the conventional design of steel work, because of the possibility that the binding of a furnace may become overheated. For ordinary structural steel bindings, many designers limit the tensile stress to 12,000 pounds per square inch. One reason for keeping the stress low is to provide adequate rigidity, since yielding of the binding would allow the arch to flatten.

MAXIMUM PRESSURE IN AN ARCH

For any brick surface supporting the thrust of an arch, the average pressure over the entire surface is given by the following formula:

$$P = \frac{F}{12 \times 12\,T}$$

Where P = average pressure in pounds per square inch.
F = the resultant thrust of the arch in pounds per running foot.
T = thickness of arch in feet.

While the average pressure can be approximated, usually the maximum pressure at any point cannot be determined, because the position of the center of thrust is not known.

When the center of thrust is near the lower edge of the brick, the maximum pressure may amount to many times the average pressure. If the line of thrust were to pass through the extreme lower edge of any brick in the arch, the pressure would at that point theoretically become infinite. Actually, the pressure would build up until one of three things would occur: (1) the hot ends of the brick would be deformed by compression, (2) the hot ends of the brick would be pinched off, or (3) the abutments would move outward. In any one of these three cases, the pressure would be lower after the adjustment had taken place.

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Table III.

CONSTANTS FOR CALCULATION OF STRESSES IN UNHEATED ARCHES

Rise in Inches Per Foot of Span	Central Angle Θ	Forces Per Foot of Arch Length		
		W Weight	H Horizontal Thrust	F Resultant Thrust at Skewback
1″	37° 50.9′	1.05 DST	1.49 W	1.57 W
1¼″	47° 4.4′	1.07 DST	1.18 W	1.28 W
1½″	56° 8.7′	1.09 DST	0.98 W	1.10 W
1.61″	60° 0.0′	1.10 DST	0.91 W	1.04 W
1¾″	65° 2.5′	1.11 DST	0.83 W	0.97 W
2″	73° 44.4′	1.14 DST	0.72 W	0.88 W
2¼″	82° 13.4′	1.17 DST	0.64 W	0.81 W
2.30″	83° 58.5′	1.17 DST	0.62 W	0.80 W
2½″	90° 28.8′	1.19 DST	0.57 W	0.76 W
2¾″	98° 29.7′	1.22 DST	0.51 W	0.71 W
3″	106° 15.6′	1.25 DST	0.46 W	0.68 W

D = Weight of brick per cubic foot. S = Span in feet. T = Thickness of arch in feet. W = Weight of brick per foot of arch length.

The constants given in Table III are based upon the assumption that the line of thrust passes from the center of arch thickness at the point of midspan, to the center of arch thickness at the skewbacks.

For sketch showing hypothetical position of line of thrust in a sprung arch, see Figure 43.

For table showing weights of refractory brick per cubic foot, see page 462.

Table IV.

MAXIMUM VALUES APPROACHED BY HORIZONTAL THRUST IN HEATED ARCH FREE TO RISE

Rise in Inches Per Foot of Span	Central Angle Θ	H_{max} Per Foot of Arch Length — Thickness of Arch in Per Cent of Span						
		4%	5%	6%	7%	8%	9%	10%
1″	37° 50.9′	1.88 H*	2.41 H	3.29 H	5.0 H	**	**	**
1¼″	47° 4.4′	1.61 H	1.86 H	2.29 H	2.80 H	3.73 H	5.34 H	**
1½″	56° 8.7′	1.47 H	1.63 H	1.94 H	2.14 H	2.55 H	3.06 H	3.88 H
1.61″	60° 0.0′	1.43 H	1.59 H	1.76 H	1.98 H	2.31 H	2.75 H	3.30 H
1¾″	65° 2.5′	1.39 H	1.52 H	1.67 H	1.93 H	2.17 H	2.41 H	2.77 H
2″	73° 44.4′	1.33 H	1.43 H	1.56 H	1.69 H	1.86 H	2.04 H	2.22 H
2¼″	82° 13.4′	1.29 H	1.38 H	1.47 H	1.58 H	1.70 H	1.84 H	2.00 H
2.30″	83° 58.5′	1.28 H	1.37 H	1.46 H	1.57 H	1.69 H	1.81 H	1.95 H
2½″	90° 28.8′	1.26 H	1.33 H	1.42 H	1.51 H	1.60 H	1.72 H	1.82 H
2¾″	98° 29.7′	1.24 H	1.29 H	1.37 H	1.45 H	1.53 H	1.63 H	1.73 H
3″	106° 15.6′	1.22 H	1.26 H	1.33 H	1.41 H	1.48 H	1.57 H	1.63 H

* H = Horizontal thrust, as determined from Table III.
** Stress excessive.

EXAMPLE OF STRESS PROBLEMS

Consider a silica brick roof arch 15 inches thick, with a 20-foot span and a central angle of 60 degrees, as illustrated in Figure 44.

S, the span = 20.0 feet
T, the thickness = 1.25 feet
r, the inside radius = 20.0 feet
D, the weight of brick per cubic foot, = 110 pounds
Θ, the central angle = 60°
h, the rise of the arch = 1.61 inches per foot of span = 32.15 inches or 2.68 feet
R, the outside radius = r + T = 21.25 feet

The following calculations are based upon the assumption that the line of thrust passes from the center of the arch thickness at mid-span to the center of arch thickness at the skewbacks.

Weight of Roof Per Foot of Arch Length:

From Table III, the weight of the arch per foot of length is equal to 1.10 DST. That is, 1.10 × 110 × 20 × 1.25 = 3025 pounds.

NOTE: The weight could have been calculated more accurately from the exact formula

$$W = \frac{\Theta}{360}\,\pi\,(R + r)\,TD$$

$$\frac{\Theta}{360}\,\pi = 0.5236$$

$$R + r = 21.25 + 20.00 = 41.25$$

Exactly, therefore, W = 0.5236 × 41.25 × 1.25 × 110 = 2970 pounds. Obviously, the weight of 3025 pounds, as determined by use of Table III, is sufficiently accurate for calculation of the arch stress.

Horizontal Thrust in Cold Arch:

From Table III, the horizontal thrust H = 0.91W. Therefore H = 0.91 × 3025 = 2750 pounds per foot of arch length.

Resultant Thrust in Cold Arch:

From Table III, the resultant thrust F = 1.04W. Therefore F = 1.04 × 3025 = 3150 pounds per foot of arch length.

Maximum Value Approached by Horizontal Thrust in Heated Arch:

From Table IV, for an arch with a central angle of 60°,

When T = 6% of Span, H_{max} = 1.76 H
When T = 7% of Span, H_{max} = 1.98 H

By interpolation, when T = 0.0625 S, H_{max} equal approximately 1.82 H. Therefore H_{max} = 1.82 × 2750; or 5000 pounds per foot of arch length.

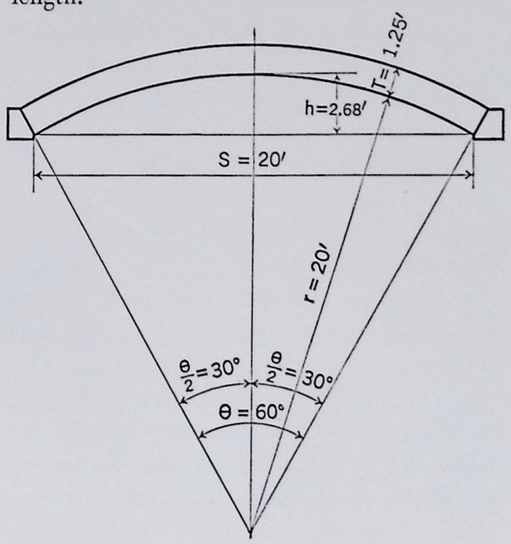


Fig. 44. Silica Brick Arch—illustrative example.

Maximum Pressure:

If the line of thrust should pass through the center of the face of the skewback, the maximum pressure P would be

$$\frac{F}{12 \times 12\ T} = \frac{3150}{12 \times 12 \times 1.25},\ \text{or } 17.5$$

pounds per square inch.

However, the actual position of the line of thrust cannot be determined and the pressure therefore cannot be calculated. It would be very high if the line of thrust were to come near the inner edge of the brick.

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COMPOUND ARCHES OF HIGH RISE

An unloaded circular segmental sprung arch with a rise greater than 3 inches per foot of span lacks stability. Greater stability will be secured if the arch is of catenary form, since the line of thrust tends to follow a catenary curve. A true catenary arch would require a large number of special shapes, and the mathematics of design is somewhat complicated. These difficulties may be avoided by the use of a compound arch which approximates a catenary in its lines. For arches with a rise of 3 to 6 inches per foot of span, this can be accomplished by a compound arch having two radii; for arches with a higher rise, three radii are required.

Great care needs to be observed in the design and construction of arches of high rise, especially if they should be built of materials having high thermal expansion, such as basic refractories. A compound arch or a catenary arch which is entirely stable when cold may become unstable at operating temperature, because of the change in the lines of the arch resulting from the thermal expansion. The higher the ratio of rise to span, the greater the danger of instability when hot. However, catenary-type arches built of silica brick in most cases will remain stable when heated. Those made of fireclay or high-alumina brick may remain stable when heated because elastic or plastic deformation may occur sufficiently to take care of the thermal expansion, especially as some of it is taken up by bedding-in of the brick surfaces at the joints. Insulation in all cases would increase the stability, since it would decrease the differential in expansion between the inner and the outer arch surfaces.

Arches of high rise are not used to any great extent except in constructions where they support superimposed brickwork, as for example in furnace walls and in checker chambers. In such construction, the arches generally are semi-circular in form. Arches of the catenary type are used relatively little. However, their greater stability, as compared with circular segmental arches of high rise, suggests the probability that they may be utilized advantageously in the design of furnaces for specialized service which must operate at extremely high temperatures. Furnaces may be designed in which both the sidewalls and the roof are replaced by a catenary-type sprung arch of high rise.

The potentialities of the commercial application of catenary-type arches may have become greater since refractories which retain strength and rigidity at extremely high temperatures have become more readily available. Among these refractories are corundum, periclase, and high-fired chrome-magnesite.

The design of catenary-type compound arches with a high rise is simplified by use of the constants given in Table V, page 259.

EXAMPLE ILLUSTRATING DESIGN OF A COMPOUND ARCH

Assume that a compound arch is to be designed with a span (S) of 12.0 feet, and a rise of 9 inches per foot of span.

Arch Dimensions: The arch dimensions are calculated from the constants given in Table V, as follows:

$h = 0.750S = 0.750 \times 12' = 9.0' = 9'\text{-}0''$

$R_1 = 0.265S = 0.265 \times 12' = 3.180' = 3'\text{-}2\frac{3}{16}''$

$R_2 = 0.574S = 0.574 \times 12' = 6.888' = 6'\text{-}10\frac{5}{8}''$

$R_3 = 1.801S = 1.801 \times 12' = 21.612' = 21'\text{-}7\frac{3}{8}''$

$m_1 = 0.1947S = 0.1947 \times 12' = 2.3364' = 2'\text{-}4\frac{1}{16}''$

$n_1 = 0.5055S = 0.5055 \times 12' = 6.0660' = 6'\text{-}0\frac{13}{16}''$

$m_2 = 1.266S = 1.266 \times 12' = 15.192' = 15'\text{-}2\frac{5}{16}''$

$n_2 = 1.103S = 1.103 \times 12' = 13.236' = 13'\text{-}2\frac{13}{16}''$

Layout of Arch:

A. Lay off the base line, the vertical center line, the skewback center points (1) and (2), and the apex (3) of the arch center line, as shown in Figure 46.

B. From point (3), measure downward on the vertical center line a distance of $3'\text{-}2\frac{3}{16}''$, equal to R_1. This locates the first center (4).

C. Locate the second center, point (5), from its coordinates m_1 and n_1; and locate the third center, point (7), from its coordinates m_2 and n_2.

D. Draw a line from the second center, point (5) through (4), a total distance equal to R_2 ($6'\text{-}10\frac{5}{8}''$), locating the point (6); and draw a line from the third center, point (7) through (5), a total distance equal to R_3 ($21'\text{-}7\frac{3}{8}''$), locating the point (8).

E. With (4) as a center, and radius R_1, describe an arc from (3) to (6); with (5) as a center, and radius R_2, describe an arc from (6) to (8); and with (7) as a center, and radius R_3, describe an arc from (8) to (1).

The layout has now been completed for the half of the arch on one side of the vertical center line. The other half may be drawn in the same manner.

Table V.

CONSTANTS FOR COMPOUND ARCHES WHICH ARE APPROXIMATELY CATENARIES

See Figures 45 and 46

Rise in Inches Per Foot of Span	No. of Radii	h	R_1	Θ_1 (Degrees)	R_2	Θ_2 (Degrees)	R_3
3	2	0.250S	0.559S	27° 0.0′	0.851S	21° 1.2′	.....
4	2	0.333S	0.449S	33° 24.0′	0.848S	24° 38.4′	.....
5	2	0.417S	0.384S	39° 0.0′	0.929S	26° 6.6′	.....
6	2	0.500S	0.347S	43° 42.0′	1.031S	26° 57.6′	.....
7½	3	0.625S	0.286S	35° 39.0′	0.565S	20° 46.2′	1.448S
9	3	0.750S	0.265S	39° 0.0′	0.574S	21° 52.2′	1.801S
12	3	1.000S	0.244S	47° 6.0′	0.717S	21° 54.6′	3.095S
15	3	1.250S	0.231S	54° 33.0′	1.016S	19° 22.2′	4.794S
18	3	1.500S	0.221S	55° 15.0′	0.968S	20° 7.8′	5.853S

Rise in Inches Per Foot of Span	No. of Radii	Θ_3 (Degrees)	β (Degrees)	m_1	n_1	m_2	n_2
3	2	.....	48° 1.2′	0.1328S	0.8194S	.....	.....
4	2	.....	58° 2.4′	0.2196S	0.7823S	.....	.....
5	2	.....	65° 6.6′	0.3428S	0.8077S	.....	.....
6	2	.....	70° 39.6′	0.4729S	0.8415S	.....	.....
7½	3	18° 31.8′	74° 57.0′	0.1624S	0.5125S	0.898S	1.001S
9	3	17° 50.4′	78° 42.6′	0.1947S	0.5055S	1.266S	1.103S
12	3	13° 13.8′	82° 14.4′	0.3466S	0.5661S	2.567S	1.418S
15	3	10° 18.0′	84° 13.2′	0.6397S	0.6864S	4.270S	1.733S
18	3	10° 54.0′	86° 16.8′	0.6134S	0.6465S	5.341S	1.880S

NOTE: In the above table, the span S and rise h are taken to the center line of the arch thickness, as shown in Figures 45 and 46, and not to the under surface as is customary with circular segmental arches.

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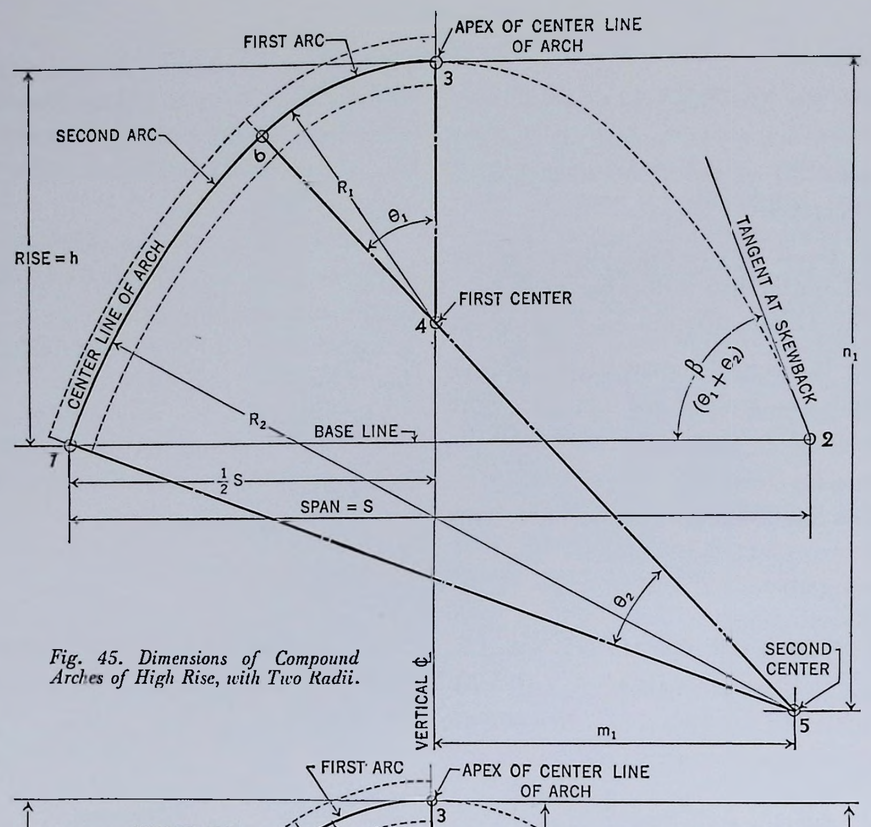


Fig. 45. Dimensions of Compound Arches of High Rise, with Two Radii.

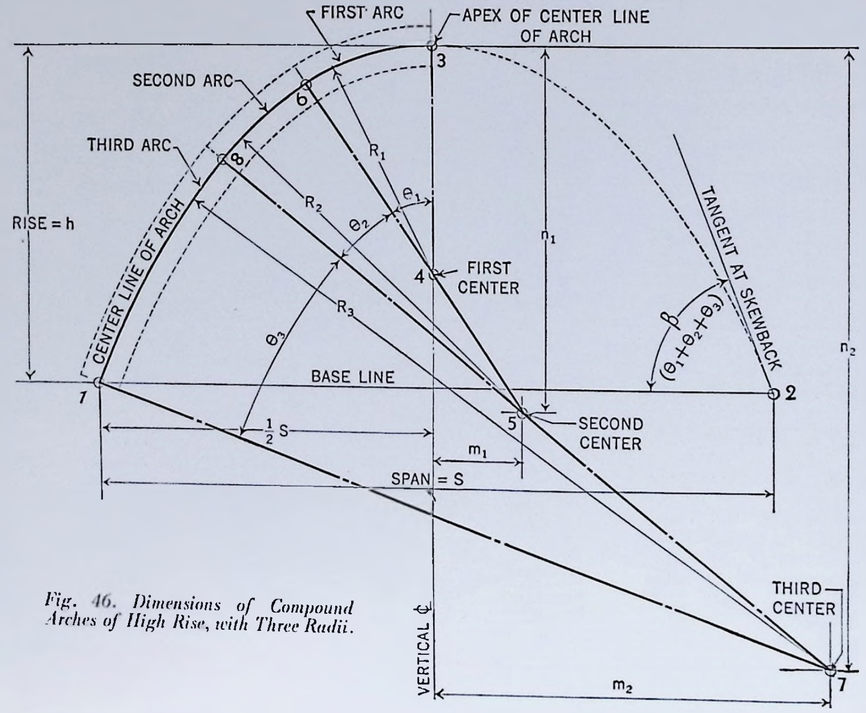
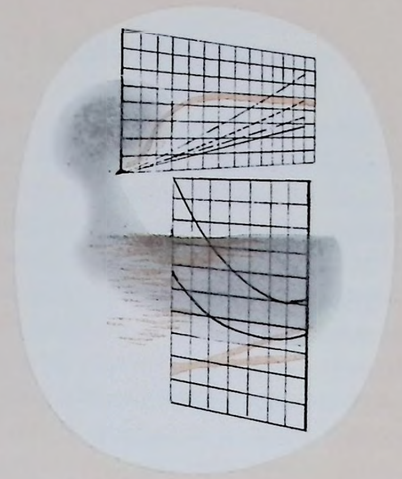


Fig. 46. Dimensions of Compound Arches of High Rise, with Three Radii.



PROPERTIES OF REFRACTORIES

HARBISON-WALKER REFRACTORIES COMPANY

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PROPERTIES OF REFRACTORIES

In this review of the properties of refractories enough theory has been included to illustrate some of the basic principles which relate to the development, manufacture, and applications of refractory materials. Special emphasis has been placed upon high-temperature mineralogy, and upon the development of the liquid phase under the influence of heat, because these are factors which primarily determine the utility of a refractory material in service. In the discussion which follows, the data are presented in the following order:

Part I. The Mineral Compositions of Refractory Materials. Special reference is made to changes which occur during heat treatment and to stability relations at high temperatures.

Part II. Other Chemical and Physical Properties of Refractories. Greatest emphasis is placed upon the particular properties which are most closely related to the utility of commercial refractory products.

The temperatures given, up to 2820°F. (1550°C.), are based on the Geophysical Laboratory Scale. Those above 2820°F. are based on the International Temperature Scale of 1948.

Most high temperatures appearing in the technical literature are measured and reported with an estimated accuracy of ±5°C., or ±9°F. In general, the temperatures appearing in this chapter represent exact conversions of reported Centigrade temperature to degrees Fahrenheit. However, because of the uncertainty of the original measurement, the last figure of the temperature in °F. is generally not significant.

Technical articles and books referred to in the text are listed on pages 336 and 338.

Part I. MINERAL COMPOSITION

MINERALS AND GLASSES

At room temperature, all refractory products which have been molded into brick and later given a ceramic bond by firing, consist of crystalline mineral particles bonded by glass or by smaller crystalline mineral particles. They contain a significant volume of small pores. When such a brick is again heated to high temperatures, as in service, a liquid develops also, largely from the groundmass materials, in proportions which depend upon the composition of the refractory and upon the temperature. The physical properties of a refractory at any given temperature are fixed by the amount and character of the minerals, glass, and liquid of which it is composed.

A mineral may be defined as a natural inorganic substance which is either definite in chemical composition and physical properties, or which varies in these respects within fixed limits. A mineral usually has a definite crystalline structure, although a few comparatively common minerals are amorphous in nature. Opal is an example of such a mineral.

A mineral having a true or congruent melting point when heated will pass completely from the crystalline condition to the liquid state at a definite temperature. When cooled slowly, the liquid formed will solidify or freeze at the same definite temperature, and will again assume the crystalline form. With rapid cooling, the liquid may solidify without crystallizing, thus forming a glass.

A mineral is said to have an incongruent melting point when it does not change from a completely solid to a completely liquid condition at a definite temperature, but dissociates, forming a different solid crystalline phase and a liquid phase. When the temperature rises above the temperature of dissociation, the solid material dissolves gradually in the liquid. As an example, the mineral clino-enstatite ($MgO \cdot SiO_2$) melts incongruently at 2835°F. (1557°C.) to form a mixture of forsterite ($2MgO \cdot SiO_2$) and liquid.

A glass differs from a crystalline material in several respects. Its chemical composition may vary continuously over rather wide limits, it lacks crystalline structure, and it has no specific melting point. When a glass is progressively heated, the change from the apparently solid state to the fluid state is gradual and continuous. When a molten glass is cooled, the change from the fluid state to the apparently solid state is likewise gradual and continuous. Theoretically, at least, a glass is not a solid at all, but is an undercooled liquid which has stiffened as it cooled, until the viscosity has become so great that the body conforms to the generally accepted concept of a "solid."

A glass will change into the crystalline condition or "devitrify" if kept for a sufficient time within a critical temperature range. Some melts crystallize even with very rapid cooling. Others must be maintained at a critical temperature for a considerable length of time before any crystals are formed. Alkali-silicate melts high in silica are extremely viscous and do not crystallize readily upon cooling. This immunity to devitrification is an essential attribute to commercial glass compositions.

THE CERAMIC BOND OF BRICK

One of the most important purposes for which brick are fired is to give them permanent mechanical strength, by causing adjacent particles to adhere. The bond developed by the heat treatment is known as a "ceramic bond."

Unfired or "green" brick consist of mixtures of particles of refractory material which usually vary from coarse through intermediate to very fine sizes. The coarser particles in some cases have a diameter of ¼ inch or more. The fines, which may be regarded as the particles which will pass a 200-mesh screen, often amount to as much as 30 per cent of the total. After having been fired, the borders of the larger particles are usually distinct; the fines generally form a more or less vitrified groundmass, which bonds together the particles of larger size. The character and continuity of this groundmass, and its degree of adherence to the larger particles, have very important effects upon the physical properties of fired refractory brick.

The strength of the ceramic bond is dependent upon the character of the brick mix as well as upon the time and temperature of firing. In many cases, the constituents of a refractory which occur in only small amounts (the so-called impurities) play an important role in the development of the bond. With some types of refractories small amounts of reactive materials are intentionally added; the bond is formed by chemical reaction of the material added with a portion of the refractory. In the manufacture of silica brick for example, about 1.8 to 3.5 per cent of lime is added for bonding.

During the firing of refractory brick, mineral dissociation or transformation occurs; such minerals as kaolinite or diaspore dissociate, and quartz is transformed wholly or in part into other forms of silica. Crystal growth and chemical reactions may occur also in the solid state,

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resulting in the formation of a strong ceramic bond between particles in contact. This type of bonding is common in basic brick compositions. However, solid-state reactions are believed to have less influence upon the bonding of silica-alumina brick than does the formation of a liquid phase. In the case of brick molded wholly or in part from calcined or dead-burned materials, some of the changes described above in this paragraph may have already occurred in the original heat treatment.

In the firing of refractory brick, a small amount of liquid can be expected to form in the groundmass at a temperature some hundreds of degrees below that at which complete fusion would occur. With rise in temperature, this liquid takes other materials present into solution and thereby increases in amount. The liquid becomes a medium suitable for the transport of material which it dissolves, and for the formation and growth of crystals, especially at interfaces between liquid and solid particles.[35-1]

Upon cooling, the liquid formed at high temperatures may become a rigid glass, or it may become partly or wholly crystalline. The relative proportions of glass and crystalline material in the bonding groundmass will depend upon its composition, and upon the rate of cooling. Rapid cooling favors the formation of glass; slow cooling, the formation of crystals.

The brick mass is bonded together and given strength by the adhesive power of the glass, by adherence of particles, and by interlacing of crystals. Elongated crystals, like those of mullite, may tend to interlace; crystals having a nearly equidimensional habit, like periclase (MgO), obviously cannot interlace.

A brick containing a large amount of glass will usually have high strength in the cold condition; but if the glass is of low viscosity at furnace operating temperatures, the brick may deform readily under pressure. For a brick to withstand pressure at high temperatures without deformation, its content of glass must be low, or the viscosity of the glass must be high, or both; in general, the brick should have been fired under conditions which are favorable to the growth of crystals.

Certain types of refractories have their load-carrying capacities at high temperatures materially increased by incorporation in the brick mixes of finely ground materials which effect changes in the body. The added material may function in one of several ways: it may react chemically with the glass and transform it into highly refractory crystalline material; it may make the glass more viscous at furnace operating temperatures; it may cause or accelerate solid-state reactions; or it may cause improvement merely by reducing the proportion of the glass. A change which reduces the amount of glass or liquid in the refractory would usually be more beneficial in service than a change which makes the glass more viscous.

EQUILIBRIUM DIAGRAMS

Melting of mixtures of two or more minerals or oxides takes place over a range of temperatures. The temperatures at which melting is complete depend upon both the relative amounts of the materials present and their compositions. The melting behavior of such mixtures and the nature of the equilibria between the solids and the liquids formed by melting have engaged the attention of many investigators. Since the early years of the twentieth century, many papers on the subject have appeared in the scientific literature. Those published by the staff of the Geophysical Laboratory of the Carnegie Institution, and more recently by the College of Mineral Industries of The Pennsylvania State University, have contributed much fundamental information to the ceramic industries.

The data are presented mainly in the form of drawings known as phase equilibrium diagrams. A compilation of these diagrams, called "Phase Diagrams for Ceramists," was published in 1956 under the auspices of the American Ceramic Society, Incorporated[56-1]; a supplement, "Phase Diagrams for Ceramists, Part II," was published in 1959[59-1]. The first volume contains a section of general material on phase diagrams, including an explanation of the phase rule, an interpretation of diagrams, experimental methods, a glossary of terms, and a selected bibliography. In 1960, the American Ceramic Society published ten large-scale equilibrium diagrams of important ternary systems.

ALUMINA-SILICA SYSTEM

The equilibrium diagram for mixtures of alumina and silica, published by Bowen and Greig,[24-1] in 1924, for the first time gave a clear and acceptable picture of the equilibrium conditions in alumina-silica compositions.

Recently, Aramaki and Roy[59-4] revised the alumina-silica diagram on the basis of standard quenching experiments, in which the specimens were heated in sealed platinum-rhodium containers to prevent losses due to exposure to the furnace atmosphere. Their results are shown in Figure 47. The new diagram is in close agreement with the older one up to 55 per cent alumina, and thus conclusions based upon the earlier diagram for silica and fireclay compositions are not materially altered by this later work. However, revisions of a major nature have been made in the high-alumina side of the diagram.

Significant features of the new diagram are the following:

(1) The earlier conclusion is confirmed that mullite of the composition $3Al_2O_3 \cdot 2SiO_2$ (71.8% Al_2O_3, 28.2% SiO_2) is in equilibrium with silica up to about 2903°F. (1595°C.). The mullite which occurs in fireclay refractories therefore has the molecular alumina: silica ratio of 3:2.

(2) The composition of mullite in equilibrium with siliceous alumina-silica liquids was found to change a little with rising temperatures above 2903°F. (1595°C.), becoming slightly more aluminous. The alumina content of the mullite at 3345°F. (1840°C.) is apparently about 72.1 per cent.

(3) Mullite does not melt incongruently as formerly believed, but has a true melting point of about 3362°F. (1850°C.). At this temperature, however, it contains approximately 73.0 per cent alumina, instead of the theoretical 71.8 per cent.

(4) There is a eutectic between corundum and mullite at 3344°F. (1840°C.) with 77.4 per cent alumina.

(5) In compositions containing more than 71.8 per cent alumina, mullite forms solid solutions with corundum. Accordingly, solid-solution mullites containing as much as 78 per cent alumina can be prepared. Those containing more than about 74.2 per cent alumina are believed to be "metastable," that is, they have limited stability.

The new alumina-silica diagram is used in the following paragraphs to illustrate the application of phase diagrams in determining the behavior of refractories at high temper-

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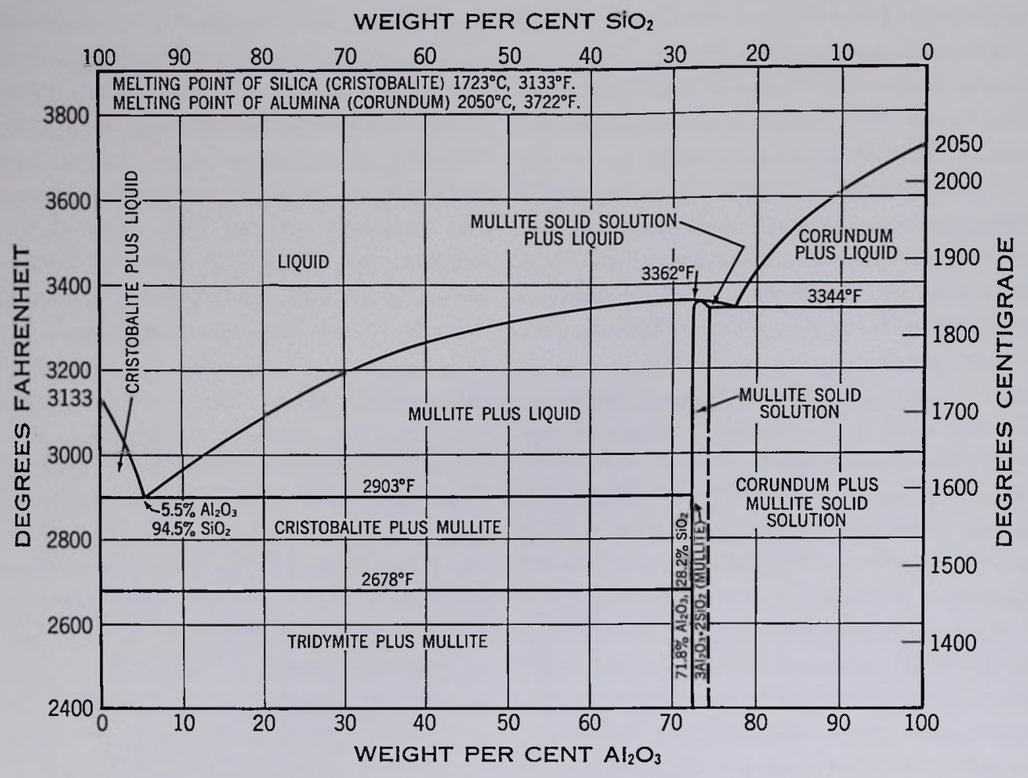


Fig. 47. Equilibrium Diagram of the System Alumina-Silica (Al_2O_3-SiO_2). After Aramaki and Roy (Nature, August, 1959)

atures. When conditions are favorable for the volatilization of silica, such as the presence of a reducing atmosphere, or a temperature of about 3270°F. (1800°C.) or above, caution must be exercised in the precise application of the phase rule data to predict or interpret reactions in compositions containing more than about 55 per cent alumina.

It cannot be emphasized too strongly that *all* phase diagrams apply strictly only (1) to completely pure materials, and (2) to conditions of complete equilibrium. Practically the first condition is never met by commercially fired refractory materials, and the second condition is seldom if ever attained in furnace practice. Moreover, phase diagrams give no information concerning rates of reaction, or the viscosity of the liquid phases, both of which have considerable effect on the properties of refractories at high temperatures. Consequently, the theoretical considerations outlined here need to be amplified by other data, for a complete understanding of the melting behavior of refractory clays and other alumina-silica materials.

Detailed Description: The temperatures of complete melting of all possible mixtures of pure silica and pure alumina, under conditions of complete equilibrium, are represented in Figure 47 by the heavy curved line (the "liquidus" line), which extends across the width of the diagram. The melting point of pure silica is 3133°F. (1723°C.). With increasing

amounts of alumina, up to 5.5 per cent, complete melting occurs at successively lower temperatures, reaching a minimum of about 2903°F. (1595°C.), at a composition of 5.5 per cent alumina and 94.5 per cent silica, and then the melting temperature rises as the alumina content exceeds 5.5 per cent. Such a composition of lowest melting point is known as a "eutectic composition," and the temperature at which it melts is known as a "eutectic temperature."

Consider any homogeneous composition of alumina and silica with *less than 5.5 per cent alumina* (Al_2O_3). To achieve homogeneity in a reasonable time, it is necessary to start with finely divided and uniformly mixed particles, and to heat them until the mullite-forming reaction is complete, preferably at a temperature just below that at which a liquid could begin to form (2903°F. or 1595°C.). As the temperature of the material is further increased, the entire mass will remain solid until the temperature of 2903°F. (1595°C.) is reached. At this temperature a portion of the batch will melt, forming an exceedingly viscous liquid of the eutectic composition (5.5 per cent Al_2O_3, 94.5 per cent SiO_2). All of the alumina will enter into the formation of this liquid, and if equilibrium conditions have been obtained, any excess silica above the eutectic ratio will remain in the solid form as cristobalite. With further temperature rise above 2903°F. the amount of solid silica will decrease, and the amount of liquid will increase through solution of the solid, until the entire mass has melted. The temperature at which complete melting occurs for any specific mixture is indicated by the heavy curved liquidus line.

Any composition of alumina and silica which contains *more than 5.5 per cent and less than 71.8 per cent alumina*, will melt in part at the eutectic temperature 2903°F. (1595°C.). The initial liquid phase will have the same composition as the eutectic (5.5 per cent alumina, 94.5 per cent silica), and the unmelted solid will consist of crystals of the mineral mullite. Mullite formed under these conditions has the chemical formula $3Al_2O_3 \cdot 2SiO_2$, corresponding to 71.8 per cent alumina, 28.2 per cent silica. When the temperature rises above 2903°F., the liquid takes mullite into solution. The amount of liquid thereby increases and its composition changes, becoming richer in alumina, until the temperature reaches the heavy curved line for the particular composition being heated, when complete melting occurs. The temperature of complete melting (the liquidus) is almost constant from *60 to about 77 per cent alumina*.

The mullite composition in equilibrium with siliceous liquid changes with the temperature, becoming somewhat more aluminous at the higher temperatures. However, the difference is so slight that the line at the right-hand side of the field of "mullite plus liquid" in Figure 47 appears to be vertical, up to about 3345°F. (1840°C.), and therefore appears to represent a constant alumina-silica ratio.

Mullite has a true or congruent melting point of 3362°F. (1850°C.). However the mullite which melts at this temperature has an alumina content of about 73.0 per cent, instead of the theoretical 71.8 per cent.

As shown in Figure 47, there is a eutectic between mullite and corundum, similar to that between silica and mullite previously described. The eutectic temperature for the mullite-corundum range is 3344°F. (1840°C.), and the eutectic contains 77.4 per cent alumina by weight. Thus any alumina-silica composition containing *more than 71.8 per cent alumina* will show the first liquid development at 3344°F. If the composition contains more than 71.8 per cent alumina, but less than 77.4 per cent, the

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solid phase in equilibrium with the liquid will be mullite; if the composition contains more than 77.4 per cent alumina, the solid phase is corundum. Again, as the temperature rises above 3344°F. (1840°C.), the solid phase (mullite or corundum) will dissolve in the liquid until complete melting occurs.

Under equilibrium conditions, mullite can take excess alumina into solid solution in the crystal, up to 74.2 per cent total alumina. In fact, mullites containing up to 78 per cent alumina are easily prepared and commonly found in fusion-cast mullite; however it is believed that the mullites richest in alumina are metastable. X-ray diffraction spacings of various solid-solution mullites vary with heat treatment almost as much as they vary with chemical composition; hence they are not reliable indices of composition. Index of refraction measurements on true glasses containing up to 77 per cent alumina were also used to locate the liquidus line in Figure 47.

The diagram (Figure 47) shows that there is no solid solution of silica in mullite under equilibrium conditions. This has been confirmed by the authors in another report.[59-5]

Relative Amounts of Components: By a simple calculation, based upon the so-called "lever principle," the amount of each component present at equilibrium can be determined for any composition and any temperature. Consider, for example, *a composition of 40 per cent alumina, 60 per cent silica*. At all temperatures included in Figure 47 below 2678°F. (1470°C.), tridymite and mullite coexist in equilibrium and are the only minerals present. Equilibrium percentages are determined thus:

$$\% \text{ tridymite} = \left(\frac{71.8 - 40.0}{71.8 - 0}\right) 100 = 44.3\%$$

$$\% \text{ mullite} = \left(\frac{40.0 - 0}{71.8 - 0}\right) 100 = 55.7\%$$

At 2678°F. (1470°C.) the tridymite changes to cristobalite. With further heating, no other changes occur until the eutectic temperature of 2903°F. (1595°C.) is reached. At that point all the cristobalite melts, with some of the mullite, forming a liquid with the composition 5.5 per cent alumina, 94.5 per cent silica. At the eutectic temperature, the relative amounts of the components as calculated, are 48.0 per cent liquid, 52.0 per cent mullite.

With further rise in temperature above 2903°F. (1595°C.) progressive solution of the mullite in the liquid occurs. The composition of the melt changes, as indicated by the curved liquidus line shown in Figure 47. All of the mullite is dissolved at about 3265°F. (1796°C.) and the material is then completely melted.

Upon cooling, the mass would undergo the same changes as described above, in reverse order. Between 3265°F. (1796°C.) and 2903°F. (1595°C.) mullite would crystallize from the liquid, and at the eutectic temperature, 2903°F. (1595°C.), the entire mass would solidify abruptly, becoming a mixture of crystals of cristobalite and mullite.

The Sillimanite Minerals: The minerals sillimanite, kyanite, and andalusite all have the theoretical composition $Al_2O_3 \cdot SiO_2$, corresponding to 62.9 per cent alumina, 37.1 per cent silica. Dissociation of these minerals can be effected by a heat treatment at a sufficiently high temperature and for a long enough time to provide the necessary energy to alter their crystal structure. By such heat treatment, any of the sillimanite minerals can be converted into a mixture consisting of about 88 per cent mullite and 12 per cent free silica.

Sillimanite begins to dissociate into mullite and free silica at about 2785°F. (1530°C.), kyanite at 2415°F. (1325°C.), and andalusite at 2460°F. (1350°C.).

MINERAL CHANGES DURING THE HEATING OF FIRE CLAY

In the commercial burning of fireclay brick, the mineral changes which occur do not follow as simple a pattern as that described on the preceding page. The main reasons are that the ground clay mixtures are not homogeneous either as to mineral composition or as to particle size, and firing temperatures are not held long enough to attain equilibrium. The mineral compositions may vary over a wide range and the grains may vary all the way from pieces ¼ inch or more in diameter to particles much smaller than one-thousandth of an inch in diameter.

Clays are composed essentially of one or more of a group of minerals classified as "clay minerals." Typically, these are hydrous aluminum silicates. *Refractory clays* consist mainly of the clay mineral kaolinite, which has the approximate composition $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$, corresponding to 39.5 per cent alumina (Al_2O_3), 46.5 per cent silica (SiO_2), and 14 per cent water (H_2O). Pure kaolinite has a P.C.E. value of Cone 35, corresponding to a softening temperature of about 3245°F. (1785°C.).

The clays of greatest importance in the refractories industry are refractory flint and semi-flint clays, refractory plastic and semi-plastic clays, and refractory kaolin.

Even clays of highest quality contain significant amounts of constituents other than the alumina-silica mineral kaolinite. Many clays contain substantial amounts of illite, a form of mica which has more combined water and less potash than is found in muscovite ($3Al_2O_3 \cdot 6SiO_2 \cdot K_2O \cdot 2H_2O$). The hydrous mica in clays is somewhat variable in composition, but apparently averages about 6 per cent in potash (K_2O). In many refractory clays the accessory mineral present in largest amount is quartz (SiO_2); in others it is diaspore ($Al_2O_3 \cdot H_2O$). Nearly all refractory clays contain minor amounts of titania-bearing minerals. Other common accessory minerals are chlorite, montmorillonite, pyrite (FeS_2), feldspars, and micaceous minerals other than illite. Siderite ($FeCO_3$) occurs in some deep-mine clays, limonite (hydrated iron oxide) in clays which occur near the surface.

The changes which take place in heating a fire clay have been the subject of extensive investigation for a great many years. Some of the changes now believed to take place on heating a fire clay composed mainly of kaolinite are outlined in the following paragraphs.[59-2]

Upon being heated, kaolinite loses most of its combined water (dehydrates) at about 750° to 980°F. (400° to 525°C.) depending on the particle size, with the formation of a semi-crystalline compound metakaolin, $2Al_2O_3 \cdot 4SiO_2$. This reaction is endothermic.

When metakaolin is heated to about 1700°F. (925°C.) an exothermic reaction takes place, in which some of the silica migrates out of the metakaolin, leaving behind a cubic spinel-type phase approximating $2Al_2O_3 \cdot 3SiO_2$ in composition. The silica set free may be amorphous; at least, it is so poorly crystallized that it cannot be identified as crystalline material by X-ray diffraction.

At about 1920° to 2010°F. (1050° to 1100°C.) the spinel-type phase begins to break down and to discard more silica. A phase resembling mullite and of uncertain composition forms, probably containing more silica than the composition $3Al_2O_3 \cdot 2SiO_2$. The discarded silica appears as cristobalite, giving a well-defined X-ray diffraction pattern. Heat is evolved in this temperature range.

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Above 2190°F. (1200°C.) cristobalite and mullite continue to develop. The mullite formed at 2550°F. (1400°C.) or above is believed to have the composition $3Al_2O_3 \cdot 2SiO_2$ with no excess silica. Thus the alumina-silica ratio varies from 1:2 in the original kaolinite and in metakaolin, through 2:3 in the spinel-type phase, to 3:2 in the final mullite.

Up to this point little has been said regarding the effects of the accessory minerals at high temperatures. Quartz which is present as an accessory mineral begins to change to cristobalite at about 2280°F. (1250°C.). If the quartz crystals are large the central portions may remain as residual quartz in bodies which have been heated to a temperature as high as 2700°F. (1480°C.). Some of the oxides present in the accessory minerals lower the temperature at which liquid begins to form and increase the amount of liquid at any given temperature. The alkalies soda and potash are especially potent in this respect, reacting to form a highly viscous liquid at temperatures several hundred degrees below the temperature at which liquid would begin to form if the body consisted wholly of alumina and silica.

In clays which are otherwise pure, a very small amount of potash is sufficient to lower the temperature of initial liquid formation to 1805°F. (985°C.). In the alkali-alumina-silica liquid, accessory minerals containing lime, magnesia, and iron oxide dissolve wholly or in part, as do both amorphous and crystalline silica and at very high temperatures even mullite. Over a wide range of temperatures above 1805°F., the liquid is so viscous that it behaves essentially as if it were a solid. However, the viscosity gradually decreases as the temperature becomes higher. The temperature of complete melting depends upon the alumina-silica ratio, and upon the compositions and amounts of the accessory minerals.

In a single ground clay, most of the larger particles have nearly the same composition as the finer sizes, which form the groundmass of fired products made from the clay. However, there is probably some concentration of accessory minerals in the groundmass. For this reason, and because of its greater fineness, the groundmass develops more liquid than the larger particles, in the firing of fireclay brick.

When fireclay brick are at the firing temperature, they consist of mullite and cristobalite crystals and a viscous liquid. On cooling, some additional cristobalite and mullite may separate from the liquid. However, much of the liquid cools to a rigid glass, which bonds the mass together and gives it strength.[35-1] Additional strength is imparted by the interlacing and adherence of crystals. Mullite is especially effective as a ceramic bond, as it forms interlacing needle-like crystals.

MINERAL COMPOSITION OF FIRECLAY AND HIGH-ALUMINA BRICK

Burned fireclay refractories are composed largely of mullite and free silica (cristobalite, quartz, and rarely tridymite). The crystals are mainly submicroscopic in size, but are identifiable by means of their X-ray diffraction patterns. Glass also is present in amounts depending upon the composition of the material, the time and temperature of firing, and the rate of cooling. Superduty fireclay brick usually contain less glass than do brick of the high-duty class. In any fireclay brick, the impurities tend to be concentrated in the glass.

In fireclay brick exposed to high temperatures, the mullite crystals increase in size. In photomicrographs of superduty fireclay brick reheated to 2910°F. (1600°C.), the presence of mullite crystals is clearly indicated.

High-alumina brick contain mullite and usually corundum, some free silica (generally cristobalite with occasional quartz), and glass in amounts varying with the alumina content of the brick. The mineral constitution is also influenced by the raw materials from which the brick were made, the mineral placement with respect to grains and matrix, the proportion of accessory oxides, and the firing treatment.

If complete equilibrium could be attained during the firing process, any pure alumina-silica refractory with less than 71.8 per cent alumina would contain no crystalline material other than mullite and free silica. One with more than 71.8 per cent alumina would contain only mullite, with a small amount of alumina dissolved in it, or the mullite solid solution and corundum. However, in brick made wholly or in part from bauxite or diaspore clay, corundum may be present even in compositions with less than 71.8 per cent alumina, and free silica may be present even in compositions with more than 71.8 per cent alumina. Under favorable conditions the development of mullite during firing proceeds to an advanced degree, yet it does not proceed to completion. The mullite formed at the surfaces of the grains of bauxite or diaspore appears to act as a protective film, retarding or preventing further reaction between the corundum of the interior of the grains and the free silica formed from the fire clay between the grains.

A similar condition exists when fused alumina (artificial corundum) is added to or is bonded by fire clay in the manufacture of high-alumina brick. When the refractory is fired, a protective film of mullite forms at the surfaces of the grains of corundum by combining with free silica released by recrystallization of the fire clay. The interior of the corundum grains is unaltered by the firing treatment.

THE MINERALS IN SILICA REFRACTORIES

Stability Relations of the Silica Minerals: The three common crystal modifications of silica are quartz, tridymite, and cristobalite. The form generally found in nature is quartz. This mineral may be converted to tridymite or cristobalite by appropriate heat treatment. The formation of tridymite appears always to require the presence of a liquid, which may be formed by reaction of silica with a suitable fluxing agent. Cristobalite is formed in the absence of a liquid. Quartz is the stable form of silica below 1598°F. (870°C.); tridymite is the stable form from 1598°F. (870°C.) to 2678°F. (1470°C.); and cristobalite is the stable form above 2678°F. (1470°C.). However, at atmospheric temperature and pressure, there is no perceptible tendency for cristobalite or tridymite to change to quartz.

In the absence of a liquid phase, quartz does not change to tridymite, even within the temperature range at which tridymite is the stable form. At about 2280°F. (1250°C.) quartz begins to change slowly to cristobalite; the rate of transformation increases rapidly as the temperature rises. At 2900°F. (1593°C.) transformation is complete in approximately one hour.

In the presence of an appropriate liquid, cristobalite changes to tridymite at temperatures between 2280°F. (1250°C.) and 2678°F. (1470°C.). The change is very slow at 2280°F. and is not rapid even at 2630°F. (about 1445°C.).

The specific gravity at room temperature of

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quartz is 2.65; that of cristobalite, 2.32; that of tridymite, 2.26. Hence the transformation of quartz to cristobalite causes a volume increase of 14.3 per cent; of quartz to tridymite, a volume increase of 17.2 per cent.

Each of the three crystal forms of silica has high-temperature and low-temperature modifications. These are known as high-quartz and low-quartz; high-cristobalite and low-cristobalite; and upper high-tridymite, lower high-tridymite, and low-tridymite. A change takes place rapidly from a low temperature to a high temperature form on heating, and from a high to a low form on cooling.

The change from low-quartz to high-quartz or the reverse, which occurs at about 1063°F. (573°C.), is accompanied by an abrupt volume increase of approximately 0.9 per cent on heating, and a corresponding shrinkage on cooling. However, the total reversible expansion which occurs between 600°F. (316°C.) and 1100°F. (593°C.) is about 3.2 per cent. When heated or cooled rapidly through the inversion point quartz has a strong tendency to crack.

The low-high inversion of cristobalite occurs at about 428°—513°F. (220°—267°C.) on heating; the reverse change on cooling takes place at about 480°—392°F. (249°—200°C.). However, the temperature is somewhat variable, and depends both on the material from which the cristobalite was formed and the temperature of formation. Cristobalite, when heated or cooled through the inversion range, has a volume change of about 2.8 per cent. Refractory brick or other bodies consisting largely of this mineral tend to crack or spall if heated or cooled rapidly through the inversion range.

Two well-crystallized tridymites occur at atmospheric temperature, designated [58-2] as tridymite-M (for metastable) and tridymite-S (for stable). Tridymite-M passes through reversible inversion points at 235° and 306°F. (113° and 152°C.); tridymite-S at 147°, 235°, and 280°F. (64°, 113°, and 138°C.). The total volume changes through the inversion points are small, probably not exceeding 0.35 per cent. So far as is known, no cracking occurs when tridymite is heated or cooled rapidly through the inversion points.

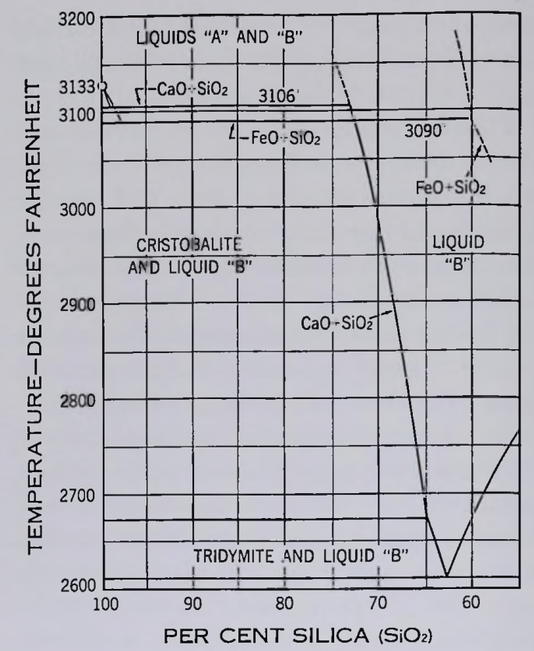


Fig. 48. Partial Equilibrium Diagram of the Binary Systems Lime-Silica and Ferrous Oxide-Silica (CaO-SiO_2 and FeO-SiO_2) Based on Data of J. W. Greig, Am. Journal of Science, 1927.

Equilibrium Diagrams and Silica Refractories: Highly siliceous mixtures of silica with certain other oxides have a constant temperature of complete melting over a wide range of composition. Within this range the mixtures form two *immiscible* liquids upon melting, instead of the usual single liquid. The two liquids do not blend, but preserve their separate identities, like mixtures of oil and water. Highly siliceous mixtures of silica with lime or with ferrous oxide exhibit this type of melting behavior, as shown in Figure 48.

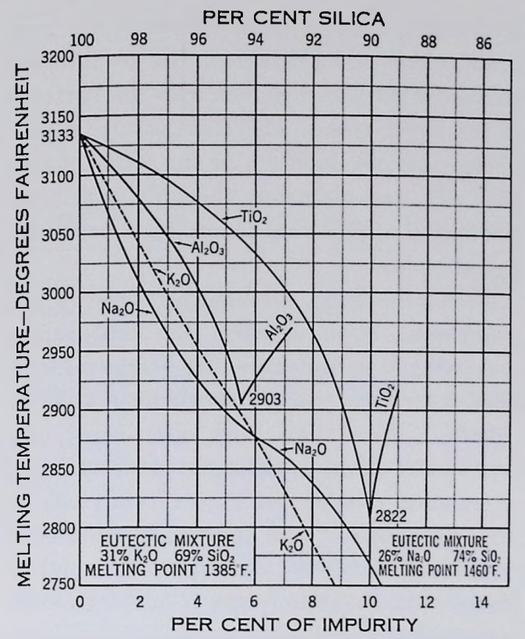


Fig. 49. Effect of Certain Impurities upon Melting Behavior of Silica.

The addition of up to 1 per cent lime to silica results in a progressive lowering of the temperature of complete melting from 3133°F. (1723°C.) to 3106°F. (1708°C.). Further additions of lime, however, do not result in additional lowering of the melting temperature, but the formation of a second liquid containing 27.5 per cent lime and having the same melting point 3106°F. Thus the addition of 2.5 per cent lime to silica would result in the formation of only (2.5 / 27.5) 100, or about 9 per cent liquid at temperatures just below 3106°F. Similarly, all mixtures of silica and ferrous oxide, containing from 1 per cent to 40 per cent ferrous oxide, under equilibrium conditions melt completely at 3090°F. (1699°C.).

The equilibrium diagrams of silica with alumina, with titania, and with the alkalies do not show the "Immiscibility Plateau" effect.[17-1] Instead, a single liquid results from melting, and the temperature of complete melting drops rapidly with even small additions of any one of these oxides. Moreover, in lime-silica or ferrous oxide-silica mixtures, a small percentage of alumina or alkalies destroys the immiscibility.

The effect of the "Immiscibility Plateau" upon the melting temperature can be seen by comparison of Figures 48 and 49. At 2920°F. (or 1605°C.), a mixture of 5.5 per cent lime with 94.5 per cent silica under equilibrium conditions will consist of 82 per cent solid material with 18 per cent liquid, while at the same temperature a mixture of 5.5 per cent alumina, soda, or potash with silica will be completely melted.

THE MINERAL CHANGES WHICH OCCUR UPON FIRING SILICA BRICK

The raw material used in the manufacture of silica refractories is a rock consisting almost wholly of quartz. In that used for making brick of conventional quality the sum of the alumina, titania, and alkalies is usually about 0.50 to 1.2 per cent, and the ferric oxide content about 0.3 to 1.0 per cent. The raw material used in the manufacture of superduty silica refractories contains about 99.0 per cent silica, with a total of 0.15 to 0.40 per cent alumina, titania, and alkalies. In the manufacturing process, 1.8 to 3.5 per cent of lime is added for bonding.

During the firing, most of the quartz changes with accompanying expansion into other forms of silica. The lime combines with silica and the impurities of the rock to form a liquid which solidifies largely to a glass on cooling. Under some conditions, the mineral pseudowollastonite ($CaO \cdot SiO_2$) is formed also.

The coarse grains in a silica brick usually

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Fig. 50. Section of STAR *Silica Brick, Unused.*
Polarized Light. Linear Magnification, 110.
The light-colored lath- and wedge-shaped areas represent tridymite crystals; the darker areas are mainly cristobalite.

contain 99+ per cent silica, often being well in excess of 99.5 per cent SiO_2. Hence the fine-grained groundmass, about 25 per cent of the total weight of the brick, contains almost all the lime and iron oxide, as well as much of the alumina, titania, and alkalies. Thus the lime content of the groundmass is of the order of 8 to 10 per cent, a significant factor in the development of the liquid phase during firing. In the system CaO-Al_2O_3-FeO-SiO_2, liquid can form at a temperature as low as about 2048°F. (1120°C.). Small amounts of alkalies may depress this temperature still further. Besides its effect on bonding strength, the liquid has a marked influence on the rate at which the mineral transformations occur.

In the firing of silica brick, conversion of quartz to cristobalite begins at about 2280°F. (1250°C.). The rate of transformation is slow at this temperature, but increases as the temperature rises. Small grains in the groundmass are converted first, together with the surfaces of the larger grains. The transformation progresses into the interiors of the larger grains gradually, and ultimately the only quartz remaining, if any, is that in the interior of the largest grains.

During the firing, the liquids formed in the groundmass begin to affect the cristobalite, converting it to tridymite, the stable form of silica at the firing temperature of about 2625°F. (1440°C.). In a silica brick after firing, the larger grains are likely to consist predominantly of cristobalite, with thin rims of tridymite at their surfaces, and with any remaining unconverted quartz in the centers of the largest grains. Most of the tridymite is in the groundmass, with the glass from which it crystallized.

The permanent linear expansion of silica brick during firing, due to the transformation of quartz to cristobalite and tridymite, is about 4.2 per cent.

Silica brick, as now manufactured, consist mainly of tridymite and cristobalite, with some glass, residual quartz, and often small quantities of a finely crystalline mineral, which has been identified as pseudowollastonite ($CaO \cdot SiO_2$). The amounts of these phases which occur in silica brick are shown in Table VI.

Silica brick ordinarily are light in color with a yellowish cast, but often are mottled or splotched in irregular brownish patterns. Such coloration is due to subtle changes in the groundmass, accompanying devitrification. These odd colorings, which are of no practical significance, are most likely to appear in brick of the highest purity, or in those containing more than about three times as much lime as alumina. As the alumina content increases, the color generally becomes less pronounced.

Table VI.
MINERAL COMPOSITION OF SILICA BRICK

Type	Per Cent				
	Tridymite	Cristobalite	Quartz	Pseudo-wollastonite	Apparently Noncrystalline Material*
Superduty	33-61	27-49	<1-3+	<2-5+	9-17
Superduty Spall-Resistant	35-38	33-35	2-3+	1-3+	20-30
Conventional	40-54	28-41	<1	<1-5+	5-24

** By difference; believed to consist of "disordered" silica and 5 to 15 per cent glass.* *< = Less than.*

THE MINERAL COMPOSITION OF MAGNESITE REFRACTORIES

Magnesite Materials: The raw materials used in the manufacture of refractories consisting essentially of the basic oxide magnesia (MgO) are (1) chemically precipitated magnesium hydroxide, (2) the mineral magnesite, which is naturally occurring magnesium carbonate, and to a minor extent (3) the mineral brucite, naturally occurring magnesium hydroxide. Chemically precipitated magnesium hydroxide, prepared by causing slaked lime or slaked calcined dolomite to react with magnesium-bearing brine, contains small amounts of accessory minerals derived from the limestone or dolomite, and from the brine. The natural mineral magnesite contains small amounts of accessory minerals, such as dolomite, serpentine, talc, chalcedony, and quartz. Iron carbonate, in solid solution with the magnesium carbonate, is present in many magnesites.

The raw magnesia-containing materials are "dead-burned" in rotary or shaft kilns to prepare them for use. The dead-burning consists of a high-temperature heat treatment which drives off chemically combined water and/or carbon dioxide, and converts the remaining product into dense grains or lumps resistant to atmospheric moisture and carbon dioxide. In dead-burning, additions such as iron oxide, alumina, silica, or lime may be made to obtain desired compositions.

The temperature of dead-burning varies from about 2800°F. to 3350°F. (1540°C. to 1845°C.), depending upon the type and purity of the product. In the process of dead-burning, magnesium hydroxide dissociates to form magnesia and water vapor; magnesium carbonate dissociates to form magnesia and carbon dioxide gas. The water vapor and the carbon dioxide escape with the kiln gases. The dead-burned product, which is known commercially as "dead-burned magnesite," consists mainly of aggregates of periclase crystals, with a fine-grained crystalline groundmass usually composed of silicates of magnesium and to a minor extent of calcium.

The color of dead-burned magnesite low in iron oxide varies from white to buff or tan. Dead-burned magnesite which contains several per cent of iron oxide is generally chocolate-brown in color, and microscopic examination shows that the periclase crystals usually contain dark moss-like inclusions. These have been identified as magnesioferrite ($MgO \cdot Fe_2O_3$).

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Table VII.
TYPICAL COMPOSITIONS OF DEAD-BURNED MAGNESITE

		For Furnace Bottoms	For Making Brick
Magnesia	(MgO)	83-98%	88-98%
Lime	(CaO)	1.0-6.0	1.0-3.5
Silica	(SiO_2)	0.5-8.0	0.5-6.0
Alumina	(Al_2O_3)	0.3-1.5	0.3-1.5
Ferric Oxide	(Fe_2O_3)	0.3-3.0	0.3-6.5

The most desirable amounts of the accessory constituents, and their relative proportions, depend upon the purposes for which the product is to be used. Dead-burned grain magnesite used in furnace hearths in general has a higher content of accessory constituents than that used for making brick. The compositions of most of the commercial dead-burned magnesites used in the United States lie within the ranges shown in Table VII.

The exact mineral composition of magnesite grains cannot be calculated accurately from the chemical composition, because adequate data regarding the six-component system MgO-CaO-Al_2O_3-FeO-Fe_2O_3-SiO_2 are not available, and because equilibrium conditions are not entirely reached in the brief period of exposure to high temperatures during dead-burning. However, the major components can be identified by painstaking research with X-ray diffraction.

The CaO-MgO-SiO_2 System: Consideration of the three-component system CaO-MgO-SiO_2 serves as an excellent starting point in studying the mineral composition of magnesite refractories. The composition triangles in this system are shown in Figure 51, which is explained as follows: Any *point* within the large equilateral triangle of Figure 51 represents a definite composition, consisting solely of CaO, MgO, and SiO_2. For example, the point "A" represents a composition of 35.9 per cent CaO, 25.6 per cent MgO, and 38.5 per cent SiO_2, which corresponds to the composition of the mineral monticellite.

The large equilateral triangle is divided by heavy lines into triangles of unequal size. These are known as "composition triangles." Each of the three apexes of any composition triangle represents the chemical composition of a specific mineral. A *line* connecting any two apexes represents all compositions in which the two minerals indicated may coexist in equilibrium. The *area* within a triangle represents all compositions in which the three minerals indicated by the apexes may coexist in equilibrium.

The particular minerals to be found in any stable blend of lime, magnesia, and silica may be predicted from the triangle within which the composition lies. Under equilibrium conditions, the body would consist of the three minerals represented by the apexes of the triangle, in relative amounts fixed by the distances from the point representing the composition, to the individual apexes.

That part of the CaO-MgO-SiO_2 system in which the magnesia is present in great excess, and in which therefore periclase (MgO) is invariably a component, is of particular interest in connection with magnesia refractories. In Figure 51 the composition triangles of this part of the system appear as full lines. The calcium and magnesium silicates which may coexist in

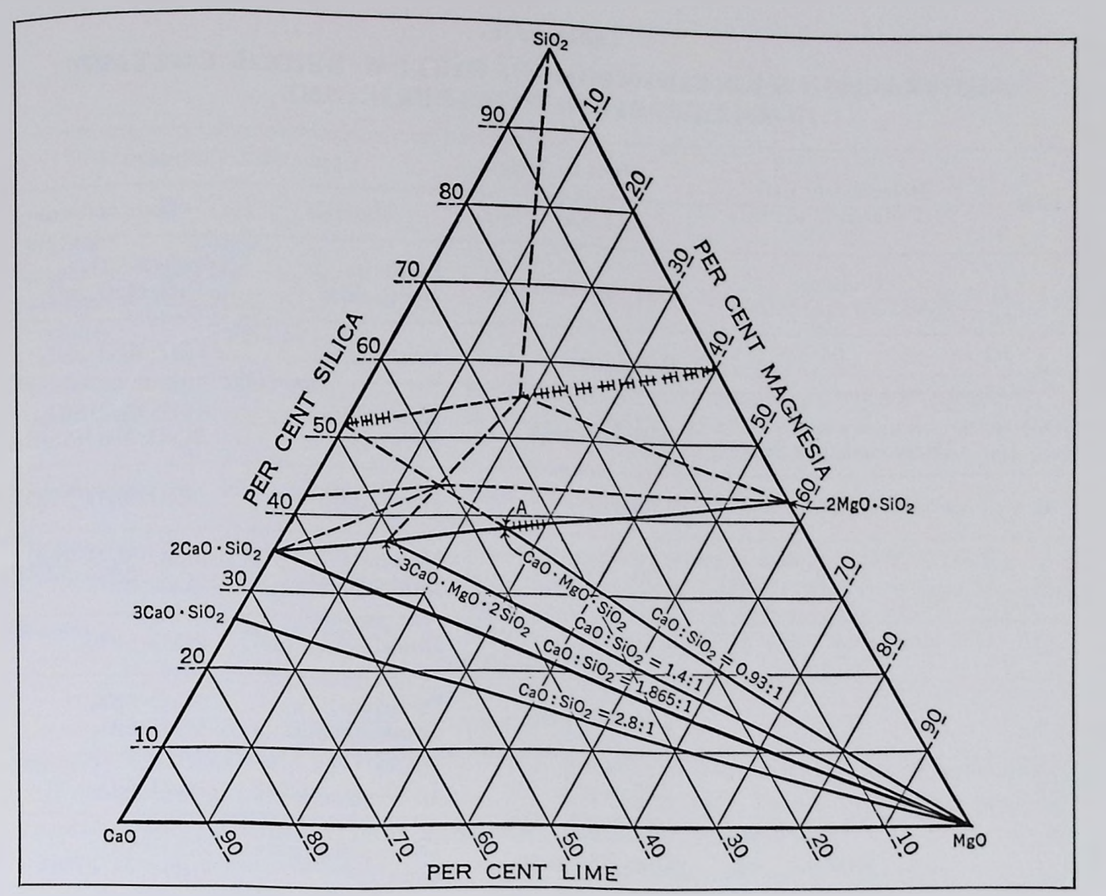


Fig. 51. Composition Triangles in the Lime-Magnesia-Silica (CaO-MgO-SiO_2) System. Compositions are given in weight per cent.

equilibrium with periclase are indicated. For any given composition, the particular silicates which may be present, and their relative proportions, are fixed by the lime-silica ratio.

In that part of the three-component system CaO-MgO-SiO_2 in which magnesia (MgO) is present in great excess, and in which the lime-silica ratio is less than 1.86 to 1 by weight (less than 2 to 1 on a molecular basis), either one or two magnesium-bearing silicate minerals will invariably be present at room temperatures, as shown in Table VIII. If the lime-silica ratio of the high-magnesia composition is 1.86 or higher, no magnesium-bearing silicates will be present.

The lime-silica ratio has an important bearing upon the melting behavior of lime-magnesia-silica compositions. Any combination of lime, magnesia, and silica alone, in which periclase is a component, and in which the amount of lime by weight is *less than 1.86 times* the amount of silica, will develop a liquid phase at 2867°F. (1575°C.), and may develop liquid at a temperature as low as 2714°F. (1490°C.). If completely homogeneous mixtures could be obtained, no combination of these oxides, in which the amount of lime is *equal to or more than 1.86*

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Table VIII.

MINERALS IN THE CaO-MgO-SiO_2 SYSTEM WHICH COEXIST IN EQUILIBRIUM WITH PERICLASE

Case	Molecules of CaO to 1 Molecule of SiO_2	Parts by Weight of CaO to 1 part of SiO_2	Compatible Components	
			Minerals	Compositions
1	Under 1 (Less CaO than SiO_2)	Less than 0.93 parts	Forsterite Monticellite	$2MgO \cdot SiO_2$ $CaO \cdot MgO \cdot SiO_2$
2	1	0.93 parts	Monticellite	$CaO \cdot MgO \cdot SiO_2$
3	1–1½ (More CaO than SiO_2)	0.93–1.40 parts	Monticellite Merwinite	$CaO \cdot MgO \cdot SiO_2$ $3CaO \cdot MgO \cdot 2SiO_2$
4	1½	1.40 parts	Merwinite	$3CaO \cdot MgO \cdot 2SiO_2$
5	1½–2	1.40–1.86 parts	Merwinite Dicalcium Silicate	$3CaO \cdot MgO \cdot 2SiO_2$ $2CaO \cdot SiO_2$
6	2	1.86 parts	Dicalcium Silicate	$2CaO \cdot SiO_2$
7	2–3	1.86–2.80 parts	Dicalcium Silicate Tricalcium Silicate	$2CaO \cdot SiO_2$ $3CaO \cdot SiO_2$
8	3	2.80 parts	Tricalcium Silicate	$3CaO \cdot SiO_2$
9	Over 3	Over 2.80 parts	Tricalcium Silicate Lime	$3CaO \cdot SiO_2$ CaO

times the amount of silica, would form liquid below 3254°F. (1790°C.). However, lower lime-silica ratios, in areas of even microscopic size, would permit small quantities of liquid to form at temperatures lower than 3254°F. (1790°C.), and would cause some coalescing together of particles, even though diffusion at higher temperatures should cause the liquid to disappear.

The Accessory Minerals in Magnesite Refractories: Incomplete data are available concerning the complex six-component system CaO-MgO-SiO_2-Al_2O_3-FeO-Fe_2O_3, the system applicable to refractories which consist essentially of magnesia. However, the more important relationships are fairly well understood. In such mineral compositions, consisting mainly of periclase, if the amount of lime is less than 0.93 times the amount of silica, the minerals forsterite and monticellite will form at high temperatures in the groundmass. If the amount of lime is between 0.93 and 1.40 times the amount of silica, monticellite and merwinite will form; and if it is between 1.40 and 1.86 times the amount of silica, merwinite and dicalcium silicate will form. In all these compositions, any ferrous oxide present dissolves in the magnesia; alumina and ferric oxide combine with the magnesia, forming the spinel minerals $MgO \cdot Al_2O_3$ and $MgO \cdot Fe_2O_3$.

Table IX.

MELTING POINTS OF COMPOUNDS WHICH MAY BE PRESENT IN MAGNESITE REFRACTORIES

		°F.	°C.
Lime	CaO	4660±	2570±
Periclase	MgO	∽5070	∽2800
Spinel	$MgO \cdot Al_2O_3$	∽3875	∽2135
Dicalcium Silicate	$2CaO \cdot SiO_2$	∽3865	∽2130
Forsterite	$2MgO \cdot SiO_2$	∽3450	∽1900

Tricalcium Silicate	$3CaO \cdot SiO_2$	Stable only from 3452°F. (1900°C.) to 2280°F. (1250°C.). At and above 3452°F. (1900°C.) it dissociates into $2CaO \cdot SiO_2$ and CaO; below 2280°F. (1250°C.) it tends to dissociate into $2CaO \cdot SiO_2$ and CaO.
Dicalcium Ferrite	$2CaO \cdot Fe_2O_3$	Melts incongruently at 2617°F. (1436°C.) forming CaO and liquid.
Magnesioferrite	$MgO \cdot Fe_2O_3$	Dissociates slightly; begins to melt at 3115°F. (1713°C.).
Monticellite	$CaO \cdot MgO \cdot SiO_2$	Melts incongruently at 2709°F. (1487°C.) to form MgO and liquid; melting complete at approximately 3000°F. (1650°C.).
Merwinite	$3CaO \cdot MgO \cdot 2SiO_2$	Melts incongruently at 2871°F. (1577°C.) to form $2CaO \cdot SiO_2$, MgO, and liquid.

∽ = *Approximately.*

If the amount of lime equals or exceeds 1.86 times the amount of silica, in the six-component system, the mineral relationships are much more complex, and the lime-silica ratio does not suffice to determine what minerals are present. The lime reacts with silica to form dicalcium or tricalcium silicate, and with alumina and ferric oxide to form calcium aluminates and calcium ferrites. Many attempts have been made to formulate rules whereby the mineral compositions at room temperatures can be calculated from the chemical analyses, but often the calculated compositions are not in satisfactory agreement with the results of microscopic and X-ray determinations.

Forsterite is a common bonding constituent of magnesite refractories of low lime content. It is highly refractory and has no undesirable mineral inversions; it is little affected by the presence of moderate amounts of ferric oxide, but reacts with lime to form the minerals monticellite and merwinite.

Monticellite and merwinite melt at relatively low temperatures, and in minor amounts may have some value in the development of the ceramic bond of magnesite brick. Dead-burned magnesite compositions having a lime-silica ratio favorable to the development of an undesirable amount of monticellite or merwinite can be corrected by the addition of sufficient lime so that there will be 1.86 times as much lime as silica, by weight. When this is done, magnesia is displaced from the silicates, and the lime and silica combine to form the compound dicalcium silicate ($2CaO \cdot SiO_2$).

Dicalcium silicate ($2CaO \cdot SiO_2$) is highly refractory. It does not react with magnesia (MgO), and it is stable in the presence of moderate amounts of ferric oxide (Fe_2O_3). At one time,

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Table X.

MELTING POINTS OF SOME CaO-MgO-SiO_2 EUTECTICS

Eutectics Between These Compounds	Melting Points of Eutectics	
	°F.	°C.
MgO and CaO	∽4172	∽2300
MgO, CaO and $3CaO \cdot SiO_2$	∽3360	∽1850
MgO, $3CaO \cdot SiO_2$ and $2CaO \cdot SiO_2$	∽3255	∽1790
MgO and $2CaO \cdot SiO_2$	∽3270	∽1800
MgO, $2CaO \cdot SiO_2$ and $3CaO \cdot MgO \cdot 2SiO_2$	2867	1575
MgO, $3CaO \cdot MgO \cdot 2SiO_2$ and $CaO \cdot MgO \cdot SiO_2$	2714	1490
MgO, $CaO \cdot MgO \cdot SiO_2$ and $2MgO \cdot SiO_2$	2736	1502
MgO and $2MgO \cdot SiO_2$	∽3380	∽1860

∽ = *Approximately.*

it was regarded as an undesirable component of basic refractories, because of its tendency to turn completely into dust on cooling; this effect results from a mineral inversion at about 1340°F. (725°C.) which is accompanied by an abrupt volume increase of 10 per cent. However, means have been found to prevent the dusting of dicalcium silicate by adding small amounts of stabilizing minerals to the raw magnesite or magnesium hydroxide, before dead-burning. These added materials inhibit the inversion of the silicate on cooling.

The lime compounds tricalcium silicate ($3CaO \cdot SiO_2$) and dicalcium ferrite ($2CaO \cdot Fe_2O_3$), which may occur in magnesite refractories having a high lime-silica ratio, are compatible with dicalcium silicate but do not coexist in equilibrium with monticellite, merwinite, or forsterite. Tricalcium silicate is unstable below about 2280°F. (about 1250°C.), and tends to dissociate into dicalcium silicate and free lime. Dicalcium ferrite is unstable above 2617°F. (1436°C.), and decomposes into free lime and a liquid high in iron oxide. It has been suggested that when this occurs the iron oxide may leave the liquid and combine with magnesia to form the mineral magnesioferrite ($MgO \cdot Fe_2O_3$); and that, if the material is cooled rapidly, the dicalcium ferrite might not re-form. Under these conditions, free lime would be present in the dead-burned magnesite after cooling.

In basic refractories, the state of oxidation of the iron changes with the temperature, and with changes in the oxygen pressure of the furnace atmosphere. When heated in *air*, free ferric oxide loses oxygen at 2530°F. (1388°C.) and changes to the spinel mineral magnetite ($FeO \cdot Fe_2O_3$). If the furnace atmosphere is strongly reducing, iron oxide will be in the form of FeO; if strongly oxidizing, it will be ferric oxide (Fe_2O_3).

An important property of magnesium oxide is its ability to absorb great amounts of iron oxide—either ferrous or ferric—without undue decrease in refractoriness. This property of magnesia, together with its very high melting temperature, is responsible, in large measure, for its value as a refractory. It accounts for the fact that refractories high in magnesia can be used advantageously in the presence of iron oxides, in either an oxidizing or a reducing atmosphere, and also, for some of the particular advantages of steel-encased basic brick.

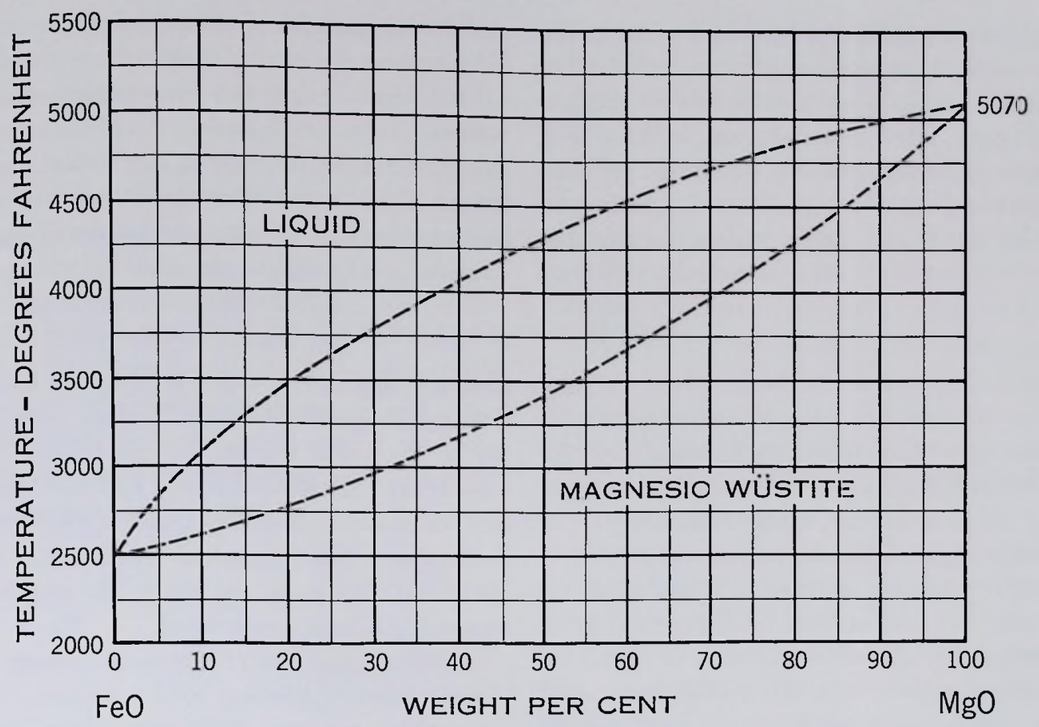


Fig. 52. Equilibrium Diagram of the System FeO-MgO. After N. L. Bowen and J. F. Schairer, Am. J. Sci. 5th Ser., 29,153 (1935).

The system MgO-FeO has not been studied in detail, but the equilibrium diagram is believed to be as shown in Figure 52, if the incongruent melting of FeO is neglected. Magnesium oxide (MgO) and *ferrous* oxide (FeO) form a continuous series of solid solutions which decrease in refractoriness with increasing proportions of ferrous oxide. However, even with more than 50 per cent FeO, the refractoriness is still high.[51-1]

Magnesium oxide reacts with *ferric* oxide (Fe_2O_3) to form magnesioferrite, which begins to melt only at 3115°F. (1713°C.), notwithstanding the fact that it contains 80 per cent Fe_2O_3. With less than 70 per cent Fe_2O_3, the temperature of incipient melting is even higher than 3115°F. (1713°C.).

At ordinary temperatures, iron oxide in dead-burned magnesite or in magnesite brick may be present *within the periclase grains* as MgO-FeO solid solution, or as inclusions of magnesioferrite ($MgO \cdot Fe_2O_3$) particles. If the lime-silica ratio by weight exceeds 1.86, iron oxide may be present also *in the groundmass* in combination with lime and alumina as brownmillerite ($4CaO \cdot Al_2O_3 \cdot Fe_2O_3$), in combination with lime as dicalcium ferrite ($2CaO \cdot Fe_2O_3$), or in solid solution with silicates.

While magnesioferrite is completely soluble in periclase at high temperatures, it separates out upon cooling, unless cooled very rapidly. This accounts for the presence of the dark-colored inclusions in periclase crystals frequently observed in microscopic examination.

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Very dense grains of magnesia often are greenish in their interiors, which were cooled out of contact with air, and chocolate-brown at their surfaces, which were exposed to air during cooling. In the greenish centers the periclase crystals probably contain ferrous oxide in solid solution; in the brown surface portions the periclase crystals contain inclusions of magnesioferrite particles. Porous grains are less likely to have green centers than dense grains.

Dead-burned magnesites sometimes contain somewhat more free lime than would be anticipated from their $CaO:SiO_2$ ratio. The free lime has no disadvantage from the standpoint of melting, but it is very active chemically and slakes upon exposure to the air.

CHROME REFRACTORIES

Ores: Chrome ores in general consist of massive or granular aggregates of chromite crystals, with minor amounts of silicates in the matrix. Refractory chrome ores may be regarded as naturally occurring mixtures of two components: (1) the essential component, a highly refractory chrome-containing spinel; (2) accessory components, consisting mainly of magnesium silicates in the form of interstitial material and veinlets. These silicates are often of complex and widely varying compositions.

Chrome Spinel: The spinel minerals all have the general formula $RO \cdot R_2O_3$ and all crystallize in the cubic system. In the spinels of chrome ores, the RO consists of FeO and MgO (ferrous oxide and magnesia), and the R_2O_3 of Cr_2O_3, Al_2O_3, and Fe_2O_3 (the sesquioxides of chromium, aluminum, and iron). The proportion of Fe_2O_3 is relatively small.

An important property of the spinel minerals is their habit of forming solid solutions, or isomorphous mixtures, with each other. The various spinel minerals are soluble in each other over a very wide range of compositions. Their tendency to form mixed crystals is so great that some of the spinel minerals are not known to occur pure in nature. For example, chromite of the formula $FeO \cdot Cr_2O_3$ is known only in meteorites; all other natural chromites are believed to be isomorphous mixtures.

Table XI.

TYPICAL ANALYSES OF CHROME ORES

Source of Ore	Cr_2O_3	Al_2O_3	FeO*	MgO	CaO	SiO_2	Ignition Loss
Cuba							
Camaguey	31.6	27.3	13.0	18.3	0.6	5.8	2.1
Moa Bay	35.6	26.3	13.9	17.2	0.3	4.1	1.4
Philippine							
Masinloc	32.1	29.2	12.6	18.8	0.6	5.5	1.0
Transvaal							
Hard Lump	41.2	16.8	26.1	9.9	0.6	3.1	0.3
High Grade**	48.4	13.9	22.9	10.7	0.2	2.6	
Rhodesia							
Dyke**	50.7	13.0	16.4	13.2	0.8	4.3	0.9
Dyke**	48.5	11.5	18.3	13.4	0.1	5.6	0.9
Turkey							
Refractory**	37.1	24.4	13.9	17.7	0.2	4.3	1.0
Metallurgical**	48.3	13.0	14.1	16.9	1.0	5.1	1.0
Metallurgical	44.5	16.2	11.9	19.9	0.2	3.9	1.3

* *All iron oxide is reported as FeO; however, a small amount is present as* Fe_2O_3.
** *From Industrial Minerals and Rocks*[69-1], *1960.*

The composition of a chrome spinel (excluding all accessory minerals) may be stated in terms of molecular ratios of RO and R_2O_3. For example, the average molecular composition of the spinel in chromite of one of the larger deposits in the Camaguey district of Cuba is approximately the following:[46-1]

RO		R_2O_3	
MgO	75%	Cr_2O_3	40%
FeO	25%	Al_2O_3	55%
		Fe_2O_3	5%
	100%		100%

This composition may be expressed more simply by the formula $\mathbf{m_{75}f_{25} \cdot (c_{40}a_{55}f_5)}$, in which m = MgO, c = Cr_2O_3, a = Al_2O_3, f outside the parentheses = FeO, f within the parentheses = Fe_2O_3. The subscripts represent molecular percentages.

Typical molecular compositions of certain other chrome spinels, as reported by J. R. Rait[46-2] and others, may be represented by the following formulas:

Cuban (Moa Bay)	$\mathbf{m_{72}f_{28}\ (c_{47}a_{50}f_3)}$
Rhodesian	$\mathbf{m_{66}f_{34}\ (c_{73}a_{21}f_6)}$
Philippine	$\mathbf{m_{73}f_{27}\ (c_{42}a_{55}f_3)}$
Transvaal, brown	$\mathbf{m_{47}f_{53}\ (c_{62}a_{28}f_{10})}$
Turkish,	
Refractory grade	$\mathbf{m_{71}f_{29}\ (c_{42}a_{55}f_3)}$
Metallurgical grade	$\mathbf{m_{74}f_{26}\ (c_{77}a_{19}f_4)}$

There is evidence which indicates that the crystals of balanced spinel in a given specimen of chrome ore may not all be of identical composition. Therefore, the molecular formula of a chrome spinel, calculated from its chemical composition, is merely an average value, and does not necessarily apply strictly to each individual spinel crystal.[46-2]

Frequently, the compositions of chrome ore are reported in terms of individual spinels, as if the ore contained a series of spinels existing side by side. However, the preponderance of evidence is that the individual spinel minerals have no identity as such in the spinel solid solution of a chromite.

Accessory Minerals: The accessory minerals which occur most abundantly in chrome ores are serpentine ($3MgO \cdot 2SiO_2 \cdot 2H_2O$) and chlorite, a complex hydrated silicate of magnesium, iron, and aluminum. The composition of clinochlore, one of the members of this group, is $5(Mg,Fe)O \cdot Al_2O_3 \cdot 3SiO_2 \cdot 4H_2O$. Other accessory minerals include the following:

Olivine	$2(Mg, Fe)O \cdot SiO_2$
Talc	$3MgO \cdot 4SiO_2 \cdot 2H_2O$
Pyroxene	
Diopside	$CaO \cdot MgO \cdot 2SiO_2$
Enstatite	$MgO \cdot SiO_2$
Bronzite	$(Mg, Fe)O \cdot SiO_2$
Hypersthene	$(Fe, Mg)O \cdot SiO_2$
Feldspar	
Anorthite	$CaO \cdot Al_2O_3 \cdot 2SiO_2$

The amount of accessory minerals in commercial chrome ores varies from 5 per cent to 25 per cent. Most of the accessory minerals have relatively low melting points, well below 3000°F. or 1650°C. The heat-resisting qualities of a chrome ore depend largely upon the character and the amount of the silicates which the ore contains.

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Table XII.
IMPORTANT SPINEL MINERALS AND THEIR MELTING POINTS

Mineral	Formula	Melting Point °F.	Melting Point °C.
Ferrochromite	$FeO \cdot Cr_2O_3$	†	†
Picrochromite	$MgO \cdot Cr_2O_3$	3956	2180
Hercynite	$FeO \cdot Al_2O_3$	∽3236	∽1780
Spinel	$MgO \cdot Al_2O_3$	∽3875	∽2135
Magnetite	$FeO \cdot Fe_2O_3$	2901	1594
Magnesioferrite	$MgO \cdot Fe_2O_3$	3115*	1713*

† *Under most conditions, would decompose before melting, on account of oxidation or reduction.*
* *Melts incongruently.* ∽ = *Approximately.*

Analyses and Melting Points: Typical analyses of chrome ores are given in Table XI. The ores used as refractories usually come within the ranges of 31 to 45 per cent chromic oxide (Cr_2O_3), 12 to 20 per cent ferrous oxide (FeO), 14 to 20 per cent magnesia (MgO), 24 to 35 per cent alumina (Al_2O_3), 3 to 6 per cent silica (SiO_2), and less than 1 per cent lime (CaO). The Philippine chrome ores are noted for their high content of alumina. To an increasing extent, ores are being used which contain as much as 26 per cent ferrous oxide and as little as 8 per cent magnesia and 10 per cent alumina.

As might be expected from its constitution, a chrome ore does not have a true melting point, but rather a melting range. The melting behavior of a particular chrome ore depends not only on the composition and refractoriness of its major component chrome spinel, but also on the amount, composition, and melting points of the silicates present, and on the furnace atmosphere, whether oxidizing or reducing.

From Table XII, showing the melting points of individual spinel minerals, it may be inferred that the most refractory chromites are those highest in magnesia and chromic oxide.

In most chrome ores of refractory grade, melting of the silicate impurities begins at temperatures as low as 2300°F. (1260°C.). As the temperature rises, some solution of the spinels in the liquid occurs, but melting of these spinels is not complete until a much higher temperature is reached—possibly as high as 3900°F. (2150°C.).

MINERAL CHANGES DURING FIRING OF CHROME ORE

The thorough investigations of Rigby, Lovell, and Green[16-2] and others,[41-2] concerning the behavior of various chrome ores and synthetic spinels on firing, appear to have established the following facts:

(1) Chrome spinels in general are balanced, containing equal molecular percentages of RO and R_2O_3 constituents.
(2) Most of the iron content of chrome ores is present as part of the RO constituent.

(3) The FeO in the spinel of most chrome ores is readily oxidized to Fe_2O_3 when the ores, or brick containing them, are fired in an oxidizing atmosphere. This results in an unbalance between RO and R_2O_3, as the RO decreases and the R_2O_3 increases. Two solid phases appear: (a) a spinel consisting mainly of $MgO \cdot R_2O_3$ and (b) a solid solution of the excess R_2O_3 constituents (Fe_2O_3, Cr_2O_3, and Al_2O_3). Frequently the solid solution is easily visible under the microscope as needle-like inclusions, as shown in Figure 53.
(4) Chrome spinels of relatively high alumina content appear to have a lesser tendency to oxidize in air at temperatures up to 2640°F. than those high in chromic oxide or iron oxide.
(5) Raw chrome ores, in which most of the iron is present as FeO, are apparently affected relatively little by heating in a reducing atmosphere. However, in a chrome ore which has been fired, the iron is present largely as Fe_2O_3 in an R_2O_3 solid solution, and is readily reduced by heating in a reducing atmosphere. In extreme cases, it may be reduced to metallic iron.
(6) In a chrome ore which has become oxidized on firing, reduction of the Fe_2O_3 in the R_2O_3 solid solution is usually accompanied by expansion and an increase in porosity, and sometimes by cracking. The expansion and cracking are observed only when the oxidized ore is exposed to reducing gases. Repeated oxidation and reduction may cause an ore to become friable. Chrome ores high in alumina show much less tendency to become friable.
(7) When a chrome ore is heated with added magnesia, as in a chrome-magnesite or magnesite-chrome brick, MgO enters the chrome spinel to replace the FeO, as it oxidizes to Fe_2O_3, and also combines with the newly formed Fe_2O_3 to maintain the spinel structures. The new spinel will have essentially the formula $MgO \cdot R_2O_3$.
(8) During oxidation, in the presence of excess magnesia, part of the Fe_2O_3 may leave the spinel crystal as MgO enters, react with MgO, and form a border of $MgO \cdot Fe_2O_3$ surrounding the chrome spinel crystal.
(9) While Fe_2O_3 in the simple spinel $MgO \cdot Fe_2O_3$ is easily reduced, it is much more stable in the spinel $MgO \cdot R_2O_3$, when the R_2O_3 consists of Al_2O_3 and Cr_2O_3, as well as Fe_2O_3. Thus, an oxidizing heat treatment of a chrome ore in the presence of excess MgO to stabilize the spinel renders it less likely to become friable when exposed to alternating oxidizing and reducing conditions.
(10) The stabilization of the chrome spinel by oxidation of FeO and absorption of MgO may be accompanied by a volume expansion of about 5 to 10 per cent, depending on the amount of FeO oxidized. This effect may be partially offset by shrinkage of the silicates present as accessory minerals.
(11) The stabilization of the chrome spinel by MgO increases the refractoriness of the spinel grains, since spinels formed by MgO with Cr_2O_3, Al_2O_3, and Fe_2O_3 have higher melting points than the corresponding spinels formed by FeO.
(12) The added magnesia also reacts with the accessory magnesium silicate minerals of low melting point present in the groundmass of the ore, and converts them to the highly refractory mineral forsterite, $2MgO \cdot SiO_2$. However, the amount of

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magnesia absorbed by the spinel is probably much greater than that which enters into the formation of forsterite in the matrix.

(13) The volume expansion on stabilization with MgO may cause the edges of the spinel grains to shatter, and may also weaken the natural bond between grains. In addition, the increase in refractoriness of the silicate groundmass, resulting from the addition of MgO, may decrease the bonding strength. Therefore a fired chrome-magnesite brick will normally not be as strong at room temperature as a brick consisting only of chrome ore, but is usually stronger at high temperature.

COMPOSITE CHROME-MAGNESITE REFRACTORIES

In the early 1930's, important discoveries were made concerning combinations of chrome ore and dead-burned magnesia. Most of the silicates in chrome ores have relatively low melting points. It was learned that if finely ground dead-burned magnesia were added to chrome refractories, the silicates would be largely converted, during firing, to the refractory mineral forsterite ($2MgO \cdot SiO_2$), which has a melting point of 3450°F. (1900°C.). Later, it was discovered that the addition of the magnesia resulted also in stabilization of the chrome spinel. These discoveries provided great impetus to the use of chrome-containing refractories, since the improvements led to the production of brick of greater utility.

Today, a large proportion of all the basic refractories used commercially consist essentially of blends of dead-burned magnesite and chrome ore in various proportions and in numerous modifications. There are two main groups: (1) chrome-magnesite brick, in which chrome ore predominates, and usually constitutes all the larger grains, while the dead-burned magnesite is confined to the fine-grained groundmass; and (2) magnesite-chrome brick, in which dead-burned magnesite, the main component, consists of a complete range of sizes, while the chrome ore is coarsely ground. However, there are various other modifications of the sizing of the particles.

In the manufacture of chrome-magnesite refractories, considerably more magnesia is customarily added than is required for reaction with the silicates. Part of the excess magnesia enters the chrome-spinel grains to maintain the $RO:R_2O_3$ balance when the FeO of the spinel is oxidized at high temperatures to Fe_2O_3; and part of the magnesia remains in the brick as free periclase.

The mineral relationships in the six-component system $CaO\text{-}MgO\text{-}SiO_2\text{-}Al_2O_3\text{-}FeO\text{-}Fe_2O_3$ have been described on preceding pages. The relationships in the broader system containing Cr_2O_3 also are similar. With a ratio of lime to silica of 1.86 or less, the phases containing lime and magnesia are the same as those shown in Table VIII, and the sesquioxides Cr_2O_3, Al_2O_3, and Fe_2O_3 are combined with FeO and MgO to form spinel solid solutions. Chrome-magnesite brick usually have a lime-silica ratio less than 0.93 by weight, and consist of spinel solid solutions, periclase, forsterite, and monticellite. At high temperatures, periclase absorbs iron oxides from the spinel grains to form solid solutions of MgO with FeO and $MgO \cdot Fe_2O_3$.

With $CaO:SiO_2$ ratios greater than 1.86 by weight, compounds of CaO with the sesquioxides will occur. This condition rarely if ever exists in commercial chrome-magnesite compositions as manufactured, but may occur in service as the result of exposure to basic slags.



Fig. 53. Photomicrograph of High-Iron Chrome Ore after Heating in an Oxidizing Atmosphere.
Reflected Light. Linear Magnification, 110.
The medium gray areas are high-iron chrome-bearing spinel crystals. The lighter areas and straight lines show separation of the R_2O_3 phase formed on oxidation. The dark areas are voids.

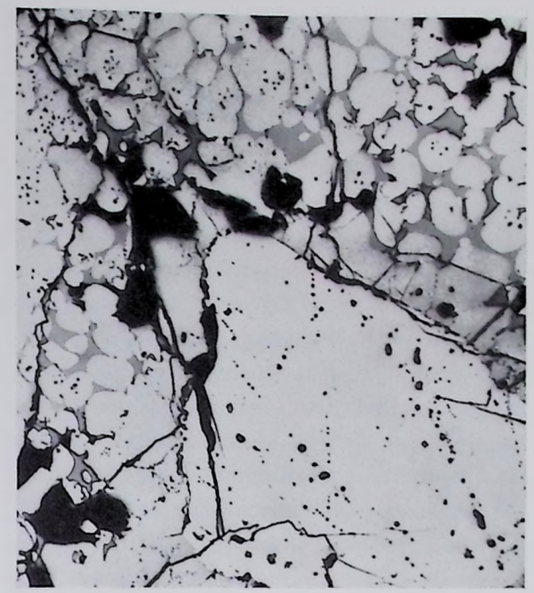


Fig. 54. Typical Section of Burned Magnesite-Chrome Brick.
Reflected Light. Linear Magnification, 110.
The numerous small light-gray areas represent rounded periclase crystals, with interstitial silicates, primarily forsterite. These crystals are shown surrounding a much larger grain of chrome ore. The black areas are voids.

While the addition of magnesia to chrome refractories increases their refractoriness, and has an important effect on their high-temperature mineralogy, the addition of chrome ore to refractories consisting mainly of dead-burned magnesite serves a different purpose. The addition of coarse chrome ore imparts improved spalling resistance to brick consisting mainly of dead-burned magnesia, apparently by providing stress relief in an otherwise relatively rigid structure. Usually, magnesite-chrome brick are chemically bonded and encased in steel sheets. They are also made with internal steel plates.

The mineral changes occurring in magnesite-chrome refractories in service are similar to those which occur in magnesite and chrome refractories. Any forsterite ($2MgO \cdot SiO_2$) or monticellite ($CaO \cdot MgO \cdot SiO_2$) present in the refractory may react with basic slags to produce secondary periclase (MgO), merwinite ($3CaO \cdot MgO \cdot 2SiO_2$), and occasionally dicalcium silicate ($2CaO \cdot SiO_2$). The ferrous oxide (FeO) in the chrome ore oxidizes to ferric oxide (Fe_2O_3) and is replaced in the spinel structure by magnesia. The ferric oxide produced reacts with additional magnesia to form magnesioferrite ($MgO \cdot Fe_2O_3$). The steel plates oxidize also, and the oxide formed diffuses into the magnesia adjacent to the plates to form additional magnesioferrite. Chrome grains adjacent to the oxidized steel plates frequently show growth of magnetite ($FeO \cdot Fe_2O_3$) or magnesioferrite ($MgO \cdot Fe_2O_3$) on the surface of the chrome spinel crystals.

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FORSTERITE REFRACTORIES

Forsterite is a magnesium silicate with the theoretical formula $2MgO \cdot SiO_2$, corresponding to 57.3 per cent magnesia (MgO), 42.7 per cent silica (SiO_2). Its melting point is 3450°F. (1900°C.). Forsterite almost always occurs in homogeneous combination with fayalite ($2FeO \cdot SiO_2$). The series of mixed crystals consisting of forsterite and fayalite is called "olivine" or "chrysolite," while the rock consisting of Mg-Fe olivine, with minor amounts of accessory minerals, is known as "dunite." Commonly the iron content of magnesium olivines used for the production of refractories corresponds to about 15 per cent of fayalite.

The accessory minerals occurring in the olivine used for making forsterite brick are largely serpentine and talc. Serpentine has the composition $3MgO \cdot 2SiO_2 \cdot 2H_2O$, and contains equal amounts of magnesia and silica by weight. The composition of talc is $3MgO \cdot 4SiO_2 \cdot 2H_2O$, corresponding to only half as much magnesia as silica by weight. Upon heating, both these minerals develop large amounts of liquid at relatively low temperatures. At 2838°F. (1559°C.) pure serpentine would form 60.5 per cent forsterite and 39.5 per cent of a siliceous liquid; at 2811°F. (1544°C.) pure talc would become 4.4 per cent cristobalite and 95.6 per cent liquid. In either case, the presence of these natural impurities in olivine lowers the temperature at which liquid forms.

The development of a considerable amount of liquid in a refractory body is not of itself a serious matter. For example, as shown on pages 295 and 296, fireclay brick contain large proportions of liquid at temperatures within their working range. Yet the liquid is so very viscous that there can be no drainage from the pores. However, brick containing magnesium silicate melts behave quite differently. Birch and Harvey[35-2] found that a brick made of Mg-Fe olivine relatively high in accessory minerals, when heated to 2640°F. (1450°C.) developed a melt of such high fluidity that liquid drained freely from the pores. They also found that this drainage could be prevented by the addition of sufficient magnesia to convert the magnesium silicates serpentine and talc into forsterite upon firing, and to combine with the iron oxide present to form magnesioferrite ($MgO \cdot Fe_2O_3$).

Forsterite brick are fired products consisting essentially of olivine with added magnesia. During the firing under oxidizing conditions, important changes take place in the forsterite-fayalite solid solution of the olivine. The forsterite is stable, and persists as such in the finished brick. The ferrous oxide (FeO) of the fayalite oxidizes to form ferric oxide (Fe_2O_3), and the silica of the fayalite is liberated. The ferric oxide then combines with a part of the added magnesia to form magnesioferrite ($MgO \cdot Fe_2O_3$). The silica liberated by the decomposition of the fayalite unites with part of the added magnesia to form secondary forsterite.

A comparable transformation occurs in the accessory silicate minerals. Any serpentine present in fissures or in the groundmass decomposes upon firing to form secondary forsterite and silica. The latter forms additional amounts of secondary forsterite by reacting with a portion of the added magnesia.

An important modification of burned forsterite brick is made by the addition of alumina which during the firing reacts with free magnesia and iron oxide from the olivine to form a solid-solution spinel. This stabilized spinel is highly resistant to growth resulting from cyclic oxidation and reduction.

Part II. CHEMICAL AND PHYSICAL PROPERTIES

SOME PHYSICAL CHARACTERISTICS—COLD

Among the properties of refractories which can be determined most readily are specific gravity, bulk density, porosity, and strength at atmospheric temperatures. These properties are often among those used as controls in the manufacturing process. The density, strength, and porosity of fired products are influenced by various factors, among which are type and quality of the material, the size and "fit" of the particles, water content at time of molding, pressure of molding, temperature and duration of firing, kiln atmosphere, and rate of cooling.

With some materials, the *specific gravity* is used as a measure of the degree to which the crystalline changes brought about by firing have taken place. In the case of most silica brick, for example, a specific gravity below 2.36 would show that the brick were burned to a sufficiently high temperature and for a long enough time to effect a desirable degree of transformation of quartz to cristobalite and tridymite.

The *bulk density*, usually expressed as weight per cubic foot, depends upon the true specific gravity and the porosity. Density of all refractories is an indirect measure of their capacity to store heat. This is a particularly important property in regenerator installations.

The *porosity* of a refractory has an effect upon its resistance to penetration by slags and fluxes, its permeability to gases, and its thermal conductivity.

The *mechanical strength* of refractory brick is governed largely by the amount and character of the groundmass material between the larger grains. The compressive strength is much higher than the tensile strength.

The strength of brick at atmospheric temperatures may provide little or no indication of their strength at furnace operating temperatures above 2000°F. However, the cold strength is an important indicator of the ability of the brick to withstand handling and shipping without damage, and to withstand abrasion and impact in low-temperature applications.

In Table XIII, data are given regarding some of the physical properties of refractory brick. The values shown in Table XIII, and in the other tables of this chapter, are not intended to be applicable to specific brands. In most cases, the figures represent typical data obtained from tests on various brands of refractories made in the United States.

CHEMICAL COMPOSITION

Chemical composition serves as a basis for classification of refractories, and as a guide to their chemical properties and melting behavior. Another important application of chemical analysis, as related to refractories, is in the control of quality of both raw materials and finished products. Minor components once thought unimportant are now recognized as controlling factors in the performance of many refractories. Among the applications of chemical analysis to quality control are the determination of the iron oxide content of some clays, the alumina content of bauxite and diaspore clays, the alumina and alkali contents

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Table XIII.
PHYSICAL PROPERTIES OF REFRACTORY BRICK

Typical Values for Machine-Made 9″ Straights

Type of Brick	True Specific Gravity	Per Cent Apparent Porosity	Cold Crushing Strength-Brick Set on End Lb. per Sq. In.	Modulus of Rupture Lb. per Sq. In.
FIRECLAY				
Superduty, Normal Burn	2.65-2.75	10-20	1500-6000	600-1600
Superduty, High-Fired	2.65-2.75	9-16	2000-8000	1000-3000
High-Duty	2.60-2.70	8-25	1500-7000	500-3000
Medium-Duty	2.55-2.65	10-25	1700-6000	800-2500
Low-Duty	2.55-2.65	10-25	2000-6000	1000-2500
Semi-Silica	2.60-2.70	22-33	1000-3000	300- 900
HIGH-ALUMINA				
50% Alumina Class	2.75-2.85	18-25	2500-6000	1000-1600
60% Alumina Class	2.90-3.05	17-27	1800-7000	600-1800
70% Alumina Class	3.15-3.25	19-30	4000-9000	1200-2200
80% Alumina Class	3.35-3.45	17-30	4000-9000	1100-3000
90% Alumina Class	3.55-3.65	13-25	4000-9000	1200-3500
Mullite Class	3.00-3.20	15-26	3500-9000	1000-3500
Corundum Class	3.75-3.95	20-29	5000-9000	1800-3000
SILICA				
Superduty	2.32-2.38	20-24	1500-3500	500-1000
Conventional	2.30-2.36	22-28	1800-4000	600-1200
BASIC				
Magnesite, Fired	3.40-3.60	16-24	5000-10000	1500-3000
Magnesite-Chrome, Fired	3.50-3.80	20-25	2000-4000	700-1300
Magnesite-Chrome, Chemically-Bonded	3.40-3.80	18-25*	2000-5000	700-1800
Chrome, Fired	3.80-4.10	18-25	3500-8000	1200-3000
Chrome-Magnesite, Fired	3.80-4.00	18-27	2500-4000	1000-1500
Chrome-Magnesite, Chemically-Bonded	3.70-4.00	18-25*	2000-5000	700-1800
Forsterite	3.30-3.40	18-25	1500-4000	700-1300
SILICON CARBIDE	3.17	18-23	6000-15000	2000-4000
ZIRCON	4.68	15-30	5000-12000	1500-2200

*The porosities of the chemically-bonded basic brick were determined after heating the brick to remove the nonpermanent bonding ingredients from the pores.

NOTE: Bulk densities, in pounds per cubic foot, are given on page 462.

Table XIV.
TYPICAL COMPOSITIONS OF FIRECLAY AND HIGH-ALUMINA BRICK

Type of Brick	Per Cent Silica (SiO_2)	Alumina (Al_2O_3)	Titania (TiO_2)	Other Oxides
FIRECLAY				
Superduty	49-56	40-44	1.5-2.5	2.5-4.0
High-Duty	51-61	35-41	1.7-3.0	3-6
Medium-Duty	57-70	25-38	1.3-2.1	4-7
Low-Duty	60-70	22-33	1.0-2.0	5-8
Semi-Silica	72-80	18-26	1.0-1.5	1-3
HIGH-ALUMINA				
50% Alumina Class	41-47	47.5-52.5	2.0-2.8	3-4
60% Alumina Class	31-37	57.5-62.5	2.0-3.3	3-4
70% Alumina Class	20-26	67.5-72.5	3.0-4.0	3-4
80% Alumina Class	11-15	77.5-82.5	3.0-4.0	3-4
90% Alumina Class	7.5-9.0	89-91	0.4-0.8	1-2
Mullite Class	18-34	60-78	0.5-3.1	1-3
Corundum Class	0.2-1.0	98.0-99.5	Trace	0.3-1.0

of silica refractories, and the percentages of silica and lime in chrome ores. Soda, potash, and lithia impurities should be low in blast-furnace refractories, load-resistant semi-silica fireclay brick, and spall-resistant fireclay and high-alumina refractories.

The chemical composition of a refractory brick may not be the most important criterion of its commercial utility, as brick of almost identical compositions may differ widely in their behavior under the same furnace conditions. Chemical analysis alone of a refractory does not permit evaluation of such properties as its stability of volume at high temperatures, or its ability to withstand pressure, slagging, or spalling.

In any given class of refractory brick the various brands commercially available differ considerably in chemical composition. For that reason, the analyses shown in Tables XIV and XV are given in the form of ranges rather than as definite values.

HIGH-TEMPERATURE PROPERTIES OF REFRACTORIES

The most significant properties of refractories are those which enable them to withstand the conditions to which they are exposed in service. These conditions may be classified broadly as thermal, mechanical, and chemical, and various combinations of the three.

Refractories must be sufficiently refractory to withstand the maximum temperatures to which they will be exposed in service, and frequently they must be resistant to the spalling effects of rapid temperature change within critical temperature intervals. They may be required to withstand varying loads, abrasive action, and penetration and corrosion by liquids and gases. For use in some service, the refractories should have low thermal conductivity; for other service, their thermal conductivity should be high.

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Table XV.

TYPICAL COMPOSITIONS OF SILICA AND BASIC BRICK

Type of Brick	Per Cent						
	Silica (SiO_2)	Alumina (Al_2O_3)	Lime (CaO)	Magnesia (MgO)	Iron Oxide (Fe_2O_3)	Chromic Oxide (Cr_2O_3)	Other Oxides
Silica							
Superduty	95-97	0.15-0.35	2.5-3.5	.....	0.3-2.2	.....	0.02-0.10
Conventional	94-97	0.45-1.20	1.8-3.5	.....	0.3-0.9	.....	0.10-0.30
Basic							
Chrome	3-6	15-34	.....	14-19	11-17	28-38	1-2
Forsterite	30-39	1-11	.....	47-55	7-11	.....	1-3
Magnesite	0.7-10.0	0.3-1.5	1.0-3.5	85-93	0.3-7.0	.....	0.5-1.0
Magnesite, High-Periclase	0.5-5.0	0.2-1.0	0.5-1.5	92-98+	0.2-1.0	.....	0.0-0.6
Magnesite, Spinel-Bonded	1.0-2.0	8.5-10.5	1.0-1.5	86-88	0.5-1.0	.....	0.1-0.6
Magnesite-Chrome*	3.0-8.5	4.5-23.0	0.7-1.5	53-82	2.5-7.5	4.5-16.0	.....
Chrome-Magnesite*	4-8	16-27	0.7-1.5	27-53	8-14	18-28	.....

* Composition after heating and removal of all volatiles.

High-temperature properties of refractories which are important in relation to service conditions include the following:

1. Refractoriness.
   Usually measured by P.C.E. tests, temperature of failure under load, or reheat tests.
2. Melting behavior.
3. Mechanical strength and load-bearing capacity.
4. Changes in dimensions when heated.
   (a) Reversible thermal expansion.
   (b) Permanent changes in volume.
5. Resistance to abrasion, mechanical erosion, and impact of solids.
6. Resistance to corrosion and erosion at high temperatures by solids, liquids, fumes, and gases.
7. Resistance to spalling.
8. Permeability.
9. Thermal conductivity.
10. Specific heat.
11. Emissivity.
12. Electrical resistivity.

THERMAL EFFECTS

The one condition obviously common to all furnace operations is high temperature. Resulting from the high temperature, and from the rate of temperature change, is a closely related combination of other thermal effects. Heat energy flows into the refractory structure when the furnace is heated, and a temperature difference develops between inside and outside surfaces of walls and arches. Part of the heat energy is stored in the refractory structure and its foundation, and part flows through walls, arches, and hearths, and is lost to the outside air through radiation and convection.

When refractories are hot, their linear dimensions and their volumes are greater than when they are cold, due to their "reversible thermal expansions." With some refractories, additional volume change, usually not reversible, results from mineral inversions and transformations and sometimes from other causes, such as the "secondary expansion" of some refractory clays, and the overfiring of others.

Within a single brick in a furnace wall or arch, there is commonly a temperature drop of many hundreds of degrees between the hot and the cold face. Consequently, differences in the amounts of thermal expansion in different sections of the brick will cause internal stresses to develop. In a refractory structure, pressure inherent in the furnace construction, such as arch stresses, generally will be increased by thermal expansion of the brickwork. Unequal volume changes resulting from rapid fluctuations in temperature may cause the development of higher stresses within the refractories than they are capable of withstanding.

The amount and viscosity of any glassy constituents of a refractory vary with the temperature, and affect the strength of a brick and its ability to withstand pressure. Crystal development and growth, solution of solids in any molten glass which may be present in the groundmass, or melting of some or all of the constituents of a refractory, will all take place under appropriate conditions. Migration of the liquid phase formed by partial melting of a brick may cause the development of zones in which constituents of relatively low melting temperature are concentrated.

Chemical reactions may occur between the refractories and the materials in the furnace, or in some cases, between different types of refractories in contact. Absorption by the refractories of material from a furnace charge, bath, or slag, or the penetration of gases or fumes into the refractories, may cause the formation of new minerals, and effect changes in the properties of the brick.

FUSION TEMPERATURES OF REFRACTORIES

The terms "melting point," "fusion temperature," and "softening temperature" all refer to the transition of a solid material into the liquid form under the influence of heat. A true melting point is the temperature at which the solid and liquid phases of the same composition coexist in equilibrium. At a very slightly higher temperature the solid will melt and at a slightly lower temperature the liquid will freeze. The terms "fusion temperature" and "softening temperature" both refer to melting which occurs over a range of temperatures.

Most commercial refractories do not have true melting points, but when heated fuse or soften progressively over a range of temperatures, within which the refractory contains both crystalline material and a liquid melt. No definite temperature marks the transition from the distinctly solid to the distinctly liquid state. The ability of a refractory to remain rigid at high temperatures depends not only upon the melting points of its crystalline components or those of the eutectics which may form from them, but also upon the amount and viscosity of any liquid which it may contain.

The different types of refractory materials vary widely in their melting behavior at high temperatures. Some refractories, such as silica, corundum, and magnesite brick, which consist essentially of pure oxides in crystalline form, have a relatively narrow range of melting. Others, such as fireclay and most high-alumina brick, fuse and soften gradually over a relatively wide range of temperatures.

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Table XVI.

TYPICAL PYROMETRIC CONE EQUIVALENTS OF REFRACTORY BRICK

Kind of Brick	Minimum P.C.E. A.S.T.M. C 27-60	Typical P.C.E.	Approximate Temperatures of Cone-Softening Under Test Conditions	
			°F.	°C.
FIRECLAY				
Superduty	33	33 to 34	3175 to 3210	1745 to 1765
High-Duty	31½	31½ to 33	3090 to 3175	1700 to 1745
Medium Duty	29	29 to 31	3020 to 3065	1660 to 1685
Low-Duty	15	15 to 27	2605 to 2985	1430 to 1640
Semi-Silica	—	27 to 31	2985 to 3065	1640 to 1685
HIGH-ALUMINA				
50% Alumina Class	34	35	3245	1785
60% Alumina Class	35	36 to 37	3280 to 3310	1805 to 1820
70% Alumina Class	36	37 to 38	3310 to 3360	1820 to 1850
80% Alumina Class*	—	39	3390	1865
90% Alumina Class*	—	40-41	3505	1930
Mullite Class*	—	38	3360	1850
Corundum Class*	—	42 Minus	3630	2000

* Estimated and shown for convenience. It is generally impractical to obtain the P.C.E. values of high-alumina brick above the 50 or 60% alumina class.

In reporting P.C.E. values the word "to" is used between two standard cone numbers to indicate that different lots of the given material have a range of softening from the lower to the higher value. A dash (-) between two standard cone numbers does not indicate a range, but shows that the material has a position as to softening approximately midway between the two pyrometric cone values.

PYROMETRIC CONE EQUIVALENT

A standard method of evaluating the high-temperature softening behavior of fireclay and some high-alumina refractories consists in the determination of their "Pyrometric Cone Equivalent," abbreviated to "P.C.E.". This method is described in detail in the Manual of A.S.T.M. Standards on Refractory Materials.[57-1]

A ground sample of the material to be tested is molded into the form of "test cones" and mounted in a ceramic plaque at a slight angle with the vertical, with a series of "standard pyrometric cones" having known time-temperature softening values. The plaque is heated at a definite rate until the test cones soften and bend. The number of the standard cone whose tip touches the plaque at the same time as the tip of a test cone is reported as the P.C.E. value of the test cone. The softening temperatures of the Standard Pyrometric Cones are given on page 468.

The P.C.E. does not indicate a definite "melting point" or "fusion point," because the test is not a measurement of temperature, but is merely "a comparison of thermal behavior in terms of standard cones."[44-1]

The P.C.E. test is widely used in evaluating the refractory quality of raw fire clays and in the quality control of fire clays while being mined, and of fireclay products during manufacture.

P.C.E. values of alumina-silica refractories are given in Table XVI.

MELTING BEHAVIOR OF ALUMINA-SILICA REFRACTORIES

Fireclay Brick: Most fireclay brick as placed in service contain both crystalline material and appreciable quantities of a rigid glass developed during the firing procedure. At low temperatures, this glass helps to bond the entire mass strongly together. The amount and strength of the glass is fixed by the alumina-silica ratio, the kinds and amounts of fluxing oxides present, the fineness of grind, and the temperature of firing. Semi-silica fireclay brick contain relatively little glassy material in the groundmass.

When a fireclay brick of the high-duty or superduty class is heated progressively, the glass retains its rigidity up to a temperature of approximately 1800° to 2000°F. (about 980° to 1095°C.), and the brick as a whole remains mechanically strong. As the temperature rises further, the glassy bond begins to lose its rigidity and gradually becomes a viscous liquid. However, within a wide range of temperatures above 2000°F. (1095°C.), the liquid remains so stiff and viscous that the brick as a whole behaves almost as it would if it were entirely solid. Within this range, any deformation occurs only as a result of outside pressure. Under load, the stiff liquid will yield slowly, serving as a lubricant for the solid particles, and permitting them to slide past each other. Under these conditions, the brick will become deformed at a rate dependent upon the amount of pressure and the temperature, which determines the viscosity of the liquid phase. At any temperature, a certain minimum load is required to cause deformation, and a brick of high porosity will usually deform more than one of low porosity.

With still further rise in temperature above the range in which the liquid is extremely viscous, it will increase in amount at the expense of the solid, and will decrease in viscosity, until finally the brick, if heated uniformly throughout, will deform merely under its own weight. The rate of heating has an effect upon the temperature at which this deformation occurs. Finally, at a sufficiently high temperature, all crystalline material suspended in the liquid will be dissolved and the brick will then be completely melted.

In a brick held at a constant high temperature, gradual solution of solid material up to the limit of its solubility in the liquid may cause some increase in the viscosity of the liquid. This fact may explain in part why a hard-burned fireclay brick generally is more resistant to pressure than one which is light-burned, and why a brick which has been thoroughly seasoned in service generally is more resistant to pressure than an unused brick. Additional factors contributing to the increased resistance to pressure are believed to be more thorough distribution of liquid throughout the brick, the growth of crystals through the influence of heat, and crystallization of a portion of the liquid during cooling, resulting from a diminishing capacity to retain dissolved material in solution.

The compressive strength of high-duty fireclay brick changes little between atmospheric temperatures and 1800° to 2000°F. (980° to 1095°C.), and any failure under load below 2000°F. (1095°C.) would occur by crushing or shearing. As the temperature rises above 2000° F. (1095°C.), the compressive strength gradually diminishes, until a condition is reached in which the brick will crush or shear under a relatively heavy load rapidly applied, but will also exhibit slow plastic deformation, similar to the "creep" of metals, under a lighter load.

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Notwithstanding the phenomena of continuous deformation at high temperatures under sufficient load, brick used in furnace walls and roofs rarely fail as a result of compressive stresses. There is a considerable temperature gradient between the inner and outer faces of the brick, and the outer, cooler portions of the brick are strong and rigid, and well able to support any load applied. Conditions are quite different when the refractories are heated to a high temperature all the way through, as in piers, common walls between furnaces, and highly insulated structures. For such service, the refractories used must be those which do not subside too much for the particular conditions at the temperatures and pressures involved.

High-Alumina Brick: The melting behavior of high-alumina brick resembles that of fireclay brick, although the amount of liquid for any given temperature is less. When high-alumina brick of the 50 to 90 per cent Al_2O_3 classes are heated, liquid begins to develop at about 1800° F. (980°C.), if any alkali impurity is present, and at progressively higher temperatures the amount of liquid increases. In the absence of impurities, liquid would begin to form at the Al_2O_3-SiO_2 eutectic temperature, 2903°F. (1595° C.). The rate of increase of the liquid phase, and its amount at any particular temperature, is usually least for brick of the highest alumina content. The temperature at which complete melting occurs is also highest for brick of highest alumina content.

Brick made of fused-alumina grains bonded with fire clay, or of mullite with a similar bond, may develop a small amount of highly viscous liquid in the groundmass at about 1800°F. (980°C.) in proportion to the amount of alkaline impurities. The other fluxes present tend to dissolve in the glass. The amount of liquid in such brick increases very slowly upon progressive heating, and its viscosity decreases up to a temperature of 3000° to 3200°F. (1650° to 1760°C.), above which liquid development may proceed rapidly. In corundum brick, very little liquid is present at any temperature below that of complete melting, about 3630°F. (2000°C.).

Most high-alumina brick undergo slow plastic deformation when subjected to pressure at high temperatures. Brick of the 90 per cent alumina class, corundum brick, and some brick of the mullite type, show superior resistance to pressure at temperatures up to 2900° to 3000°F.

The Load Test: The standard laboratory tests for refractories include one for the determination of the behavior of brick under load at high temperatures. In this test, two 9-inch straight brick are set on end in a furnace of specified design, and a vertical load of 25 pounds per square inch is applied. In the standard procedure, A.S.T.M. Method C 16, the temperature is gradually raised in accordance with a definitely prescribed schedule. For fireclay and high-alumina brick, the maximum temperature is held for 1½ hours, after which the furnace is allowed to cool by radiation to 1830°F. (1000° C.), or lower, before the load is removed. The amount of subsidence is reported as percentage of the original length. The normal temperature of the hold for high-duty fireclay brick is 2460°F. (1350°C.); for superduty fireclay brick, 2640°F. (1450°C.). However, recent improvements in the high-temperature strength of certain types of high-duty fireclay brick, especially checker brick, have led to their being tested at 2640°F. For most classes of high-alumina brick, the top temperature of testing is 2640°F. (1450°C.); for those of the 90 per cent alumina class and for mullite and corundum brick, it is 2900°F. (1595°C.) and 3000°F. (1650°C.).

The temperature of initial plastic deformation of fireclay brick under a pressure of 25 pounds per square inch varies considerably among the various classes, among various brands of the same class, and between hard- and light-burned brick of the same brand. Approximate mean values are 2325°F. for superduty brick, 2250°F. for high-duty and 2175°F. for medium-duty brick. A group of representative high-duty fireclay brick showed no appreciable subsidence even after 100 hours when subjected to a load of 25 pounds per square inch at 2200°F. (1205°C.).[52-1] After 24 hours at 2400°F. (1315°C.) the subsidence varied from 0.9 to 3.8 per cent.

The 1½-hour holding period of the standard procedure terminates the test before the state is reached at which there is a constant rate of deformation. In long-time 25 psi load tests at 2400°F. and 2500°F., two superduty fireclay brick reached essentially a steady rate of subsidence after 20 to 30 hours, whereas most of the high-duty brands tested required 40 to 60 hours. At the end of the 100-hour test at 2400°, the high-fired superduty fireclay brick was subsiding at the rate of 0.006 per cent in length per hour, the normally fired superduty brick at 0.012 per cent, and four brands of high-duty fireclay brick at an average rate of about 0.024 per cent. At a testing temperature of 2500°F., all rates of subsidence were appreciably higher.[52-1]

The load test at 25 psi is an accelerated test, as in service the pressure is usually considerably less than this.

Table XVII.

TYPICAL RESULTS OF LOAD TEST AT 25 POUNDS PER SQUARE INCH—ALUMINA-SILICA BRICK

Type of Brick	Constant Temperature for 1½ Hours		Linear Subsidence
	°F.	°C.	Per Cent
FIRECLAY			
Superduty	2640	1450	2-8
Superduty, High-Fired	2640	1450	0.5-3.0
High-Duty	2460	1350	0.5-7.0
Medium-Duty	2460	1350	3-10
Semi-Silica	2640	1450	0.5-3.0
HIGH-ALUMINA			
50% Alumina Class	2640	1450	4-6
60% Alumina Class	2640	1450	2-5
70% Alumina Class	2640	1450	2-5
80% Alumina Class	2640	1450	1-5
90% Alumina Class	2900	1595	0-3
Mullite Class	2900	1595	1-5
Corundum Class	3000	1650	0.5-1.5

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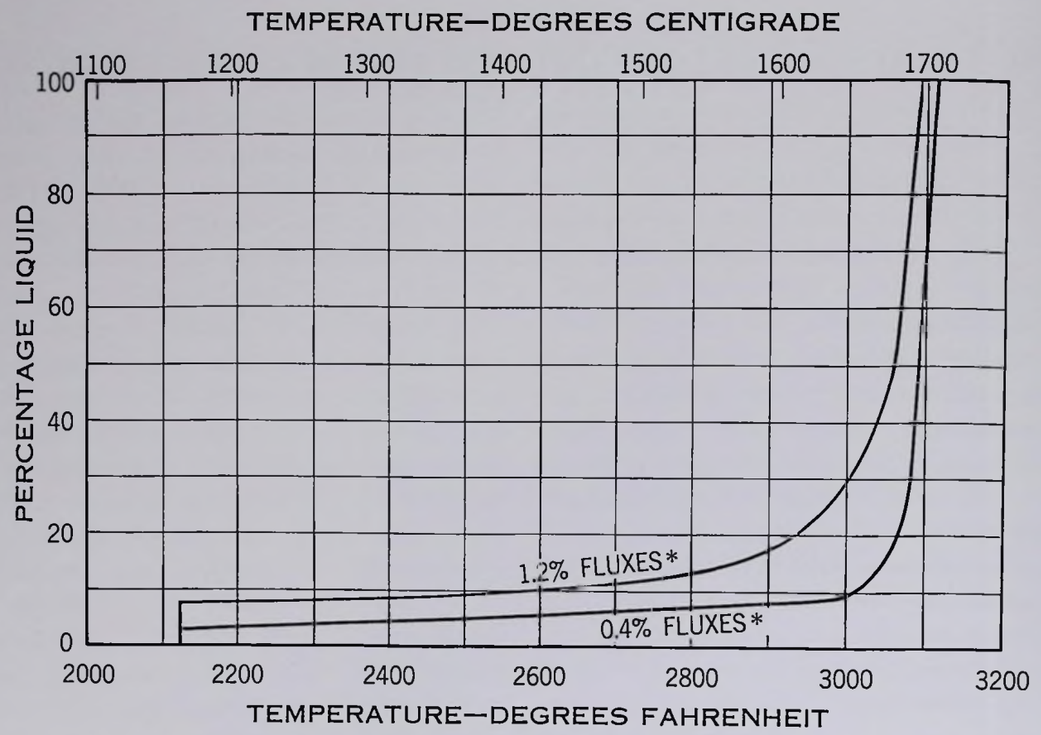


Fig. 55. Estimated Progress of Melting in Two Silica Brick Compositions.
** Total Alumina + Titania + Alkalies.*

MELTING BEHAVIOR OF SILICA BRICK

Silica refractories differ greatly from fireclay refractories in their melting behavior. In the cold condition, a silica brick is almost wholly crystalline. The crystal phase generally consists largely of tridymite and cristobalite, with a small amount of residual quartz. When heated, very little liquid develops below the lime-alumina-silica eutectic temperature of 2138°F. (1170°C.).

R. E. Birch[41-1] has estimated the rate of liquid formation in a silica brick containing 1.2 per cent Al_2O_3 plus TiO_2 and alkalies, and in one containing 0.4 per cent Al_2O_3 plus TiO_2 and alkalies. Because these liquid-forming oxides have similar effects, they were all treated as alumina for the purpose of the calculation. The percentages of liquid at different temperatures were estimated from the equilibrium diagram of the CaO-Al_2O_3-SiO_2 system. As shown in Figure 55, the amount of liquid increases very slowly until the temperature is well above 2900°F. (1595°C.). At 3000°F. (1650°C.), the calculated amount of liquid was about 30 per cent for the brick containing 1.2 per cent fluxes, and only about 10 per cent for the one with 0.4 per cent fluxes.

Even at 2900°F. (1595°C.), silica brick retain their rigidity. The crystalline portion forms a rigid skeleton, with liquid merely between the solid crystals. In the load test at 25 pounds per square inch, conventional silica brick usually fail at a temperature of about 2975° to 3025°F. (1635° to 1665°C.); failure, when it occurs, is abrupt. Superduty silica brick withstand the 25-pound load up to about 3060° to 3090°F. (1680° to 1700°C.), at which temperature abrupt failure by shearing occurs. It is estimated that the brick are about one-third melted at the temperature of failure.

The ultimate melting temperatures of conventional and superduty silica brick differ less than their temperatures of failure in the standard load test. In the absence of outside fluxing agents, a silica brick of the conventional type in a furnace wall or roof may begin to show evidence of surface melting at about 3085°F. (1695°C.); superduty silica, at about 3105°F. (1705°C.).

MELTING BEHAVIOR OF BASIC REFRACTORIES

Most basic brick bonded by firing are composed of highly refractory crystalline granules with a groundmass of finely crystalline silicate minerals. The groundmass of chemically-bonded brick contains also chemical bonding agents, some of which burn out when the brick are heated in service.

Magnesite brick are composed mainly of periclase grains in a silicate matrix or groundmass of small amount. Most of the iron oxide present is distributed uniformly throughout the periclase grains. The silicate groundmass is composed of silica, lime, alumina, a minor portion of the iron oxide, and a small amount of magnesia. Brick of very high magnesia content, as for example 97 to 98 per cent, consist almost wholly of crystalline magnesia (periclase), with very little groundmass material.

Chrome brick consist of chrome spinel grains with a groundmass which is largely magnesium silicate. The groundmass also contains iron oxide and small amounts of lime and other oxides. Forsterite brick are composed of granules which are mainly primary forsterite, and of groundmass material containing secondary forsterite, periclase, magnesioferrite, and a small quantity of other minerals.

The minerals periclase, chrome spinel, and forsterite all have extremely high melting temperatures. Periclase, with a melting point of 5070°F. (2800°C.) is the most refractory of this group. However, the groundmass material in basic refractories may vary widely in refractoriness. In some magnesite compositions, for example, liquid begins to develop in the groundmass at temperatures little if any above 2300°F. (1260°C.); in others, at temperatures probably approaching 2700°F. (1480°C.). Hence, the softening behavior under heat and the ultimate refractoriness of basic brick are fixed largely by the amount and composition of the groundmass minerals. A basic brick as a whole will be highly refractory either if the groundmass material has a high melting temperature, or if it is small in amount.

In the rising-temperature load test at 25 pounds per square inch, most basic brick fail abruptly by shearing, when the temperature becomes high enough to weaken the bond. The temperature of failure will range from about 2350° to 2600°F. for chrome brick, and 2700° to above 3100°F. for other basic brick, depending upon the composition of the refractory, the kind and amount of groundmass material, the method of manufacture, and the temperature at which the brick were fired.

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Table XVIII.

TYPICAL RESULTS OF LOAD TEST AT 25 POUNDS PER SQUARE INCH—BASIC BRICK

Type of Brick	Rising Temperature — Brick Fail at Temperatures Above	
	°F.	°C.
BASIC		
Chrome, Fired	2350-2600	1290-1425
Chrome-Magnesite, Fired	2850-3050	1565-1675
Chrome-Magnesite, Chemically-Bonded	2750-3000	1510-1650
Magnesite, Fired, Regular	2700-3050	1480-1675
Magnesite, Fired (Highest magnesia content)	2900-3100+	1595-1705+
Magnesite-Chrome, Fired	2900-3050	1595-1675
Magnesite-Chrome, Chemically-Bonded	2700-2900	1480-1595
Forsterite, Fired	2950-3050	1620-1675

CHANGES IN DIMENSIONS

Permanent Changes at High Temperatures: In the firing of refractory brick, permanent changes in dimensions generally occur, altering the individual brick from the mold size to the fired size. It is desirable that these changes be completed in the firing, as far as is industrially possible, in order to prevent excessive expansion or shrinkage later in service. However, the changes in dimensions and in volume require time as well as a suitable temperature for their completion. As firing proceeds, the rate of change in dimensions gradually diminishes to such an extent that it is rarely feasible to attain complete expansion or contraction during the firing process. In service therefore, if the furnace temperature is high enough, and if it is maintained for a sufficient length of time, there will be an additional change in dimensions, generally slight and of a permanent character. Excessive changes in dimensions in service are objectionable, on account of their harmful effects on the stability of the furnace.

Determination of the amount of permanent change in the dimensions of refractory brick which may occur at high temperatures is made by subjecting them to a reheat test.

High-temperature reheat tests may be used to reveal (1) whether a refractory brick of a given quality has been fired long enough, or at a high enough temperature, or if not fired, whether it is made of sufficiently volume-stable materials, and (2) whether a brick has adequate refractoriness and volume stability. The tests may be thus used to estimate refractoriness. The results however must be interpreted with caution as the amount of shrinkage or expansion of a refractory depends not only on its characteristics, but also on the temperature and time of heating during the tests. The results of a short-time reheat test may not be a sufficient basis for predicting the long-term volume changes which a refractory may undergo in service, at a different temperature, and under other different conditions.

In the Standard A.S.T.M. Reheat Test, Method C 113, the brick are placed in a furnace and gradually heated to a predetermined temperature, which is held for five hours. After cooling, measurements are made to determine the change in linear dimensions and volume.

In the reheat test at 2550°F. (1400°C.), high-duty fireclay brick generally show a slight linear contraction, up to 1.5 per cent. In the test at 2910°F. (1600°C.), superduty fireclay brick usually shrink 0 to 1.0 per cent in length. Some fireclay brick expand slightly in the reheat test. However, the expansion generally does not occur if the brick are subjected to a slight pressure.

For high-alumina brick of the 50 to 80 per cent alumina classes, the temperature of the reheat is usually 2910°F. (1600°C.). Some brick show a linear shrinkage up to 2.0 to 2.5 per cent; others an expansion up to 3.5 per cent or more. For brick of the 90 per cent alumina class, for corundum brick, and for mullite brick, the temperature of the test may be 3140°F. (1725°C.), and the linear change is usually within the range of minus 0.5 per cent to plus 1.5 per cent.

The reheat test is not usually applied to silica brick, as the apparent specific gravity provides an adequate measure of the amount of permanent or residual expansion.

In the reheat test at 2910°F. (1600°C.), most basic brick show a slight linear shrinkage, varying from a few tenths of a per cent or less for some types of brick, up to 2.5 per cent for others. Chemically-bonded chrome-magnesite brick have a slight linear expansion in the test, generally amounting to less than 1 per cent. High-fired chrome-magnesite brick usually have little or no shrinkage in the reheat test at 2910°F. (1600°C.) and a shrinkage of only some tenths of a per cent at 3000°F. (1650°C.).

Permanent expansion of refractory brick at high temperatures may result from various conditions, including the following:

(a) Mineral Formation and Transformation: As one example of expansion from this cause, certain high-alumina brick are made of a calcined alumina mineral—diaspore or bauxite—blended with refractory fire clay. Such brick when heated may show a permanent expansion which is attributed to additional formation of mullite, by reaction of particles of free alumina with silica from the clay. Another example is provided by silica brick, which may expand slightly in a high-temperature reheat test, as a result of transformation of any residual quartz to cristobalite and tridymite. In the test, unless the brick are heated and cooled slowly through the low-temperature range, microscopic internal cracks may develop which will cause a small increase in the exterior volume.

(b) Secondary Expansion: A permanent linear expansion on reheating, with some increase in porosity, is known as "secondary expansion." It is a characteristic of various highly refractory clays. It may possibly be caused by separation of clay particles along original bedding planes. The secondary expansion may be fairly high in amount when single brick, not confined in any way, are tested; but it is small in amount if the brick when heated are subjected to even light pressure, as in a furnace wall. In many cases this slight expansion is advantageous, for it tightens the joints.

(c) Overfiring: When certain clays, such as the plastic clays used for making ladle brick for the steel industry, are heated beyond a critical temperature, they tend to swell and become vesicular. This phenomenon is known as "overfiring."

Reversible Thermal Expansion: In common with practically all structural materials, refrac-

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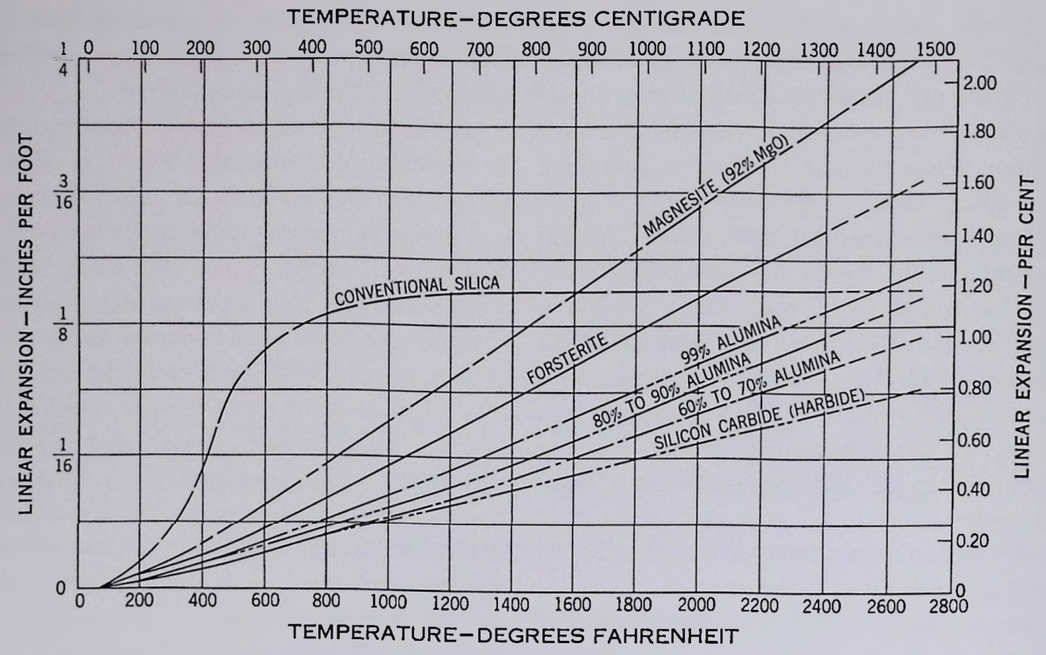


Fig. 56. Approximate Reversible Thermal Expansion of Refractory Brick.

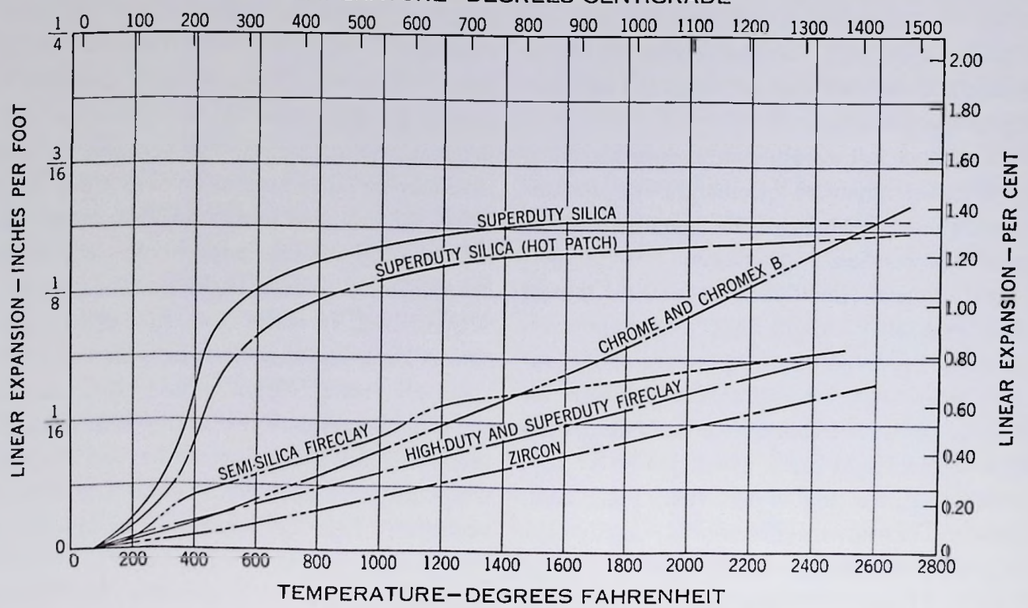


Fig. 57. Approximate Reversible Thermal Expansion of Refractory Brick.

tory brick expand when heated and contract when cooled. If no changes of a permanent nature occur during the heating, the brick return to their original dimensions when cooled. This effect, therefore, is known as the "reversible thermal expansion."

The linear thermal expansions of a number of types of refractory brick are given in Figures 56 and 57. The expansions of different brands in each class of refractory differ somewhat among themselves, and the data therefore represent mean values. Magnesite and forsterite brick have relatively high rates of thermal expansion; fireclay, silicon carbide, zircon brick, and most insulating firebrick have relatively low rates. The thermal expansions of other refractories have intermediate values.

The thermal expansion of most refractories proceeds at a fairly uniform rate over their entire working range of temperature. However, the greater part of the expansion of silica brick takes place below 800°F. (about 425°C.).

RESISTANCE TO ABRASION AND IMPACT

In many types of service, refractories are subjected to impact of heavy pieces of material charged into the furnace; abrasion by moving metallic or nonmetallic solids; or direct impingement by abrasive dusts in rapidly moving gases. For greatest resistance to these actions, the brick should be mechanically strong and well-bonded, hard and tough.

A common method of evaluating the low-temperature abradability of refractories is by means of a standard rattler test (A.S.T.M. C 7), which indicates the combined effects of impact and abrasion. Other methods have been investigated which depend on abrasion by impingement. In these tests, the surfaces of the specimens are blasted with an abrasive granular material such as silica sand or silicon carbide grains, or with small iron or steel shot. The brick which are strongest generally show the highest resistance to abrasion. As compared with other properties, the modulus of rupture apparently gives the best indication of resistance to abrasion of this kind.

It is considered probable that the resistance to abrasion of some refractories, such as high-duty fireclay brick, increases somewhat between atmospheric temperatures and 2000°F. On the other hand, the resistance of chemically-bonded brick when heated to moderate temperatures is considerably less than before heating. Data are not available concerning the relationship between the resistance to abrasion of refractories at atmospheric temperatures and at furnace operating temperatures.

SPALLING

Spalling may be defined as the loss of fragments or spalls from the face of a refractory brick or structure through cracking and rupture, with exposure of inner portions of the original refractory mass. In various types of furnace operation, the service conditions are necessarily such as to expose the brickwork to spalling influences. The resistance of refractory brick to spalling is enhanced by proper design of the shapes, by optimum sizing of the grains, and by close control of each step in manufacture. For a given refractory the amount of spalling which occurs in service can be reduced to a minimum by proper design, construction,

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and operation of the furnaces.

Spalling of refractory brick is of three general types: thermal, mechanical, and structural.

Thermal Spalling: This type of spalling is caused by stresses resulting from unequal rates of expansion or contraction in different parts of the brick, and usually is associated with rapid changes in temperature. The brick of greatest resistance to thermal spalling are those having the lowest average thermal expansion, with freedom from a high rate of thermal expansion through any narrow temperature range, high tensile strength, and a texture conducive to flexibility and relief of stress. With other factors equal, the temperature gradients and the stresses which cause spalling are least in brick having the highest thermal conductivities. A refractory of a given mineral composition will usually have the maximum resistance to spalling when the extensibility, the ratio of strength s to modulus of elasticity E (s/E) is a maximum.

The spalling characteristics of fireclay brick are largely dependent upon the proportion of free silica in the constituent clays, upon the size and "fit" of the particles, and upon the amount and composition of the glassy bond. The amount and character of the glass is fixed by the quantity and kind of accessory minerals in the clays, and by the time and temperature of firing. Within the temperature range at which the glass is rigid (from room temperature up to 1800° to 2000°F., or 980° to 1095°C.), a high content of glass is conducive to spalling. However, at temperatures high enough to cause the glassy bond to become somewhat viscous, fireclay brick are very resistant to spalling.

Relatively porous high-duty fireclay brick, when light burned, are usually more resistant initially to thermal spalling than are denser hard-burned brick, and they retain this property in service if subjected to temperatures which are low or merely moderate. However, if the light-burned brick are subjected to high temperature in service, their spalling resistance is lowered.

Superduty fireclay brick of the spall-resistant type, while dense and hard burned, have very high resistance to thermal spalling, and they retain this resistance upon exposure to high temperatures.

Some high-alumina brick also have excellent resistance to spalling. However, some brands of fireclay and high-alumina brick are customarily used in service where other properties are much more important than ability to withstand thermal shock, and these essential properties may be enhanced in manufacture at the expense of spalling resistance.

Most silica brick are sensitive to rapid temperature change below a dull red heat, on account of the abrupt volume change accompanying the crystalline inversion of the mineral cristobalite. However, silica brick may be heated very rapidly without thermal spalling after they have reached a temperature of about 1200°F. (650°C.) throughout, and they may safely be cooled rapidly from furnace operating temperatures to about 1200°F. (650°C.).

A spalling test used for silica brick consists in placing a panel of brick in the door of a furnace and heating the furnace to 1500°F. at successively higher rates until visible cracking occurs. Under the conditions of this test, a heating rate higher than 200°F. per hour generally caused visible cracking in the usual silica brick, while spall-resistant brands could be heated without cracking at rates of 500°F. per hour or somewhat higher. In furnace practice, safe rates of heating will be determined by various details of furnace design and operation.

Basic brick in general do not have as high resistance to thermal spalling as fireclay and high-alumina brick. However, by proper selection of raw materials, and by appropriate manufacturing techniques, basic brick of superior resistance to thermal shock are made. Among those of highest resistance to spalling are brick of high periclase content with a bond of magnesium aluminate spinel or of chrome spinels. The metal encasing of basic brick has the effect of increasing spalling resistance at lower temperatures by holding pieces in place even after cracking occurs. This effect also extends to higher temperatures by oxidation of the metal, reaction with the magnesia, and formation of a continuous bond between adjacent brick.

Mechanical Spalling: The spalling of a refractory brick caused by stresses resulting from impact or pressure is known as "mechanical spalling." Shattering or spalling of brickwork may result from such influences as the rapid drying of wet brickwork; inadequate provision for thermal expansion; or pinching of hot ends of brick, especially in furnace arches.

The brick which are strongest and toughest at operating temperatures have the greatest resistance to mechanical spalling.

"Pinch spalling" is frequently observed in sprung arches because the hot ends of the brick expand more than the cold ends. This condition is aggravated by rapid heating, because the furnace structure cannot adjust rapidly to the expansion forces. The differential expansion may cause a concentration of arch stresses upon relatively small bearing surfaces at the inner ends of the brick. Insulation decreases the temperature gradient through a roof arch, and tends to reduce pinch spalling somewhat.

Structural Spalling: Structural spalling is defined as "the spalling of a refractory unit caused by stresses resulting from differential changes in the structure of the unit."[57-1] The word "structural," as used in this connection, does not refer to the furnace or the furnace lining assembly, but to the texture of the individual brick units in the lining.

Contributing to structural spalling are changes which occur in service, in the texture and composition of the hotter portions of the brick, through the action of heat, through the absorption of slags or fluxes, and through their reactions with the refractory. These alterations may result in the formation of zones in the brick which differ in their mineral content, and in their chemical and physical properties. Following the development of a zoned structure, the hot ends of the brick may spall or fall off for various reasons, including differences in thermal expansion or contraction between adjacent zones, increased sensitiveness to rapid temperature change, or the presence of shrinkage or expansion cracks.

Panel Spalling Test: This test, which is applicable to fireclay, most high-alumina, and some basic brick, is intended to measure the comparative resistance of the brick to thermal and structural spalling. In the A.S.T.M. Standard Method C 38, 14 brick are laid as stretchers in a movable panel, to form a section about 18 inches square. One side of the panel is backed with insulation, while the other side is exposed to the desired heat treatments. The test consists of the following procedure:

(a) A 24-hour preheat at 2910°F. (1600°C.) for high-duty fireclay and some high-alumina brick, or 3000°F. (1650°C.) for superduty fireclay, most high-alumina, and basic brick.

(b) A thermal shock treatment, consisting of 12 cycles in which the face of the panel is alternately heated to 2550°F. (1400°C.) and cooled in a specified manner.

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Table XIX.
TYPICAL RESISTANCES OF REFRACTORIES TO THERMAL SPALLING

Type of Brick	Comparative Resistance to Spalling*
FIRECLAY	
Superduty	
(a) Spall-Resistant	Superior
(b) Regular	Excellent
High-Duty	
(a) Spall-Resistant	Good
(b) Regular	Fair
Semi-Silica	Good
HIGH-ALUMINA	
45, 50, and 60% Alumina Classes	Superior to Good
Classes above 60% Alumina	Superior to Fair
SILICA	
All Types	Excellent above 1200°F. (650°C.)
General Duty (Conventional and Superduty)	Poor below 1200°F. (650°C.)
Spall-Resistant (Conventional and Superduty)	Fair below 1200°F. (650°C.)
BASIC	
Chrome, Fired	Fair
Chrome-Magnesite, Chemically-Bonded	Good to Fair
Chrome-Magnesite, Fired	Good to Fair
Magnesite, Fired or Chemically-Bonded	Fair
Magnesite, Fired (High-Periclase)	Excellent
Magnesite-Chrome, Chemically-Bonded	Superior to Excellent
Magnestie-Chrome, Fired	Very Superior to Excellent
Spinel-Bonded Magnesite, Fired	Superior
Forsterite	Fair

*NOTE: In the table above the brick have been divided into groups. The ratings as to spalling resistance are comparative only within each group.

Results are reported in terms of the average percentage loss in weight.

In some applications, high resistance to spalling is not an essential requirement. For these conditions, the brick may be made by manufacturing techniques which enhance other physical properties without particular regard to the effect on spalling resistance.

Data on the comparative spalling resistance of various refractories are given in Table XIX.

PERMEABILITY

In service, the extent to which refractories are penetrated by fluids or gases frequently has an important bearing upon their utility. A completely impermeable refractory would be attacked by molten fluxes only at exposed faces. However, when a flux penetrates into the pores, the area exposed to chemical attack is multiplied many times. Such an effect as the deposition of carbon within the pores of a brick, through decomposition of carbon monoxide gas, depends upon the ability of the gas to penetrate the refractory.

While permeability of a refractory is related to its porosity, the relationship is not direct. The volume of a fluid or gas which flows into or through a refractory body per unit of time is influenced by the number and size of the open pores, the extent to which they are interconnected, and the orientation and diameters of the connecting channels. The temperature also is important, because it affects not only the volume of a gas, but also the viscosity of the penetrating gases and other fluids. The viscosity of molten slags, fluxes, and glass decreases with rising temperatures, and their ability to penetrate a refractory therefore in-

Table XX.
TYPICAL RESULTS OF PERMEABILITY TESTS

Type and Class of Brick	Relative Permeability to Air at Atmospheric Temperature
FIRECLAY	
Superduty	Moderate to High
Superduty, Blast-Furnace, High-Fired	Low
High-Duty, Power-Pressed	Low to High
Semi-Silica	Low to High
SILICA	
Superduty	High
Conventional	High
HIGH-ALUMINA	
60% Alumina Class	Moderate
70% Alumina Class	Very Low to Low
80% Alumina Class	Very Low to Low
90% Alumina Class	Very Low to Low
Corundum (99+% Al_2O_3)	Moderate
BASIC*	
Chrome, Fired	Low
Chrome-Magnesite, Fired	High
Chrome-Magnesite, Chemically-Bonded	Very Low
Magnesite, Fired	Low to Moderate
Magnesite-Chrome, Chemically-Bonded	Very Low
Magnesite-Chrome, Fired	High
FORSTERITE L, Fired	Low to Moderate
SILICON CARBIDE, Clay-Bonded	Very Low
ZIRCON	Very Low

* Chemically-bonded basic brick, in the cold condition, are almost impermeable. At high temperatures, they lose this property. In service at high temperatures, the hot ends of such brick may be permeable to furnace gases, while the cold ends may remain almost impermeable.

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creases. However, as shown by Clews and Green,[32-1, 33-1] the rate of flow of air through refractory brick decreases as the temperature rises, being only about 0.4 times as great at 1560°F. (850°C.) as at 50°F. (10°C.). It was shown that the decrease in permeability is caused by increase in the viscosity of the air with rising temperature. The viscosity of other gases also increases with rising temperatures.

The Harbison-Walker Research Department has determined the relative permeabilities of full-sized 9-inch straight brick to air at room temperature under a definite applied pressure. The results show wide differences in the permeabilities of different types of refractories, and even of different brands of the same type. Insulating firebrick have the greatest permeability, as well as the widest range of permeability. The permeability of blast-furnace brick was found to be extremely low.

CHEMICAL REACTIONS AFFECTING REFRACTORIES

In most types of furnaces, chemical action is one of the greatest factors contributing to the ultimate destruction of the refractory linings. In service, a refractory material may react with material charged into the furnace, with slags or other products of furnace operation, with fuel ash, with furnace gases, with fumes or dust in the gases, or in some cases with other refractory materials. Most metallurgical slags, lime added as a flux, glass batches, the oxides of metals, alkaline earths, and portland cement clinker have destructive chemical action upon refractory materials. Coal ash of low-fusion point and high in basic oxides is very corrosive, as are the various kinds of ash resulting from the burning of some fuel oils, wood, sugar mill bagasse, and other organic materials.

Absorption by the refractories of liquid material from a furnace charge, bath, or slag, or the penetration of gases or fumes into the refractories, may change the size and orientation of crystals, form new minerals or glass, and thus alter the texture and change the physical and chemical characteristics of the brick. Continuing corrosion of a refractory requires both a continuing supply of fluxing agents and removal of the reaction products.

The term "slag attack" is used to designate (a) chemical reactions and solutions which corrode the surface of a refractory lining in service, and (b) reactions which take place within the refractory between it and molten slag or other fluxing agents which have been absorbed. Erosion, a physical process, often accompanies or follows corrosion, a chemical process. An example of erosion is the washing away of granules of a refractory after the bond between the grains has been dissolved by a flux.

The compositions of many industrial slags, of the refractories which they contact in service and of the reaction products derived from them are exceedingly complex. Consequently the nature of the reactions between slags and refractories is not well understood, and the available equilibrium diagrams do not suffice to explain these reactions satisfactorily. Because of the many variables involved in the corrosion of refractories, it has not been found possible to adopt a single slag test of general utility.

The most advantageous selection of refractories frequently is governed by the chemical nature of fluxing agents present in the furnace. Alkaline materials are highly basic; most metallurgical slags and metallic oxides are basic; and fluxes high in silica are acidic. It is a natural assumption and generally true that basic refractories should be used in service where basic fluxes come in contact with the furnace linings, and acid refractories with acid fluxes. However, there are many exceptions to this general principle, due to differences in operating and reaction temperatures, reaction rates, viscosities of reaction products, and the formation of protective glazes and coatings upon the refractories. Moreover, as shown in Figure 48, page 272, small proportions of free lime or ferrous oxide have relatively little effect upon the melting temperature of silica, notwithstanding the fact that these oxides are highly basic and silica is highly acidic. However, large amounts of ferrous oxide may be very damaging to silica brick at high temperatures.

Fireclay, high-alumina, or silica brick generally are used where the corrosive agent is acidic. Fireclay or high-alumina refractories may be preferred if the flux is only slightly basic, while for use in contact with highly basic slags, the refractories which give best service generally consist of magnesia, chrome, or a blend of these two materials.

In some batch operations, the nature of the slag may change during the processing cycle. Thus a slag which is acidic at the beginning of the heat treatment may become basic in later stages. The refractories which are exposed to both types of slag should have reasonably good resistance to corrosion by both. In general, basic brick of special compositions give best service.

Fireclay brick in general serve well to resist coal ash, and high-alumina brick to withstand the corrosive ash of fuel oil. Silica brick are resistant to dusts and fumes containing ferric oxide, magnetite, or lime. However, they are not resistant to molten slags which are high in lime or in other basic oxides. Silica, basic, and high-alumina brick all are used with good results in contact with strongly alkaline dusts and fumes within their temperature limits, which may be widely different for different conditions of exposure.

The intensity of the corrosive action will depend upon such conditions as the following:

1. Factors Related to the Furnace.

- Nature of the furnace operation.
- Furnace design.
- Position of the refractory in the furnace.
- Temperature of operation.
- Furnace atmosphere.

2. Factors Related to the Refractories.

- Chemical and mineral composition of the refractory material.
- Porosity and permeability of the refractory.
- Temperature gradient through the brick, which governs the depth to which a molten flux will penetrate.

3. Factors Related to the Fluxing Materials and Reaction Products.

- Chemical composition and melting temperature of the fluxing agent.
- Rate at which the fluxing agent is supplied.
- Fluidity of the fluxing agent at the furnace temperature.
- The tendency of the flux to "wet" and penetrate the refractory.
- Rate of reaction between the fluxing agent and the refractory. Rates of reaction generally increase rapidly as the temperature rises.
- Agitation or turbulence of molten fluxing agent flowing down the face of the furnace wall. The turbulence is usually caused by moving gases.
- Fluidity of the reaction product.
- Rate at which the reaction product flows away from the face of the refractory, or is removed in other ways.
- Turbulence of a slag floating upon a molten bath.
- Convection currents, as in a molten bath, such as glass.
- Static head of a molten bath.

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The temperature at which brick and slagging agents react is often the principal factor governing the maximum allowable furnace temperature. In some cases, a temperature rise of a relatively few degrees above a point of safe operation will cause destruction of a lining in a short time. Therefore, a change in furnace practice which raises the operating temperature even slightly may necessitate a change in the type of refractory used.

The relative chemical characteristics of the refractories and fluxing agents in contact determine the character of the reaction products, but do not necessarily determine the rates of reaction. If the reaction between fluxing agent and refractory occurs rapidly, the reaction products may be formed in large amounts, and the amount of corrosion will be severe. If the rate of reaction is low, the products will be formed in small amounts, and the refractory may have excellent resistance to attack.[49-1] A furnace slag or product of high viscosity may freeze and adhere to the lining, forming a coating. Under some conditions of operation, as in rotary cement kilns, this coating acts as a protective layer, shielding the brickwork from chemical attack and from abrasion. Another example of such protection is afforded by the magnetite coating on copper converter linings. It is important that the operating conditions be so regulated as to retain the coating, while avoiding excessive build-up which would restrict the areas of furnace openings. Coatings which gradually increase in thickness usually must be removed periodically. When this is done the brick are subjected to mechanical damage by the tools used, and not infrequently portions of the brickwork are broken away with the coating.

A slag or fuel ash of low viscosity will tend to flow down a furnace wall, leaving only a thin coating. The extent to which it will corrode the brick chemically will depend not only on the compositions of the slag and refractory, but also on the rates at which fresh slag is supplied, and at which it flows down the surface of the refractory. The lining may gradually become thinner as brick material is dissolved by the slag and washed away, and as undissolved particles become loosened and removed. The depth of slag penetration depends upon various factors, of which the permeability of the brick, the temperature drop through the refractory wall, and the temperature-viscosity relations of the slag are among the most important.

At high temperatures, basic brick containing chrome ore may absorb molten magnetite or magnetite fumes. Under these conditions, the exposed end of the brick may increase greatly in volume and break off. This phenomenon is referred to as a "bursting expansion." It can be largely overcome by the use of chrome-magnesite or magnesite-chrome brick having a special composition and texture.

Dust and fume in furnace gases may have a strongly corrosive action upon refractories. This is illustrated by the effect of the alkaline dust and volatilized alkalies upon the ports, regenerator walls, arches, and checkers of glass tanks. Alkaline vapors in furnace gases tend to cause a surface glazing of fireclay brick linings, especially those of the semi-silica class.

In service at temperatures too low to cause severe surface corrosion, soda or potash in furnace dust or fumes may react with fireclay brick and some high-alumina brick, forming either the soda-bearing mineral nephelite ($Na_2O \cdot Al_2O_3 \cdot 2SiO_2$) or the potash-bearing minerals kaliophilite ($K_2O \cdot Al_2O_3 \cdot 2SiO_2$) or leucite ($K_2O \cdot Al_2O_3 \cdot 4SiO_2$). The altered zone of the brick tends to spall off in relatively thick slabs, either because the reaction is accompanied by expansion or shrinkage of the brick material, or because there is a difference in the rates of thermal expansion between the altered and the unaltered portion of the refractory. In the presence of fumes formed from sodium sulfate, the complex mineral noselite may form. It is composed of soda, sulfur trioxide, alumina, and silica.

Petroleum ash containing vanadium pentoxide and alkalies is very destructive to fireclay brick at high temperatures. High-alumina brick, especially those of the 70 to 90 per cent alumina classes, have relatively high resistance to vanadium oxide and alkalies in oil ash.

Zoning of Brick: One of the most striking phenomena, in connection with the use of refractory brick, is their tendency to develop a zoned or banded structure in service. In some cases, the border between zones is sharp; in others, there is a transition interval between one zone and the next.

The zoning is a manifestation of the "Ludwig-Sorret effect," in accordance with which fluids will diffuse from an area of higher temperature to one of lower temperature, under the driving force of the temperature gradient. Liquids formed in refractories from small amounts of impurities or from absorption of slags or fluxes may migrate through the pore structure from the hotter toward the cooler end of the brick and concentrate in temperature zones where their viscosity is so high that they lack mobility for further diffusion. Other causes of zoning may be such factors as formation, growth or transformation of crystalline material, or reaction of brick material with penetrating gases.

As a result of zone formation, there is a tendency in some brick for the development of cracks parallel to the isotherms. Spalling is likely to occur if there is a marked difference in the rates of thermal expansion of adjoining zones, or if there is a marked permanent change in volume of a portion of the brick which is impregnated with a fluxing agent.

"Secondary Reactions: In service, secondary chemical reactions involving the refractories frequently occur. A liquid may form at the surface of a refractory, as a result of reaction between the refractory and the material originating in the furnace. This liquid may then come in contact with refractory brick of another type with damaging results. Such a reaction might occur in glass-tank regenerators in which alumina-silica brick crowns and basic brick checkers are used. The alkaline dust from the glass batch reacts with the alumina-silica brick of the regenerator crowns, forming a liquid which drops on the checker below. With basic checkers, further chemical reaction will occur which may be damaging, even at relatively low temperatures. For this reason, it is generally considered good practice to use basic crowns in glass-tank regenerator chambers which utilize basic brick checkers."[51-1]

Furnace Atmosphere: Furnace gases probably have more effect upon the properties of refractory materials than is generally realized. The nature of the furnace atmosphere—whether oxidizing or reducing—is important. For the durability of most refractories an oxidizing atmosphere is to be preferred. However, carbon and graphite will burn in an oxidizing atmosphere. At 1650°F., silicon carbide will react slowly with oxygen from the air, carbon dioxide, water vapor, or combustion gases[49-2]; the reaction rate is more rapid at higher temperatures. To retard this oxidation, the grains of silicon carbide refractories are usually protected by a coating of ceramic material.

In a reducing atmosphere, most iron-bearing slags are far more corrosive to alumina-silica and some other refractories than in an oxidizing

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atmosphere. This is not the case with magnesia, which may dissolve relatively large amounts of ferrous oxide without harmful consequences.

Exposure of a basic brick to alternate oxidizing and reducing conditions will cause iron oxide particles in the brick to undergo repeated changes in their state of oxidation and their volume. Such action may affect the ceramic bond and cause the brick to become friable unless the iron oxide content is relatively low.

Some types of refractories are damaged by carbon monoxide gas within a critical temperature range. In the presence of certain catalysts, such as minute quantities of small iron oxide particles occurring within the refractory, the carbon monoxide will decompose into carbon dioxide gas and solid carbon. The reaction takes place most rapidly between 700° and 1000°F. In this critical temperature range, carbon monoxide gas may change the particles of iron oxide into iron carbide or metallic iron, and deposit carbon around them. The continued deposition of carbon may develop internal stresses great enough to disrupt the bond of the brick, and cause it to disintegrate into fragments in a relatively short time.

Some superduty and high-duty fireclay brick and high-alumina brick which have been fired to Cone 18 or higher under controlled firing conditions are practically immune to disintegration by carbon monoxide gas. The high temperature of firing causes the minute iron oxide particles in the brick to combine chemically with silica and alumina, forming a complex silicate which does not catalyze the reaction $2CO \longrightarrow CO_2 + C$.

Partially cracked natural gas has an effect similar to that of carbon monoxide in that it may decompose and deposit carbon within a critical temperature range. Disintegration of brick by natural gas is a phenomenon similar to disintegration by carbon monoxide, but appears to take place in a different temperature range—900°F. to 1500°F.

In refractory brick of many kinds, the bond is weakened by exposure at various critical furnace temperatures to water vapor, sulfur dioxide, sulfur trioxide, hydrogen, chlorine, hydrogen chloride, volatile oxides of metals, and by carbon monoxide even above the temperature at which it may decompose and deposit carbon. Some refractories are much more resistant than others to the harmful effects of gases.

Chlorine forms volatile chlorides at about 1750°F. with some of the components of various refractories. Up to about 800°F., magnesia will hydrate and slake at atmospheric pressure in the presence of steam. The hydration can be minimized by treatment of the magnesia with an inhibiting agent.

In multiple-hearth roasters used for roasting sulfide ores, the hot furnace gases may contain sulfur dioxide, sulfur trioxide, and water vapor. In the cooler parts of the linings these gases may react with some brick to cause the formation of aluminum sulfate, together with swelling and weakening of the brickwork. This action is known as "sulfating." Similar effects may be observed in the cooler sections of regenerators of furnaces which utilize fuels containing sulfur, or which process charges containing sulfur compounds.

The oxides of copper may volatilize under the usual operating conditions of refining furnaces. Both the cuprous (Cu_2O) and cupric (CuO) oxides exert a destructive action on some of the refractories by which they are absorbed. For example in copper refining electric furnace roofs, silica brick are severely damaged by the oxides in the reducing atmosphere.

REACTIONS BETWEEN REFRACTORIES

When no single kind of refractory material is adequate to meet the various conditions prevailing in the different parts of a furnace, two or more different kinds may be employed in the construction. However, refractories of dissimilar chemical compositions, such as magnesite brick and fireclay brick, may react chemically with each other, if in contact at high temperatures. Furnace fumes, dusts, and slags can accelerate these reactions.

In the high-temperature portions of a furnace, it is good practice to separate two reactive refractories by an intermediate course of brick which will not react with either at the temperature of operation, or by a joint formed of a nonreactive bonding mortar. In the cooler parts of the furnace, such precautions generally are unnecessary.

"At temperatures corresponding to the melting points of eutectic compositions, chemical reactions and some melting can be expected to occur at the surfaces of contact between refractories of different types. For instance, the eutectic between alumina and silica has a melting point of 2903°F.

"If the temperature is sufficiently high, any commercial refractory brick except some which are fused-cast will develop a liquid phase in some amount, even though the brick as a whole may remain strong and rigid. Most of the impurities of the refractory may be concentrated in the liquid phase. Frequently this liquid phase will be responsible for a reaction of one refractory with another to a greater extent than will the formation of eutectics between the principal oxides of each refractory.

"A liquid of high fluidity, within a refractory, may flow downward by the action of gravity, or it may diffuse in all directions, into adjacent brick, by capillary attraction."[51-1]

Laboratory Tests: The results of laboratory investigations to determine the temperatures of reaction between refractories are given in Table XXI. Tests were made at 2550°, 2730°, 2910°, 3000°, and 3100°F. (1400°, 1500°, 1600°, 1650°, and 1705°C.) in an oxidizing atmosphere in a gas-fired furnace. Each maximum temperature was held for a period of 5 hours. The heating-up period was 3 hours for the tests at 2550° and 2730°, 5 hours for 2910°, 6 hours for 3000°, and 7 hours for 3100°F.

The reaction between magnesite brick and high-duty fireclay brick, in the tests made at 2730°F. (1500°C.), was accompanied by the formation of a thin liquid slag. The reaction between magnesite brick and silica brick was much less severe, but became damaging at about 2910°F. (1600°C.).

General Comments: "The test data cannot be more than a general guide as to the degree of reaction which may be anticipated in service. With longer periods of heating, or in the presence of slags, fumes, or reducing gases, or when the brick are subjected to high pressures, the temperatures of reactions may be lower. Therefore, two refractories which reacted only slightly or not at all in the laboratory tests at a given temperature might be damaging to one another at the same temperature after longer periods of time in service. On the other hand, in furnace walls which radiate heat to the atmosphere and in which there is a marked drop in temperature from the inner to the outer face, the reactions may be less severe than in the tests," made under soaking heats.

Obviously mortars of excellent quality could have a corrosive effect on brick with which they are chemically incompatible.

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Table XXI.

TEMPERATURES OF REACTION BETWEEN REFRACTORIES

Type or Class of Refractories in Contact	Magnesite, 92% MgO	Magnesite-Chrome, C. B.	Chrome-Magnesite, C. B.	Chrome-Magnesite, Fired	Forsterite, Stabilized	Chrome, Fired	90% Alumina	70% Alumina
	1	2	3	4	5	6	7	8
1. Magnesite, 92% MgO								
2550°F.	...	...	...	...	...	...	...	...
2730°F.	...	...	...	...	...	...	...	...
2910°F.	...	...	...	...	...	...	...	N
3000°F.	...	...	...	...	N	N	...	S
3100°F.	...	...	N	N	*	S	N	D
2. Magnesite-Chrome, C. B.								
2550°F.	...	...	...	...	...	...	...	...
2730°F.	...	...	...	...	...	...	N	N
2910°F.	...	...	...	...	...	...	S	S
3000°F.	...	...	...	...	S	...	S	S
3100°F.	...	...	...	...	*	...	S	D
3. Chrome-Magnesite, C. B.								
2550°F.	...	...	...	...	...	...	...	...
2730°F.	...	...	...	...	...	...	...	N
2910°F.	...	...	...	...	N	...	N	S
3000°F.	...	...	...	...	S	...	S	S
3100°F.	N	...	...	...	*	...	S	D
4. Chrome-Magnesite, Fired								
2730°F.	...	...	...	...	...	...	...	N
2910°F.	...	...	...	...	N	...	N	S
3000°F.	...	...	...	...	S	...	S	S
3100°F.	N	...	...	...	...	...	S	D
5. Forsterite, Stabilized								
2550°F.	...	...	...	...	...	...	...	...
2730°F.	...	...	...	...	...	...	...	...
2910°F.	...	...	N	N	...	N	N	N
3000°F.	N	S	S	S	...	S	D	D
3100°F.	*	*	*	...	...	*	...	...
6. Chrome, Fired								
2730°F.	...	...	...	...	...	...	...	N
2910°F.	...	...	...	...	N	...	N	S
3000°F.	N	...	...	...	S	...	S	S
3100°F.	S	...	...	...	*	...	S	...
7. 90% Alumina								
2730°F.	...	N	...	...	...	...	...	...
2910°F.	...	S	N	N	N	N	..	...
3000°F.	...	S	S	S	D	S	...	...
3100°F.	N	S	S	S	...	S	...	...
8. 70% Alumina								
2730°F.	...	N	N	N	...	N	...	...
2910°F.	N	S	S	S	N	S	...	...
3000°F.	S	S	S	S	D	S	...	...
3100°F.	D	D	D	D	...	...	...	...

N = No Reaction; S = Slight Reaction; D = Damaging Reaction; C.B. = Chemically-Bonded.

* One or the other of this pair of brick is not sufficiently refractory for exposure to a soaking heat at the temperature indicated.

Table XXI, Continued

TEMPERATURES OF REACTION BETWEEN REFRACTORIES

Type or Class of Refractories in Contact	Zircon	Fireclay, Superduty	Fireclay, High-Duty	Fireclay, Semi-Silica	Silicon Carbide, Clay-Bonded	Silica, Conventional	Silica, Superduty
	9	10	11	12	13	14	15
1. Magnesite, 92% MgO							
2550°F.	...	S	S	N	N	N	N
2730°F.	...	D	D	D	S	S	S
2910°F.	...	...	...	...	...	D	D
3000°F.	...	...	...	...	...	...	...
3100°F.	...	...	...	...	...	...	...
2. Magnesite-Chrome, C. B.							
2550°F.	...	...	...	S	S	...	...
2730°F.	...	...	...	S	D	N	N
2910°F.	...	...	...	*	...	S	S
3000°F.	S	...	...	...	...	D	S
3100°F.	D	...	...	...	...	...	*
3. Chrome-Magnesite, C. B.							
2550°F.	...	...	...	S	S	...	...
2730°F.	...	...	N	S	D	N	N
2910°F.	...	N	S	*	...	S	S
3000°F.	...	S	S	...	...	S	S
3100°F.	...	*	*	...	...	*	*
4. Chrome-Magnesite, Fired							
2730°F.	N	...	N	N	N	N	...
2910°F.	S	N	S	*	D	S	N
3000°F.	S	S	S	...	...	S	S
3100°F.	S	*	*	...	...	*	*
5. Forsterite, Stabilized							
2550°F.	...	...	...	N	...	...	...
2730°F.	N	N	N	S	N	...	...
2910°F.	S	S	S	*	D	N	N
3000°F.	D	D	D	...	...	S	S
3100°F.	...	...	...	...	...	*	*
6. Chrome, Fired							
2730°F.	...	N	N	N	N	...	...
2910°F.	...	S	S	*	D	N	N
3000°F.	...	S	S	...	...	S	S
3100°F.	...	*	*	...	...	*	*
7. 90% Alumina							
2730°F.	...	...	...	N	...	...	...
2910°F.	...	...	...	*	N	N	N
3000°F.	...	...	N	...	S	S	S
3100°F.	...	...	*	...	S	*	*
8. 70% Alumina							
2730°F.	...	...	...	N	...	N	...
2910°F.	...	...	...	*	N	S	...
3000°F.	...	...	N	...	S	S	...
3100°F.	...	...	*	...	D	*	...

N = No Reaction; S = Slight Reaction; D = Damaging Reaction; C.B. = Chemically-Bonded.

* One or the other of this pair of brick is not sufficiently refractory for exposure to a soaking heat at the temperature indicated.

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Table XXI, Continued
TEMPERATURES OF REACTION BETWEEN REFRACTORIES

Type or Class of Refractories in Contact	Zircon	Fireclay, Superduty	Fireclay, High-Duty	Fireclay, Semi-Silica	Silicon Carbide, Clay-Bonded	Silica, Conventional	Silica, Superduty
	9	10	11	12	13	14	15
9. Zircon							
2730°F.	...	...	...	N	...	...	...
2910°F.	...	...	...	*	...	...	...
3000°F.	...	...	...	...	S	N	...
3100°F.	...	...	...	...	S	*	...
10. Fireclay, Superduty							
2550°F.	...	...	...	...	...	...	...
2730°F.	...	...	...	...	...	...	N
2910°F.	...	...	...	...	N	...	D
3000°F.	...	...	...	...	S	...	...
3100°F.	...	...	...	...	*	...	...
11. Fireclay, High-Duty							
2550°F.	...	...	...	...	...	N	N
2730°F.	...	...	...	...	N	S	S
2910°F.	...	...	...	...	S	D	D
3000°F.	...	...	...	...	S	...	...
3100°F.	...	...	...	...	*	...	...
12. Fireclay, Semi-Silica							
2550°F.	...	...	...	...	...	...	...
2730°F.	N	...	...	...	N	...	N
2910°F.	*	...	...	...	*	...	*
3000°F.	S	S	S	...	...	S	S
3100°F.	S	*	*	...	...	*	*
13. Silicon Carbide, Clay-Bonded							
2550°F.	...	...	...	...	...	...	...
2730°F.	...	...	N	N	...	...	...
2910°F.	...	N	S	*	...	N	N
3000°F.	S	S	S	...	...	S	S
3100°F.	S	*	*	...	...	*	*
14. Silica, Conventional							
2550°F.	...	...	N	...	...	...	...
2730°F.	...	...	S	...	...	...	...
2910°F.	...	...	D	...	N	...	...
3000°F.	N	...	...	...	S	...	...
3100°F.	*	...	...	...	*	...	...
15. Silica, Superduty							
2550°F.	...	...	N	...	...	...	...
2730°F.	...	N	S	N	...	...	...
2910°F.	...	D	D	*	N	...	...
3000°F.	...	...	...	...	S	...	...
3100°F.	...	...	...	...	*	...	...

N = No Reaction; S = Slight Reaction; D = Damaging Reaction; C.B. = Chemically-Bonded.

* One or the other of this pair of brick is not sufficiently refractory for exposure to a soaking heat at the temperature indicated.

NOTE: The reactions between refractories of different types may vary somewhat from the data in the above table, because of differences in chemical and mineral compositions between different brands of the same class.

Table XXII.
APPROXIMATE ELECTRICAL RESISTIVITY OF SOME HIGH-ALUMINA BRICK

°C.	Ohms per Centimeter Cube: Corundum (99+% Al_2O_3)	Ohms per Centimeter Cube: 85% Al_2O_3	Ohms per Centimeter Cube: 60-70% Al_2O_3 (Not including mullite class)
800	5,800,000	214,500	6,500—18,000
900	2,300,000	92,000	3,000— 8,000
1000	930,000	50,000	1,400— 4,000
1100	370,000	26,000	800— 2,000
1200	140,000	9,900	500— 1,400
1300	56,000	3,700	300— 900
1400	24,000	.....	240— 700

ELECTRICAL RESISTIVITY

The electrical resistivity of refractories is important in connection with some electric furnace operations. The results reported by various observers for any particular type of refractory material show wide variations, due probably in part to differences in the materials which were studied, and in part to differences in test methods used.

In Figure 58, page 318, the approximate electrical resistivities of several refractory materials are given. The figures from which the chart was prepared were taken from papers which have appeared in the technical press of the United States and Europe over a period of years. In the chart, the resistivities are shown as bands rather than as lines, in order to include the results obtained by various investigators.

For all the refractories included in the chart, the electrical resistivities are very high at low temperatures, but drop rapidly as the temperature rises. At 800°C. (1470°F.), pure magnesia has a resistivity of more than 100 million ohms per centimeter cube; at 1500°C. (2730°F.), its resistivity is only a little above 10,000 ohms. The resistivity of commercial magnesite brick is lower than these figures. At 1500°C. (2730°F.), the electrical resistivity of commercial silica brick, as usually determined, lies between 2000 and 8000 ohms per centimeter cube; that of fireclay brick, between 300 and 1050 ohms; that of chrome brick, between 18 and 250 ohms.

The tabulated data on high-alumina and corundum brick which appear in Table XXII are based on the work of several investigators.[32-2,53-1]

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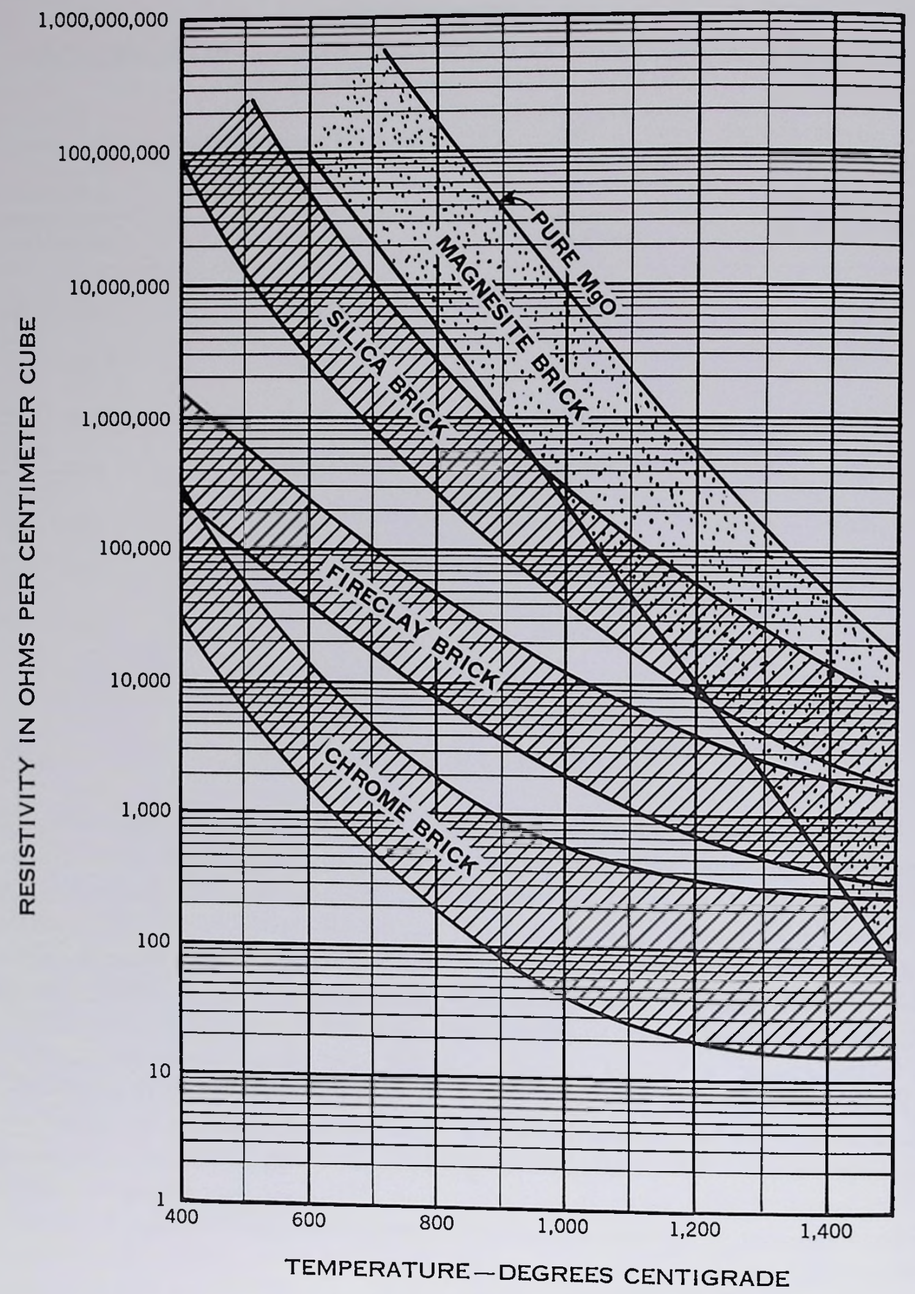


Fig. 58. Approximate Electrical Resistivity of Refractory Brick.

Table XXIII.
SPECIFIC HEATS OF REFRACTORY BRICK AND MINERALS

Mean Specific Heats between 32°F. and T° F. in Btu per pound per °F.

T° F.	Fireclay Brick	Silica Brick	Magnesite Brick	Chrome Brick	Forsterite Brick	T° F.	Mullite $3Al_2O_3 \cdot 2SiO_2$	Cristobalite SiO_2	Periclase MgO	Corundum Al_2O_3
32	0.193	0.169	0.208	0.170	0.180	32	0.184	0.165	0.208	0.171
200	0.199	0.188	0.219	0.176	0.200	200	0.192	0.183	0.227	0.196
400	0.206	0.211	0.232	0.182	0.216	400	0.214	0.204	0.240	0.214
600	0.212	0.229	0.242	0.188	0.230	600	0.223	0.239	0.251	0.226
800	0.220	0.238	0.251	0.194	0.240	800	0.229	0.251	0.257	0.235
1000	0.227	0.246	0.258	0.199	0.246	1000	0.233	0.258	0.262	0.242
1200	0.234	0.252	0.263	0.204	0.250	1200	0.237	0.264	0.267	0.248
1400	0.241	0.256	0.268	0.208	0.254	1400	0.240	0.268	0.270	0.252
1600	0.248	0.260	0.273	0.212	0.258	1600	0.242	0.271	0.274	0.257
1800	0.253	0.264	0.278	0.216	0.262	1800	0.245	0.273	0.277	0.260
2000	0.258	0.268	0.283	0.220	0.266	2000	0.247	0.275	0.280	0.264
2200	0.262	0.272	0.288	0.222	0.270	2200	0.249	0.277	0.282	0.267
2400	0.266	0.276	0.293	0.224	0.274	2400	0.251	0.278	0.285	0.270
2600	0.269	0.279	0.297	0.226	0.278	2600	0.253	0.279	0.288	0.273
						2800	0.255	0.280	0.290	0.276
						3000	0.256	0.281	0.292	0.279
						3200	0.258		0.294	0.282

The data on the specific heats of refractory brick are based on the work of various observers, whose results do not agree with exactness.

The specific heats of minerals were calculated from data given in Paper 1058 of the Geophysical Laboratory, Carnegie Institution of Washington, "Heat Capacity; Heat of Fusion," by Roy W. Goranson, 1942.

SPECIFIC HEAT AND HEAT CAPACITY

TABLE XXIII gives the specific heats of certain refractory brick and refractory minerals. The heat content of a brick at any temperature is a function of its specific heat and of its weight. It may be calculated from the following formula:

$$H = SW\ (T-32)$$

H = the heat content of the brick above 32°F., in British thermal units (Btu).
S = the mean specific heat of the brick between 32°F. and its mean temperature.
W = weight of brick in pounds.
T = mean temperature of brick in degrees F.

EMISSIVITY

The capacity of a material for radiating heat is called its emissivity. This is expressed as a fraction or percentage of the ideal "black body" radiation of heat which is the maximum possible and is never quite attained by any actual material. A good radiator is an equally good absorber of heat. A good reflector, obviously, is a poor absorber, and consequently a poor radiator. "Monochromatic" emissivity refers to the ability to radiate at a particular wave length, usually in the visible part of the spectrum. "Total" emissivity refers to heat radiation over the entire spectrum of wave lengths.

The total emissivity of most refractories

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Table XXIV.
REPRESENTATIVE VALUES OF TOTAL EMISSIVITY

Material	Temperature, Degrees F.						
	200	400	800	1600	2000	2400	2800
Fireclay Brick	.90	(.90)	(.90)	.81	.76	.72	.68
Silica Brick	(.90)	....	....	.82 to .65	.78 to .60	.74 to .57	.67 to .52
Chrome-Magnesite Brick	....	....	....	.87	.82	.75	.67
Chrome Brick	(.90)	....	....	.97	.975	....	....
High-Alumina Brick	.90	.85	.79	(.50)	....	....	....
Mullite Brick	....	....	....	.53	.53	.62	.63
Silicon Carbide Brick	....	....	....	.92	.89	.87	.86

Figures in parenthesis were obtained by extrapolation of test data.

decreases somewhat with increase in temperature, although there are a few exceptions. The chief factors influencing the emissivity are surface roughness, grain size, porosity, and content of compounds of heavy metals such as iron and chromium. Higher total emissivity goes with larger grain size and greater porosity, but probably only because they increase the surface roughness. Their effect is much greater as regards monochromatic emissivity. Brick surfaces which become glazed in service may have about 6 per cent higher reflectivity and corresponding lower emissivity than the surfaces of new brick. Furnace conditions which cause roughness of brick surfaces, such as mechanical erosion, tend to increase the emissivity. Of two similar refractories side by side in a furnace roof, one may glow more brightly than the other because of a difference in emissivity, or because of some component favoring catalytic combustion.

Heat is lost from the exterior areas of furnaces by both radiation and convection. The loss by unobstructed radiation to surroundings at T_2 degrees F., in Btu per hour per square foot of exterior surface at temperature T_1, is given by the equation:

$$.173\ E\left[\left(\frac{T_1+460}{100}\right)^4-\left(\frac{T_2+460}{100}\right)^4\right]$$

where E, the emissivity at T_1, is usually about .90 for refractory exteriors.

HEAT TRANSFER

When a furnace is heated, thermal energy flows into the refractory structure, causing a temperature difference to develop between inside and outside surfaces of walls and arches. Part of this thermal energy is stored in the refractory structure and its foundation, and part flows through the walls, roofs, and hearths, and is lost to the outside air by radiation and convection. The amount of heat which so escapes is often of considerable importance in the economy of the process. In estimating the quantities of heat flowing through the parts of a furnace, use is made of a coefficient known as the "thermal conductivity" or "K-value" of the material involved in the construction. The value of K differs not only for different materials, but usually also for the same material at different temperatures.

Thermal Conductivity: The coefficient of thermal conductivity (K) is defined as "the quantity of heat that will flow across unit area in unit time, if the temperature gradient across this area is unity."[51-2] In standard engineering units, as applied to refractories, the "thermal conductivity" K represents the amount of heat, in British thermal units, which will flow through the refractory per hour, per square foot of surface, per degree F. temperature difference between the hotter and the colder faces, and for 1-inch thickness.

The approximate thermal conductivities of various refractories are given in Tables XXVI to XXIX and Figures 60 to 63 inclusive. Most of these data were obtained from an extensive series of tests conducted at the Harbison-Walker Garber Research Center. Some of the data shown was obtained from other laboratories. A thorough study of the literature was also made, and some of the conductivity curves shown are composites of Harbison-Walker data and of data obtained from other sources.

J. B. Austin[39-1] in 1939 made a thorough study of the factors which affect the thermal conductivity of refractory materials. The main factors are the chemical and mineral composition of the refractory, the amount of amorphous material (glass or liquid) which it contains, its porosity, and its temperature.

For any particular type of refractory, the proportion of pore space is unquestionably the most important factor affecting the amount of heat which will flow through it at a given temperature. Within the temperature range covered by this study, the thermal conductivity decreases with increasing porosity.

At atmospheric temperatures, the thermal conductivity of a glass is considerably lower than that of crystalline material of the same composition. With rising temperatures, the conductivity of glasses tends to increase, while that of crystalline material tends to decrease. However, in refractory bodies consisting of crystal aggregates with a limited amount of glass, this effect is often obscured by other factors. The conductivity of a refractory in service at high temperature is changed somewhat either by an increase in the amount of glass or liquid it contains, or by devitrification of the glass.

The conductivity of some refractories appears to increase more rapidly at temperatures above approximately 2000°F., although only limited data are available for temperatures this high. This effect may be due, at least partly, to increased radiation across the pores of the refractory at these temperatures. There would be greater transmission of heat across large pores than across small ones.

High thermal conductivity is desirable for refractories used in constructions requiring the transfer of heat through brickwork, as in retorts, muffles, by-product coke-oven walls, and recuperators. In most types of furnaces, however, low thermal conductivity is desirable for heat conservation, but is usually less important than other properties of the refractories.

Heat Flow: The amount of heat flowing through a refractory wall in service under equilibrium conditions is *directly proportional* to (1) the thermal conductivity (K) of the refractory material; (2) the temperature drop (T_1—T_2) from the hot face to the cold face; (3) the area (A) of the wall; and (4) the time (t). The heat flow is *inversely proportional* to the thickness (d) of the wall. These relations are expressed by the well-known formula:

$$Q=\frac{K\,(T_1-T_2)\,At}{d}$$

The rate of heat flow in refractory constructions can be calculated only approximately for

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several reasons, including the following:

(1) The conductivity values, upon which the computations are based, have not been determined with a high degree of precision.

(2) The temperatures of the hotter and the cooler faces of the refractory wall or roof are rarely known with exactness.

(3) The conductivity of a refractory may be altered in service by mineral changes in the refractory, by vitrification of the refractory, or by absorption of slags or other materials.

(4) The thickness of a furnace lining may not remain constant during operation, as the lining may become thinner because of wear and transmit more heat; or it may become thicker because of the formation of a solid coating (as in rotary cement kilns) and transmit less heat.

(5) The rate of heat flow is influenced by the pressure of the furnace gases, and by the permeability of the refractory. A positive pressure tends to force hot gases out through the walls, and a negative pressure to draw cold outside air into the furnace.

(6) The rate of heat flow may be influenced by the thickness of the joints and by the character of the bonding mortar.

Other important factors which affect the amount of heat flowing through refractory constructions include the emissivity of the refractory or metal furnace shell; the kind of gases within the furnace; and external convection currents and other air currents.

Effects of Gases: In refractory structures built of insulating firebrick or other very porous refractories, the type of furnace atmosphere can have a very appreciable effect on the heat loss through the refractory walls. This is especially true of atmospheres with a high content of hydrogen.

Most protective atmospheres, including dissociated ammonia, exothermic gases and endothermic gases, contain appreciable percentages of hydrogen. The conductivity of the hydrogen must be taken into consideration in calculating the heat losses through the refractory walls of controlled-atmosphere heat-treating furnaces.

The thermal conductivity of hydrogen is approximately seven times as great as that of air. Consequently, the presence of hydrogen gas in the pores of a porous refractory product increases the rate of heat flow through the refractory. With an atmosphere of 100 per cent hydrogen, the heat flow through an insulating firebrick or other refractory with similar porosity would be 2 to 2½ times as great as in an atmosphere of air. At lower concentrations of hydrogen, the increase will be less and the relationship is almost directly proportional to the percentage of hydrogen present.

As compared with the conductivity of air, that of nitrogen is 100 per cent, carbon dioxide about 59 per cent, and carbon monoxide about 97 per cent.

The Mean Thermal Conductivity: The conductivity curve of a refractory material may be obtained by plotting the results of a series of laboratory tests taken at different temperature intervals. In each test, the conductivity reported is the mean value between temperatures recorded for thermocouple points situated near the hot and the cold faces of the refractory. The line connecting the various points representing a series of tests gives the conductivity curve, and represents the *mean* conductivities. Only if the conductivity "curve" is a straight line does it represent *true* conductivities also. However, even if the conductivity is represented by a curved line, the deviations from true conductivity values are usually less than the errors of observation.

For the standard A.S.T.M. method, the precision of thermal conductivity data (the closeness of agreement among different tests on the same material) is of the order of plus or minus 5 per cent, and the accuracy is within plus or minus 10 per cent. However, there may be even greater variations between brick of the same class but of different manufacture. For example, a variation in the degree of firing will usually result in some change in thermal conductivity.

Table XXV.

APPROXIMATE THERMAL DATA FOR WALLS 13½ INCHES THICK WITH HOT-FACE TEMPERATURE OF 2600°F.

Kind of Brick	Cold-Face Temperature	Heat Flow per Square Foot of Wall per Hour
Fireclay, High-Duty	465°F.	1490 Btu
70% Alumina	490°F.	1650 Btu
Forsterite L	500°F.	1720 Btu
Silica	505°F.	1790 Btu
Chrome	565°F.	2280 Btu
90% Alumina		
Korundal	560°F.	2200 Btu
Korundal XD	620°F.	2790 Btu
Magnesite (92% MgO)	750°F.	4330 Btu

For temperatures up to about 2000°F., the K-values given in the Tables and charts in general represent laboratory determinations. For temperatures above 2000°F. they are mainly extrapolations, and above 2400°F. may be considered as probably having a lower degree of accuracy than plus or minus 10 per cent. In accordance with common procedure, the last digit in the figures reported for K-values has little or no significance.

Approximate thermal data for walls 13½ inches thick and a hot-face temperature of 2600°F. are given in Table XXV.

Unfired Refractories: The estimation of heat flow through refractories which have not been fired in the manufacturing process presents serious difficulties. Chemically-bonded brick and monolith-forming refractories, which fall in this category, begin to undergo physical and chemical changes almost as soon as they are heated in service. These changes have a pronounced and complicating effect on the thermal conductivity of the refractories.

Consider the case of a wall built of castable material, to be heated on one side in service, while exposed to the air on the other. Before heat is applied, the completed wall has a strong hydraulic bond throughout its entire thickness. When the furnace is fired, a temperature difference develops between the interior and exterior surfaces. In any part of the wall heated above about 900°F., the chemically combined water is gradually driven off. In any part above 1800° to 2000°F., a second change, the development of a ceramic bond, takes place also. Consequently, by the time the wall has essentially reached thermal equilibrium, and no further appreciable changes are occurring, the wall has a well-developed zoned structure.

In the first or coolest zone, where the maximum temperature is below 900°F., the refractory retains its hydraulic bond, and the thermal conductivity is relatively high.

In the second or middle zone, the hydraulic

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and chemical bonds have been partly destroyed, but the temperature is not high enough for the development of a ceramic bond. The strength is moderate, and the conductivity is low.

In the third or highest temperature zone, where the minimum temperature is above 1800°F., pyrochemical reactions have taken place which form a strong permanent bond—the so-called ceramic bond. The thermal conductivity is much higher than that of the middle zone.

The conditions described above are illustrated schematically in Figure 59, which shows that each zone has its own thermal conductivity characteristics.

Depending on the particular construction and the operating temperature, a monolithic component of a refractory structure could consist of (1) all three zones, (2) the unaffected portion alone (Zone 1), (3) the portion with a ceramic bond alone (Zone 3), or (4) a combination of any two adjacent zones.

Considerable data are available from the work of Hansen and Livovich[53-2,58-4] on the thermal conductivity of castables which have been preheated to 1800° to 2000°F. This corresponds roughly to the minimum temperature at which the ceramic bond is developed. Relatively little other information is available in the literature regarding the conductivities of castable and other unfired refractory materials.

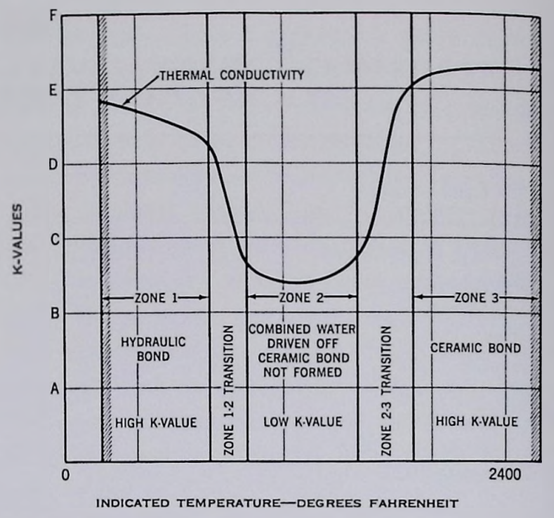


Fig. 59. Schematic Illustration of Variations in Thermal Conductivity Through a Castable Wall Heated on One Side Only, And Not Insulated.

HEAT-FLOW CALCULATIONS

Subjected to the limitations mentioned on pages 321 and 322, the amount of heat flowing through a wall or arch can be estimated with sufficient accuracy for most engineering purposes.

SYMBOLS USED

q	= the rate of heat flow in Btu perhour.	k	= *mean* thermal conductivity of a single-component wall.
q_1	= the rate of heat flow in Btu per square foot per hour.	k_1, k_2, etc.	= *mean* thermal conductivities of the successive components of a composite wall, beginning at the hotter side.
Q	= the total quantity of heat in Btu flowing through a wall or arch in any given length of time t.	$K_{1\text{-}2}$	= thermal conductivity at the mean temperature between T_1 and T_2.
T_1	= temperature of hot face of wall, degrees F.	A	= area in square feet.
T_2	= temperature of cold face of wall, degrees F.	t	= time in hours.
K, k	= thermal conductivity in Btu per square foot per hour, per degrees F. temperature difference, for one-inch thickness.	d	= thickness of single-component wall in inches.
K_1, K_2, etc.	= thermal conductivity at the *definite* temperatures T_1, T_2, etc.	d_1, d_2, etc.	= thicknesses of the successive components of a composite wall, beginning at the hotter side.

FORMULAS

Determination of q, the rate of heat flow through a wall or arch per hour:

(Formula 1A): $q = k\,(T_1 - T_2)\,\frac{A}{d}$

For composite walls:

(Formula 1B): $q = \frac{(T_1 - T_2)\,A}{\frac{d_1}{k_1} + \frac{d_2}{k_2} \cdots\cdots \frac{d_n}{k_n}}$

Determination of q_1, the rate of heat flow per square foot per hour:

(Formula 2A): $q_1 = k\,(T_1 - T_2)\,\frac{1}{d}$

For composite walls:

(Formula 2B): $q_1 = \frac{T_1 - T_2}{\frac{d_1}{k_1} + \frac{d_2}{k_2} \cdots\cdots \frac{d_n}{k_n}}$

Determination of Q, the amount of heat flowing through a wall or arch in a given length of time t:

(Formula 3): $Q = qt$

Estimation of k, the mean thermal conductivity between T_1 and T_2.

(A) If the conductivity curve is a straight line:

(Formula 4): $k = K_{1\text{-}2} = K$ at mean temperature $\frac{T_1 + T_2}{2}$

That is, mean k is the same as K at the mean temperature.

(B) If the conductivity is represented by a curved line:

(a) The mean conductivities can be estimated visually from the charts.

(b) The mean conductivity k can be assumed to be the same as the conductivity at the mean temperature (Formula 4). In most cases, this value is slightly lower than the mean conductivity, but is generally within the limits of precision of the data.

(c) The mean conductivity can be estimated from Formula 5.

(Formula 5): $k = \text{approximately } \frac{K_1 + K_2 + 2K_{1\text{-}2}}{4}$

(d) The mean conductivity can be calculated most accurately by the use of integral calculus. However, this method is not used in the present text, because the precision of the data is not high enough to justify the amount of work involved.

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Table XXVI.

APPROXIMATE THERMAL CONDUCTIVITIES OF FIRECLAY BRICK

Btu per Hour, per Square Foot, per Degree F. Temperature Difference, for One-Inch Thickness

Kind of Brick	Density*	Mean Conductivity at T°F.													
		200	400	600	800	1000	1200	1400	1600	1800	2000	2200	2400	2600	2800
Superduty Fireclay High-Fired (Cone 18)	147	9.7	9.7	9.7	9.8	9.9	10.0	10.2	10.3	10.5	10.7	10.9	11.1	11.3	....
Conventional Firing (Alamo)	146	8.7	8.8	9.0	9.1	9.3	9.4	9.6	9.7	9.9	10.0	10.2	10.4	10.5	....
High-Duty Fireclay Aluminous	136	8.4	8.5	8.7	8.8	9.0	9.2	9.3	9.5	9.6	9.8	9.9	10.1	....	....
Siliceous (Woodland X)	127	7.1	7.3	7.4	7.6	7.8	8.0	8.1	8.3	8.5	8.7	8.8	9.0	....	....
Semi-Silica Fireclay (Kaosil)	125	5.8	6.2	6.5	6.9	7.3	7.6	8.0	8.3	8.7	9.0	9.4	9.8	....	....

* *Pounds per Cubic Foot.*

NOTE: For brick of the same type, class, composition, and burn, the conductivities are approximately proportional to the bulk densities (weights in pounds per cubic foot).

Table XXVII.

APPROXIMATE THERMAL CONDUCTIVITIES OF INSULATING FIREBRICK

Btu per Hour, per Square Foot, per Degree F. Temperature Difference, for One-Inch Thickness

	Density*	Thermal Conductivity at T°F.													
		200	400	600	800	1000	1200	1400	1600	1800	2000	2200	2400	2600	2800
H-W 16-20	36	1.06	1.20	1.34	1.48	1.63	1.77	1.91	2.05	2.19	....	....	....	....	....
H-W 20	38	1.26	1.40	1.54	1.68	1.83	1.97	2.11	2.25	2.40	....	....	....	....	....
H-W 23	46	1.44	1.59	1.75	1.91	2.06	2.22	2.38	2.53	2.69	2.85	3.00	....	....	....
H-W 23-LI	31	0.78	0.86	0.94	1.02	1.09	1.17	1.25	1.33	1.41	1.48	1.56	....	....	....
H-W 26	49	1.83	1.98	2.13	2.28	2.43	2.58	2.73	2.88	3.03	3.18	3.33	3.48	....	....
H-W 28	56	1.95	2.10	2.25	2.40	2.55	2.70	2.85	3.00	3.15	3.30	3.45	3.60	3.75	3.90
H-W 30	60	2.20	2.35	2.50	2.65	2.80	2.95	3.10	3.25	3.40	3.55	3.70	3.85	4.00	4.15

* *Pounds per Cubic Foot.*

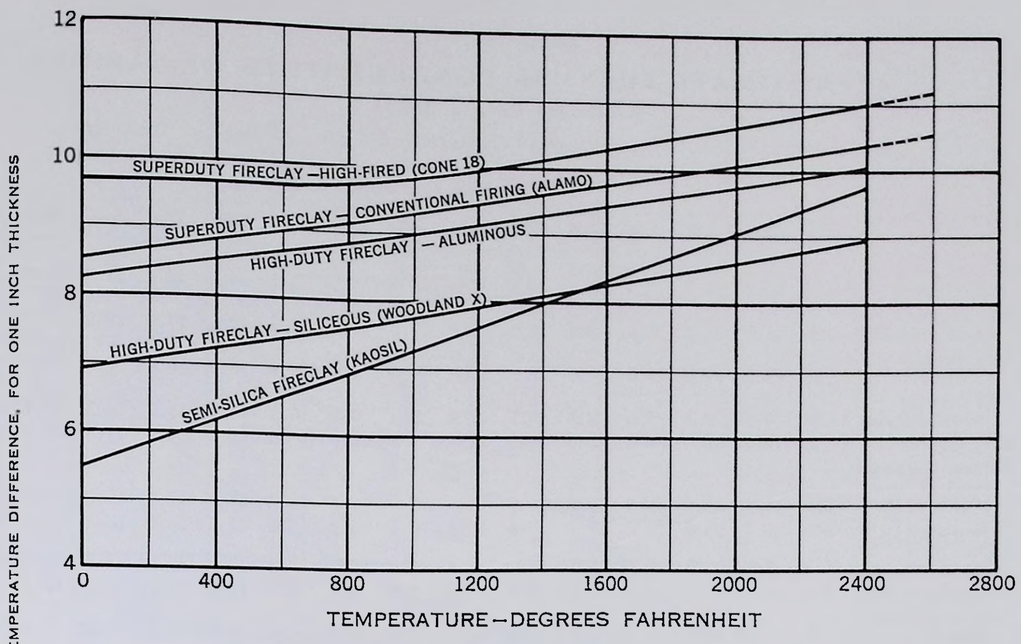


Fig. 60. Approximate Thermal Conductivities of Fireclay Brick.

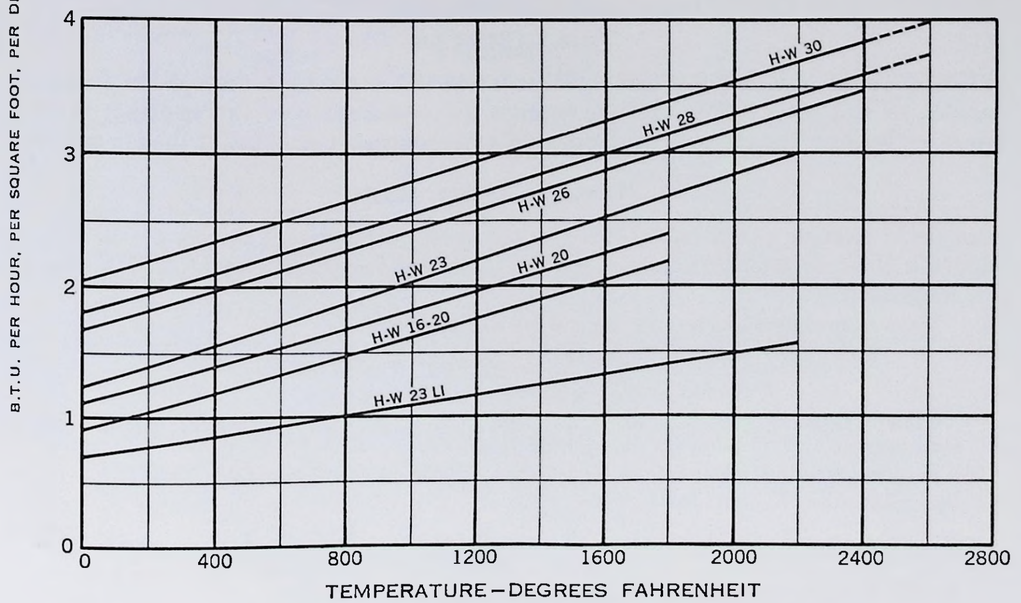


Fig. 61. Approximate Thermal Conductivities of Insulating Firebrick.

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Table XXVIII.

APPROXIMATE THERMAL CONDUCTIVITIES OF VARIOUS REFRACTORY BRICK

Btu per Hour, per Square Foot, per Degree F. Temperature Difference, for One-Inch Thickness

Kind of Brick	Density*	Mean Conductivity at T°F.													
		200	400	600	800	1000	1200	1400	1600	1800	2000	2200	2400	2600	2800
90% Alumina (Korundal)	174	20.4	18.7	17.3	16.1	15.2	14.3	13.9	13.5	13.3	13.2	13.2	13.3	13.5	13.8
90% Alumina (Korundal XD)	186	25.7	23.6	21.8	20.4	19.3	18.5	17.8	17.5	17.5	17.7	17.9	18.2	18.6	19.0
70% Alumina (Alusite)	151	12.0	11.5	11.0	10.6	10.2	10.0	9.9	9.9	10.0	10.2	10.5	10.8	11.2	11.5
60% Alumina (Anchor Dash)	148	9.3	9.4	9.5	9.6	9.7	9.8	9.8	9.9	10.0	10.1	10.2	10.3	10.4	10.5
H-W Chrome	190	16.4	16.4	16.4	16.3	16.0	15.7	15.4	15.0	14.5	14.0	13.8	13.7	13.9	13.9
Chrome-Magnesite, Fired (Chromex B)	188	14.5	14.0	13.5	13.2	13.0	12.8	12.7	12.7	12.7	12.8	12.9	13.0	13.1	13.2
H-W Zircon	235	26.3	23.0	20.6	18.7	17.6	16.8	16.5	16.3	16.4	16.5	16.6	16.8	17.0	17.2
Silica (Star and Vega)	115	7.1	7.8	8.4	9.1	9.7	10.4	11.0	11.7	12.3	13.0	13.6	14.3	14.9	15.6
Silica (Vega HP)	113	6.8	7.2	7.5	7.9	8.2	8.5	8.9	9.3	9.7	10.3	10.9	11.6	12.4	13.0
Insulating Silica (Vegalite)	59	2.07	2.30	2.58	2.87	3.20	3.60	4.00	4.46	4.96	5.54	6.18	6.82	7.6	8.4

* *Pounds per Cubic Foot.*

NOTE: For brick of the same type, class, composition, and burn, the conductivities are approximately proportional to the bulk densities (weights in pounds per cubic foot).

EXAMPLES

In the following examples, it is assumed that the brick are placed in the walls of furnaces surrounded by still air at 70°F., that the furnace temperature is constant, and that there is no difference between the pressure of the gas within the furnaces and that of the air outside.

One-Component Walls

Example A: *Estimate q_1, the rate of heat flow per square foot per hour through a wall 13½ inches thick built of aluminous high-duty fireclay brick, with a hot-face temperature of 2600°F. and a cold-face temperature of 465°F.*

Mean temperature between the hot and the cold face =

$$\frac{T_1 + T_2}{2} = \frac{2600 + 465}{2} = 1532.5°F. \text{ (Use 1535°F.)}$$

From Formula 4, page 325, the mean conductivity k between T_1 (2600°F.) and T_2 (465°F.) is the conductivity K at the mean temperature of 1535°F.

K of the fireclay brick at 1400°F. = 9.3; K at 1600°F. = 9.5 (From Table XXVII).

By interpolation, $K_{1\text{-}2}$ at 1535°F. is 9.43 = k

From Formula 2A, $q_1 = k\,(T_1 - T_2)\,\frac{1}{d} = 9.43\,(2600 - 465)\left(\frac{1}{13\frac{1}{2}}\right)$

= 1490 Btu per square foot per hour. (See Footnote to Table XXVII).

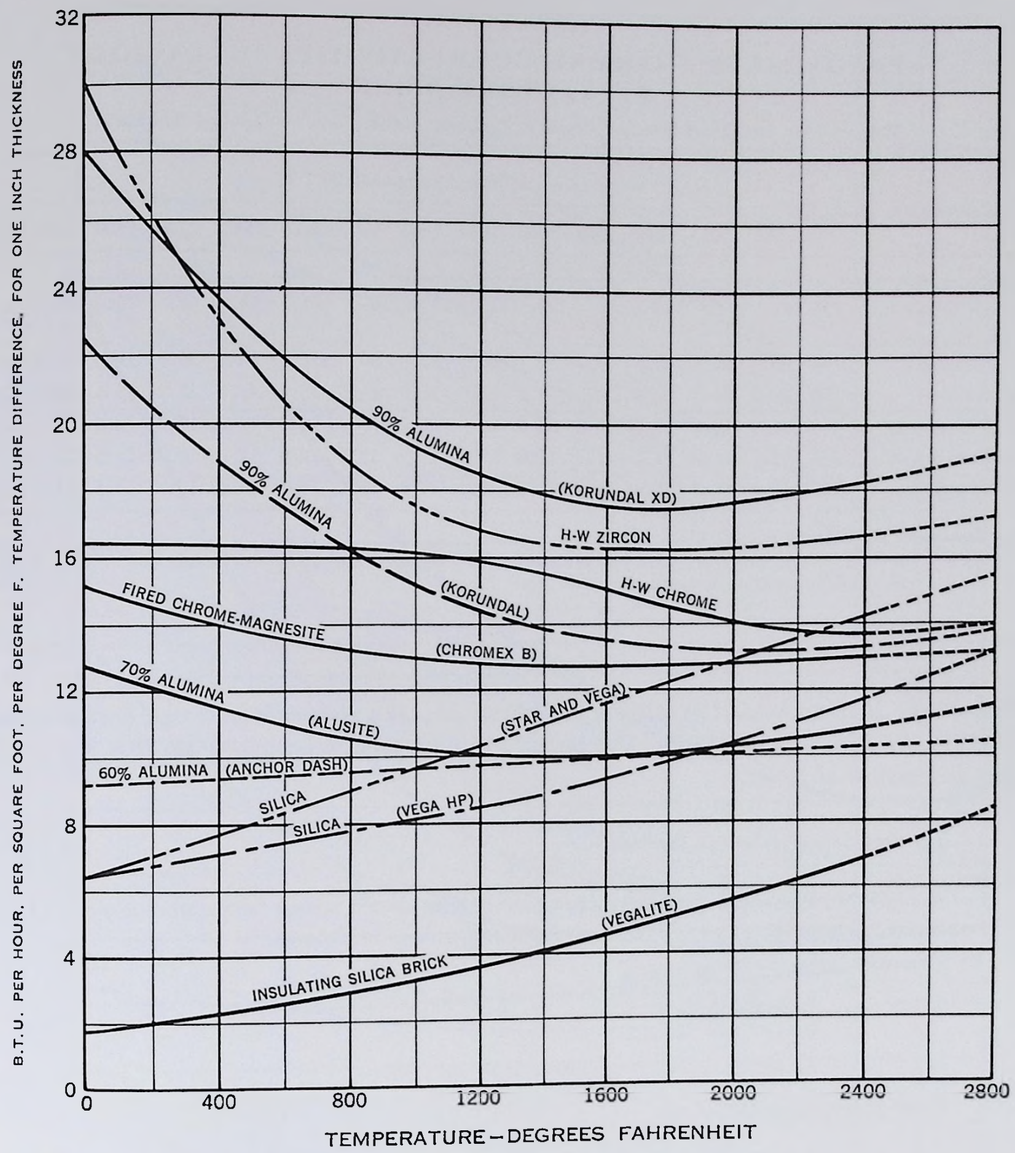


Fig. 62. Approximate Thermal Conductivities of Various Refractory Brick.

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Table XXIX.

APPROXIMATE THERMAL CONDUCTIVITIES OF VARIOUS REFRACTORY BRICK

Btu per Hour, per Square Foot, per Degree F. Temperature Difference, for One-Inch Thickness

Kind of Brick	Density*	Mean Conductivity at T°F.													
		200	400	600	800	1000	1200	1400	1600	1800	2000	2200	2400	2600	2800
Bonded Silicon Carbide (HARBIDE)	166	131.	130.	128.	126.	122.	118.	113.	107.	102.	94.	86.	78.	70.	62.
H-W MAGNESITE (92% MgO)	174	63.	54.	48.	43.	39.	36.	33.	30.	28.	26.2	25.0	24.2	24.0	24.6
MAGNECON	170	29.4	25.6	22.4	20.0	18.2	16.9	16.0	15.5	15.3	15.1	15.2	15.4	15.6	15.8
H-W CORUNDUM	180	46.5	39.0	33.0	28.2	24.6	22.0	20.1	18.9	18.2	17.8	17.8	18.0	18.6	19.2
MAGNEX B	174	12.3	11.9	11.7	11.7	11.8	11.9	12.2	12.4	12.6	12.9	13.3	13.5	13.8	14.2
FORSTERITE L	164	15.0	13.3	11.9	11.1	10.5	10.2	10.0	10.1	10.2	10.4	10.7	11.1	11.5	12.0

* *Pounds per Cubic Foot.*

NOTE: For brick of the same type, class, and composition, the conductivities are approximately proportional to the bulk densities (weights in pounds per cubic foot).

Example B: *How much heat (Q) will flow in 24 hours through a magnesite brick wall having an area of 25 square feet and a thickness of 13½ inches, with a hot-face temperature of 2600°F. and a cold-face temperature of 750°F.?*

The mean temperature of the wall is $\frac{2600 + 750}{2} = 1675°F.$

As shown in Figure 63, the conductivity of magnesite plotted against temperature is a curved line, and estimation of the mean conductivity is not as simple as in Example A.

From the table, or chart,

K_1 at 2600° = 24.0

K_2 at 750° = 44.3

$K_{1\text{-}2}$ at the mean temperature 1675° = 29.3

From Formula 5, page 325,

$$k \text{ (the mean conductivity)} = \text{approximately } \frac{24.0 + 44.3 + 2(29.3)}{4} = 31.7$$

From Formula 3,

$$Q = qt = k\,(T_1 - T_2)\,\frac{At}{d} = 31.7\,(2600 - 750)\,\frac{25 \times 24}{13.5} = 2{,}600{,}000 \text{ Btu.}$$

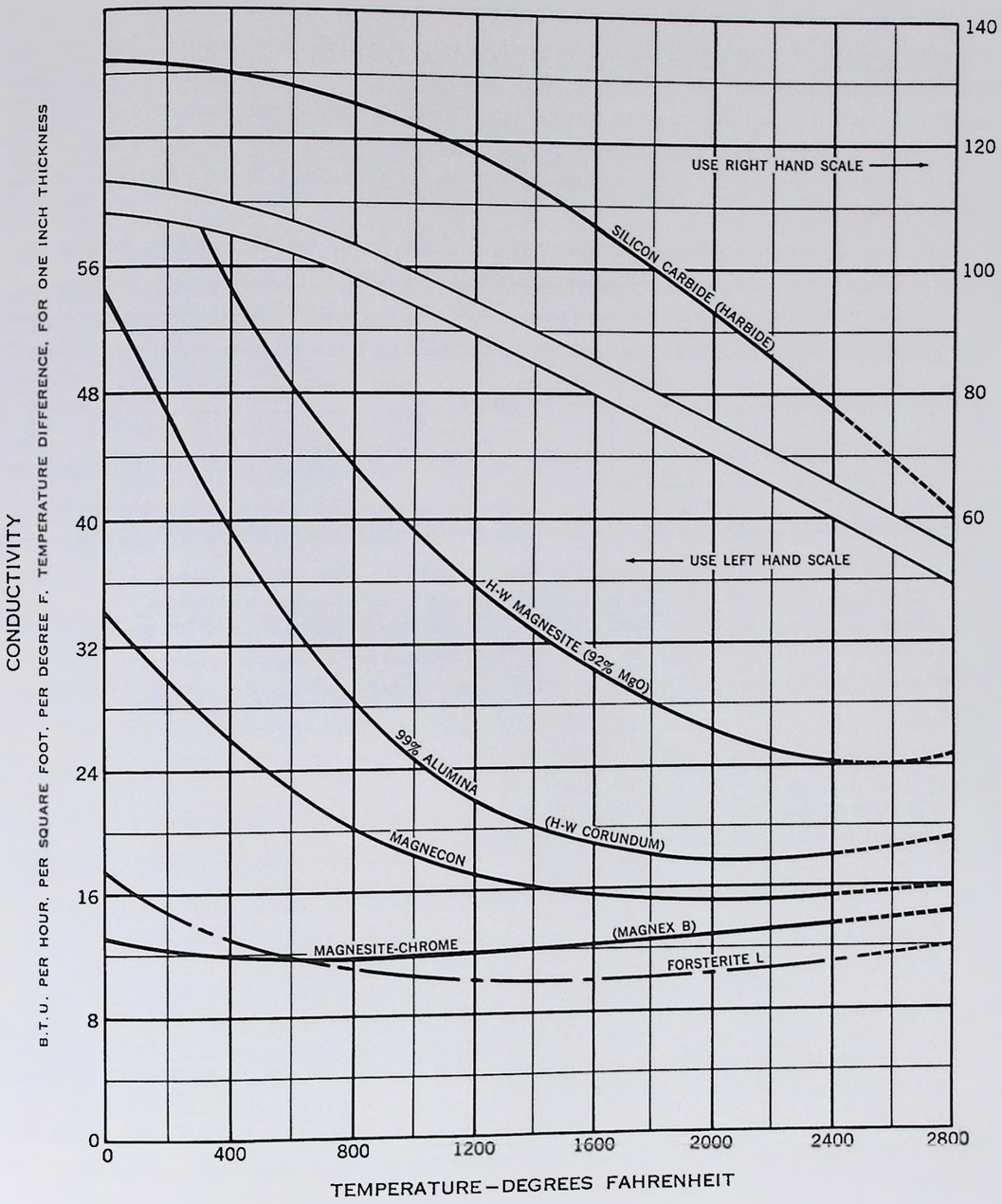


Fig. 63. Approximate Thermal Conductivities of Various Refractory Brick.

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In many heat-transfer problems, the hot-face temperature is known approximately, but both the cold-face temperature and the amount of heat transmitted must be estimated. Such problems usually are solved by a trial-and-error method based upon the assumption that the furnaces are surrounded by still air, and that consequently all of the heat which flows through a wall is lost from the outside surface by radiation and convection. The method may be illustrated by the following example:

Example C: *Estimate the cold-face temperature (T_2) and the rate of heat flow (q_1) for a silica brick wall 13½ inches thick, having a hot-face temperature (T_1) of 2600°F.*

First Trial: Assume the cold-face temperature (T_2) = 400°F.

Mean temperature of wall = $\frac{400 + 2600}{2}$ = 1500°F.

From Table XXVIII, the conductivity of silica brick at 1500°F. is 11.35.

$T_1 - T_2 = 2600 - 400 = 2200$°F.

From Formula 2A, page 325, the amount of heat flowing through the wall, $q_1 = \frac{11.35 \times 2200}{13.5}$ = 1850 Btu per square foot per hour.

This is equal to the amount of heat lost from the wall by radiation and convection.

From the heat-transmission chart, page 337, it is seen that for a loss of 1850 Btu per square foot per hour, the cold-face temperature of the wall is 515°F.

Obviously, the assumed temperature of 400°F. is not correct, and another assumption must be made.

Second Trial: Assume T_2 = 515°F. (from First Trial).

(In this method, the cold-face temperature (T_2) as determined by the calculation of one trial, is always the cold-face temperature assumed for the next trial.)

Mean temperature of wall = $\frac{515 + 2600}{2}$ = 1560°F.

From Table XXVIII, the conductivity of silica brick at 1560°F. = 11.56.

$T_1 - T_2 = 2600 - 515 = 2085$°F.

From Formula 2A, $q_1 = \frac{11.56 \times 2085}{13.5}$ = 1785 Btu per square foot per hour.

From the heat-transmission chart, page 337, a heat loss of 1785 Btu per square foot per hour corresponds to a cold-face temperature of 505°F.

Since 505°F. is within 10° of the assumed temperature of 515°, no further trials are made.

Conclusion:

Heat loss q_1 = 1785 Btu per square foot per hour.

Cold-face temperature (T_2) = 505°F.

Two-Component Walls

A method for estimating heat flow, interface temperatures, and cold-face temperatures of a composite wall, when the hot-face temperature is known, is illustrated in Example D. The method consists in (1) estimating the "equivalent thickness" of the wall in terms of one of the components and (2) solving the problem for this thickness by the trial-and-error method used in Example C. Example E follows the standard A.S.T.M. procedure, which is based on "thermal resistances."

Example D: *A furnace wall consists of 9-inch conventionally fired superduty fireclay brick backed by 4½ inches of H-W 23 insulating brick. The hot-face temperature is 2500°F. Estimate the rate of heat flow per square foot per hour (q_1), the interface temperature, and the cold-face temperature (T_2).*

First Trial: Assume the cold-face temperature (T_2) = 500°F.

Assume also that the temperature drop from the hot face to the interface between fireclay brick and insulating brick is one-fourth of the total temperature drop from hot face to cold face. Then,

Interface temperature = 2500 — ¼ (2500 — 500) = 2500 — 500 = 2000°F.

Mean temperature of fireclay brick component of wall = ½ (2500 + 2000) = 2250°F.

Mean temperature of H-W 23 component of wall = ½ (2000 + 500) = 1250°F.

Conductivity of superduty fireclay brick at 2250°F. = 10.25 (Table XXVI, page 326.)
Conductivity of H-W 23 at 1250°F. = 2.26 (Table XXVII, page 326.)

The "relative insulating value" of H-W 23 is found by dividing the thermal conductivity of fireclay brick by that of H-W 23. Therefore, the relative insulating value of H-W 23 = $\frac{10.25}{2.26}$ = 4.54, on a basis of 1.0 for fireclay brick.

The "equivalent thickness" of the entire wall, in terms of fireclay brick = d = (9″ x 1) + (4.5″ x 4.54) = 29.43″.

From Formula 2A, page 325, $q_1 = \frac{k\ (T_1 - T_2)}{d}$ in Btu per square foot per hour.

k = 10.25, the conductivity of fireclay brick at 2000°F.; $T_1 - T_2 = 2500 - 500 = 2000$°F.

$q_1 = \frac{10.25 \times 2000}{29.43}$ = 700 Btu per square foot per hour.

From heat-transmission chart, page 337, the cold-face temperature corresponding to a heat loss of 700 Btu per square foot per hour is 310°F. The cold-face temperature assumed (500°F.) is obviously incorrect, and another assumption must be made.

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Second Trial: Assume T_2 (cold-face temperature) = 310°F. (from First Trial).

(In this method, the cold-face temperature (T_2) determined by the calculations of one trial is always the assumed cold-face temperature for the next trial.)

First, the estimated interface temperature is revised, using the equivalent thickness for the entire wall (29.43″) as determined in Trial 1 above.

Estimated temperature drop through fireclay brick component of wall =

$$\frac{9''}{29.43''}\ (2500 - 310) = 670°F.$$

Revised interface temperature = 2500 — 670 = 1830°F.

Revised mean temperature of fireclay brick component of wall = $\frac{2500 + 1830}{2}$ = 2165°F.

Revised mean temperature of H-W 23 component of wall = $\frac{1830 + 310}{2}$ = 1070°F.

K of superduty fireclay brick at 2165°F. = 10.17 (Table XXVI, page 326).
K of H-W 23 at 1070°F. = 2.12 (Table XXVII, page 326).

Revised "relative insulating value" of H-W 23 = $\frac{10.17}{2.12}$ = 4.79, as compared with fireclay brick = 1.0.

Revised equivalent thickness of wall = (9″ x 1) + (4.5″ x 4.79) = 30.56″.

$$q_1 = \frac{10.17\ (2500 - 310)}{30.56} = 730 \text{ Btu per square foot per hour.}$$

From heat-transmission chart, page 337, cold-face temperature corresponding to heat loss of 730 Btu per square foot per hour = 320°F.

Since this is within 10° of the assumed temperature of 310°F. a third trial is unnecessary.

Final estimate of temperature drop through fireclay brick in wall =

$$\frac{9''}{30.56''}\ (2500 - 320) = 642°F.$$

Final estimate of interface temperature = 2500 — 642 = 1858°F. (1860°F. to nearest 5°).

Conclusion:

q_1 = 730 Btu, the heat flow per square foot per hour,
T_2 (cold-face temperature) = 320°F.
Interface temperature = 1860°F.

Example E: *Solve Example D by the Standard (or Thermal Resistance) Method, in which q_1 (the heat flow per square foot per hour) is determined from Formula 2B.*

$$q_1 = \frac{T_1 - T_2}{\frac{d_1}{k_1} + \frac{d_2}{k_2} \text{ .....}}$$

In this formula, $\frac{d_1}{k_1}$, $\frac{d_2}{k_2}$ etc. are the "thermal resistances" of the individual components.

First Trial: Assume that the cold-face temperature is 500°F.

Also assume, as before, that the interface temperature is 2000°F.

Mean temperature of fireclay component of wall = 2250°F.

Mean temperature of H-W 23 component of wall = 1250°F.

Conductivity of conventionally fired superduty fireclay brick at 2250°F. = 10.25 (Table XXVI, page 326).

Conductivity of H-W 23 at 1250°F. = 2.26 (Table XXVII, page 326).

$$q_1 = \frac{T_1 - T_2}{\frac{d_1}{k_1} + \frac{d_2}{k_2}} = \frac{2500 - 500}{\frac{9}{10.25} + \frac{4.5}{2.26}} = \frac{2000}{.878 + 1.991} = \frac{2000}{2.869} = 700 \text{ Btu per sq. foot per hour.}$$

From heat-transmission chart, page 337, the cold-face temperature corresponding to a heat loss of 700 Btu per square foot per hour is 310°F.

The cold-face temperature assumed (500°F.) is obviously incorrect, and another assumption must be made.

Second Trial: Assume T_2 (cold-face temperature) is 310° (from First Trial).

The temperature drop through the fireclay component of the wall is $q_1 \times \frac{d_1}{k_1}$ = 700 x .878 = 615°F.

Interface temperature 2500 — 615 = 1885°F.

Mean temperature, fireclay brick component of wall = $\frac{2500 + 1885}{2}$ = 2190°F.

Mean temperature, insulating brick component of wall = $\frac{1885 + 310}{2}$ = 1100°F.

Mean conductivity of superduty fireclay brick at 2190° = 10.19.
Mean conductivity of H-W 23 at 1100° = 2.14.

$$q_1 = \frac{T_1 - T_2}{\frac{d_1}{k_1} + \frac{d_2}{k_2}} = \frac{2500 - 310}{\frac{9}{10.19} + \frac{4.5}{2.14}} = \frac{2190}{.883 + 2.10} = \frac{2190}{2.983} = 735 \text{ Btu per sq. foot per hour.}$$

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From the heat-transmission chart, the cold-face temperature corresponding to a heat loss of 735 Btu is 325°F. This is within 15° of the assumed temperature of 310°, and another trial is not entirely necessary. However, it is customary to continue the calculations until the assumed and the final temperatures agree within 10°.

Third Trial: Assume T_2 (cold-face temperature) = 325°F.

Temperature drop through 9 inches of fireclay brick = $\frac{q}{A} \times \frac{d_1}{k_1}$ = 735 x .883 = 650°F.

Interface temperature = 2500 — 650 = 1850°F.

Mean conductivities = 10.18 for k_1, and 2.13 for k_2.

$$q_1 = \frac{2500 - 325}{\frac{9}{10.18} + \frac{4.5}{2.13}} = \frac{2175}{.885 + 2.11} = \frac{2175}{2.995} = 725 \text{ Btu per square foot per hour.}$$

Cold-face corresponding to heat loss of 725 Btu = 320°F.

Interface temperature = 2500 — (725 x .885) = 2500 — 640 = 1860°F.

Conclusions:

q_1 = 725 Btu, the heat flow per square foot per hour,
Cold-face temperature = 320°F.
Interface temperature = 1860°F.

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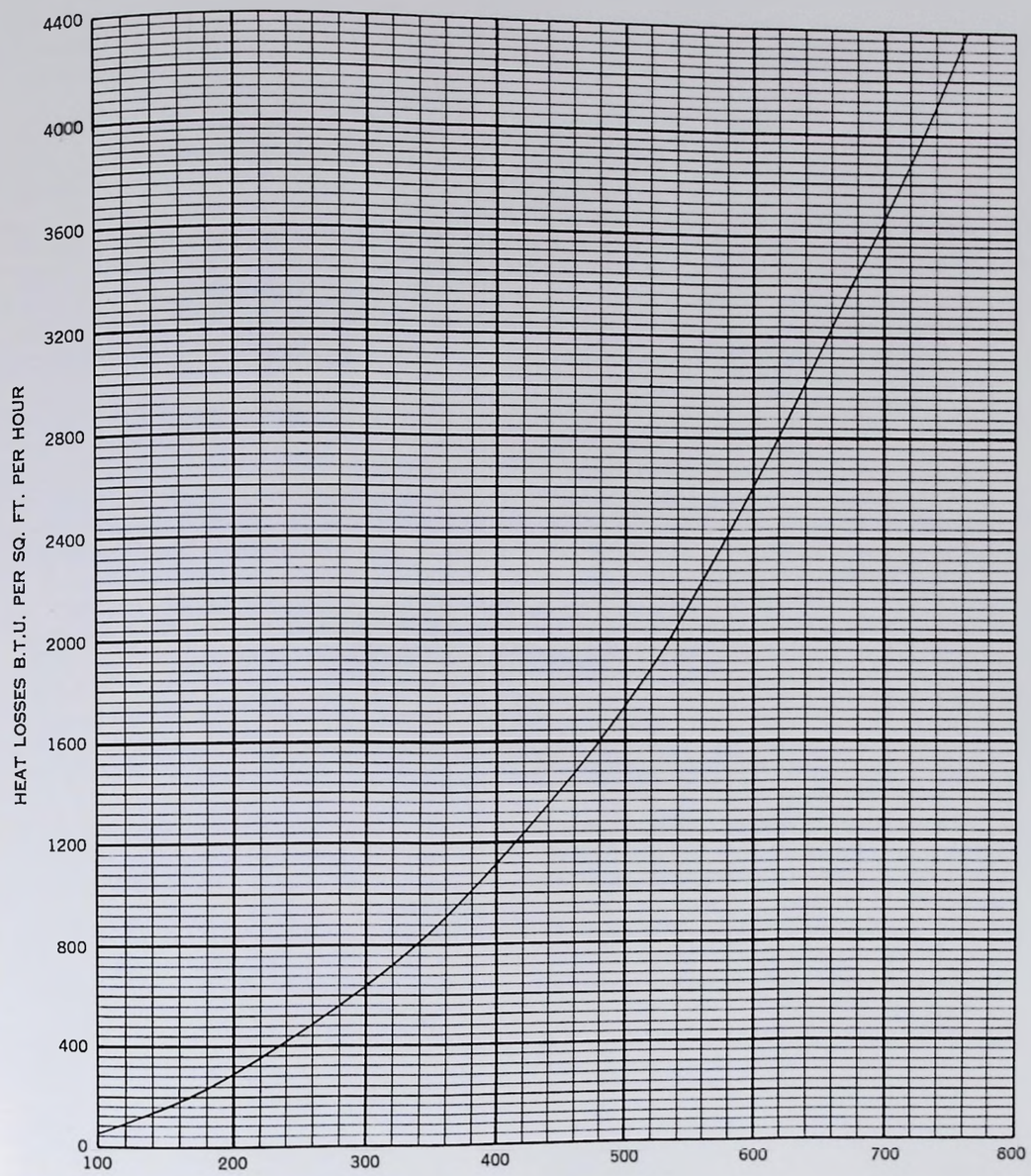


Fig. 64. Heat Transmission from Vertical Walls to Still Air at 70° Fahrenheit. Heat Transmitted Equals Heat Radiated Plus Heat Lost Through Convection.

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APPLICATIONS OF REFRACTORIES

HARBISON-WALKER REFRACTORIES COMPANY

APPLICATIONS OF REFRACTORIES IN FURNACE CONSTRUCTION

The applications of refractory products in a considerable number of representative industrial furnaces are reviewed briefly on the following pages. While it is obviously impracticable to present all types of industrial furnaces and their numerous modifications, the various kinds of furnace practice described have been so chosen as to give a broad survey of the industrial applications of the types of refractories which are commercially available, and of the service conditions for which they are advantageously employed.

The designs of the various furnaces shown illustrate good current practice. Most of the drawings do not represent actual furnaces, but are composites, prepared with the cooperation of prominent designers and operators. Harbison-Walker does not design or build furnaces, but gladly cooperates with designers and builders by supplying data regarding the properties of refractory products, by giving information concerning the service conditions under which they are applicable, and by assisting in the design of refractory brick shapes. Harbison-Walker products are used in every type of industrial furnace.

Even for furnaces of the same size and design, and used to perform the same function, variables can be involved which cause differences in service and necessitate the use of different kinds of refractories. Past service data for similar operating conditions often provide the soundest basis for an initial choice of the refractories. For a particular application, selection of the most economical and serviceable refractories may require study by an engineer of wide experience in the use of these materials. Such studies are included in the service rendered by the company to users of refractories.

Harbison-Walker makes every effort to supply only products which meet high standards of quality and which are considered best suited for their intended purposes. As explained on page 476, performance guarantees are not made, since the manufacturer has no control over the conditions to which his products are subjected in service.

Progress in many industrial processes continues at accelerated rates, accompanied by evolutionary developments. These changes create the need for refractories to meet more severe operating conditions. Harbison-Walker keeps pace with the need for specific kinds of refractories through a continuous program of research and product development.

ALUMINUM

Aluminum occurs abundantly in the earth's crust as a component of many different kinds of rock. However, practically all of the aluminum metal produced commercially is extracted from bauxite ore, which consists of aluminum oxide (alumina) chemically combined with water. Commercial ore contains also varying small proportions of such materials as silica, iron oxide, titania, and other mineral oxides.

Calcining Bauxite: As mined, bauxite often contains relatively large amounts of free moisture. It is frequently dried or calcined prior to shipment. The rotary kilns used for this purpose are equipped with Dutch ovens for firing. These are lined with high-duty fireclay brick. Whenever large tonnages are put through the calcining kilns at high temperatures, the refractory lining materials should be carefully selected, with particular attention to the abrasive nature of the charge. Harbison-Walker brands of high-duty and superduty fireclay brick such as Walsh T, H-W Special, Alamo, and Varnon serve well.

Calcining Aluminum Hydroxide: Unlike many other metals, aluminum today is not reduced directly from the ore. The calcined bauxite is chemically treated with caustic soda under pressure to produce sodium aluminate from which aluminum hydroxide is precipitated. The aluminum hydroxide is calcined in rotary kilns at the temperature required to drive off the combined water and to form commercially pure alumina (Al_2O_3).

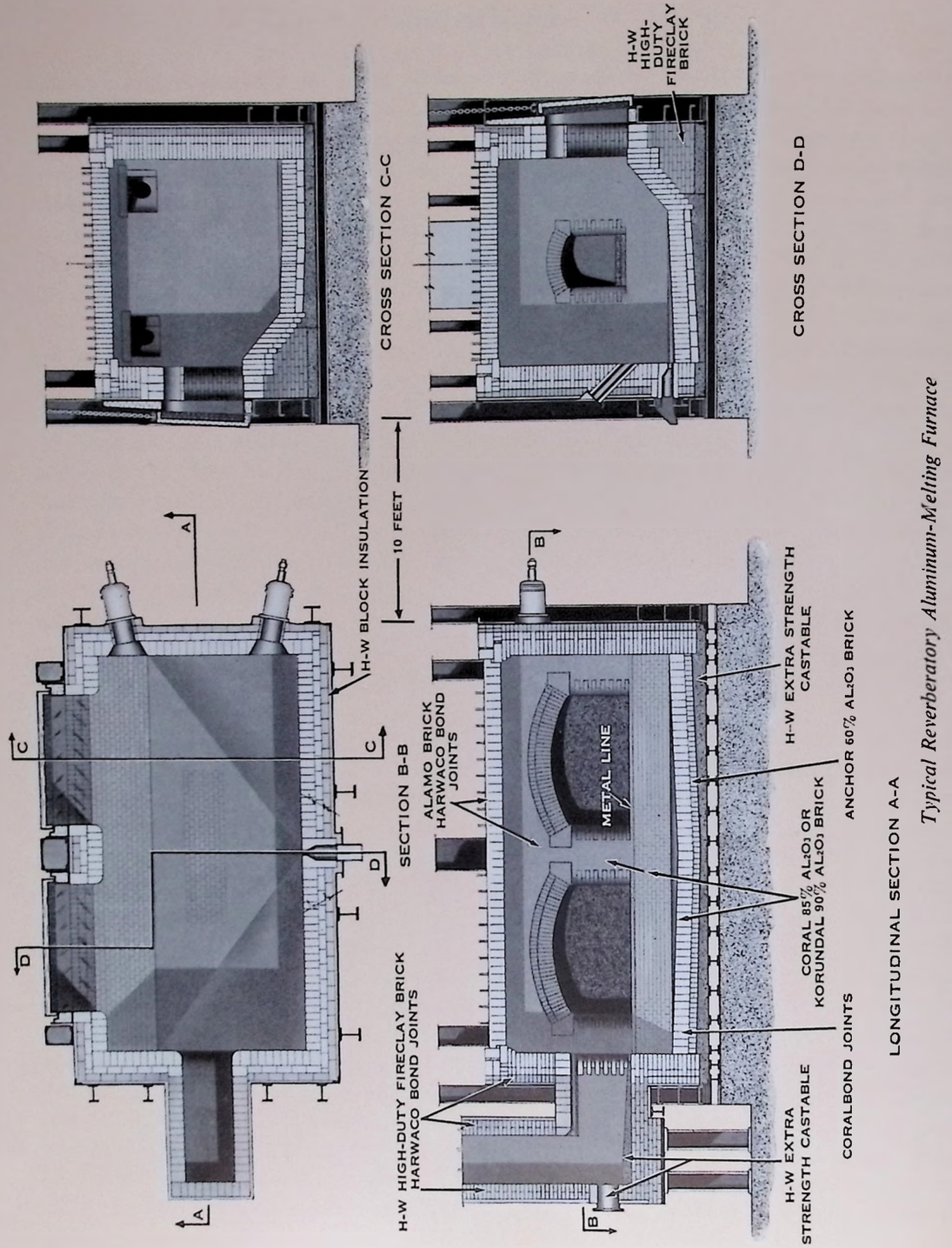
The temperatures involved and the highly abrasive character of the charge as it penetrates the joints necessitate the use of the proper refractories and the correct installation procedure for lining these kilns. Varnon and Alamo superduty fireclay brick are most widely used for lining the high-temperature zone and for building the dams which are installed to give longer retention time and prevent surging. In the cooler sections of the kiln high-duty fireclay brick such as H-W Crown, Coleman XX, and Walsh XX give long service. Harwaco Bond is used for laying the brick with very thin joints or for grouting linings which are installed without mortar.

Pot Furnaces: Reduction of alumina to the metal is accomplished by electrolysis in cells referred to as pots, which usually are lined with carbon blocks or carbon paste. In some instances, fireclay brick or refractory insulation is used between the steel shell and the carbon-block linings. The bottoms of the pots usually consist of carbon paste rammed into place, with an insulating layer of alumina or other material in powder form between the steel shell and the carbon. H-W Lightweight Castable 22 and Rototherm insulating firebrick are used to good advantage in some installations.

Carbon-Baking Furnaces: The carbon anodes for the pots may be of the self-baking (Soderberg) or prebaked types. When prebaked anodes are used they are fired in ring-type furnaces as described on page 359. Continuous tunnel kilns promise to become used economically for baking the carbon electrodes. Harbison-Walker brands of high-duty and superduty fireclay brick, possessing the optimum combination of properties, used through many years with excellent results, continue to be widely regarded as the standard of quality in this application.

Ladles: The ladles used to transport molten aluminum from the electrolytic cells to furnaces for further refining or casting are usually lined with dense high-duty fireclay brick. Various types of castables also are used.

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Typical Reverberatory Aluminum-Melting Furnace

Aluminum-Melting Furnaces: The refractories best suited for lining aluminum-melting and holding furnaces depend upon design of the furnace, the melting rate, the kind of metal or scrap charged and alloys to be produced as well as other operating conditions.

In the upper sidewalls and roof, ALAMO superduty fireclay brick, several brands of H-W high-duty fireclay brick, and superduty fireclay plastic refractories give excellent results.

Bottoms and sidewalls up to about 15 inches above sill level are the most critical areas and the most careful selection of refractories is necessary for best economy. Resistance to corrosion, reaction, and penetration by molten aluminum and its various alloys is important, as is the ability to withstand mechanical abuse.

Special dense high-duty fireclay brick and ANCHOR 60 per cent alumina brick have been widely used, particularly when objection to silicon pickup is not a factor. When operating conditions are severe and high purity is essential, KORUNDAL 90 per cent alumina brand has been considered a standard at many plants. The CORAL brands of 85 per cent alumina brick were developed primarily for aluminum-melting furnaces. They are exceedingly resistant to reaction with aluminum and its alloys and have excellent strength at operating temperatures.

CORALBOND, an 85 per cent alumina mortar, is uniquely superior for laying all the various brick in the bottoms and lower sidewalls of aluminum-melting furnaces. HARWACO BOND and THERMOLITH also are widely used.

Where monolithic linings are preferred for the bottom and lower sidewalls, Harbison-Walker plastic refractories, castables, and ramming mixes are used in many installations.

BLAST-FURNACE LININGS

IN 1871, Harbison-Walker manufactured its first iron blast-furnace lining. During the years which have followed, the company has made the greater proportion of all the blast-furnace refractories used in the United States. The large number of Harbison-Walker linings in service today—more than those of any other manufacture—testify to their high standing in the industry.

In keeping with the company's leadership in this field, additions have been made to the list of long established brands of blast-furnace brick. The new brands include refractories having enhanced properties for the more severe operating conditions. Their manufacture in various industrial locations over the country provides advantages in deliveries and transportation costs. Today's operators may make their selection from the following brands:

Superduty Fireclay Brick

VARNON BF	made in Missouri
VARNON BF DASH	made in Missouri

High-Duty Fireclay Brick (Cone 18 Burn)

H-W 18 ALA	made in Alabama
H-W 18 KY	made in Kentucky
H-W 18 MO	made in Missouri
H-W 18 PA	made in Pennsylvania

High-Duty Fireclay Brick

H-W ALA BF	made in Alabama
H-W KY BF	made in Kentucky
H-W MO BF DASH	made in Missouri
BENEZET BF	made in Pennsylvania

Harbison-Walker blast-furnace refractories have been used under all different operating conditions, in all sizes and designs of furnaces, and with all classes of ores and fuels. The company has always given special attention to the manufacture of blast-furnace refractories, and

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many world's records on furnace tonnage have been made with Harbison-Walker linings.

Blast-furnace refractories are manufactured from the best selected fire clays, and close laboratory control insures the uniform high quality of the raw materials. Rigid control procedures also play an important part in every step of the manufacturing process. The sizing to which the clays are ground, the moisture content, the pressure at which the brick are molded, the temperature of firing, and the firing conditions are all kept within close predetermined limits. Continuous tunnel kilns are used for firing the brick.

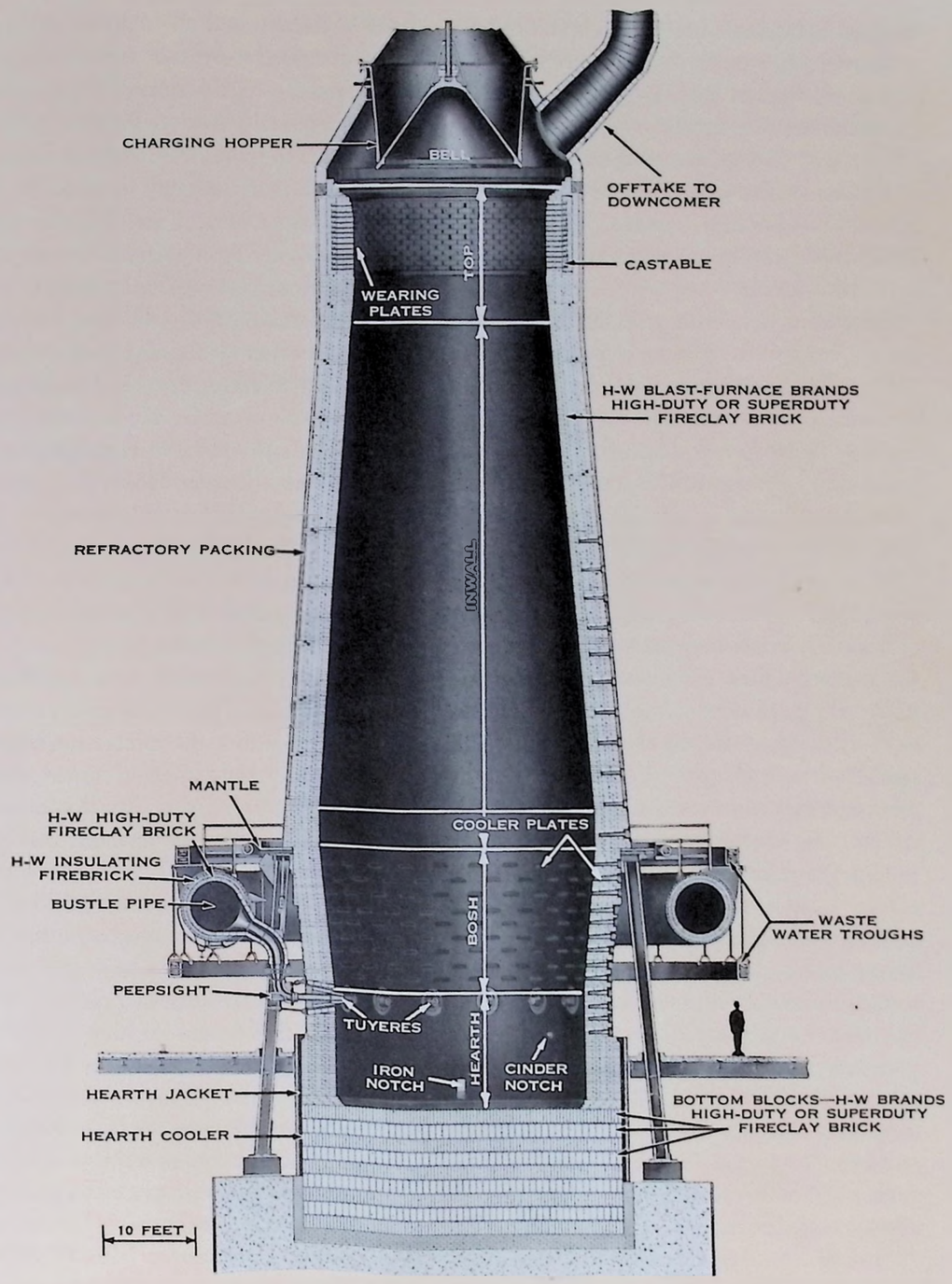
While service conditions vary considerably in the different sections of a blast-furnace lining, certain characteristics for the refractories are essential for all locations. Good workmanship and uniformity in size of the brick are necessary to insure tight close-fitting construction, which is exceedingly important for securing maximum lining service. Blast-furnace refractories should be strong, tough, dense, of uniform texture, and of low permeability. Special power-press equipment, used for making all Harbison-Walker blast-furnace brick, contributes to the achievement of the most desirable physical properties. Further improvement in the characteristics of blast-furnace refractories is one of the important phases of the continuing research program.

The Harbison-Walker brands of blast-furnace refractories listed above, selected for the particular operating conditions and furnace size and design, fulfill the requirements of complete linings.

Top: Brick for the blast-furnace top are not required to withstand especially high temperatures. However, they must possess properties which are developed only by temperatures of firing so high that only highly refractory brick will withstand them. The critical temperature range for carbon deposition, as described below, comes close to the working face and high resistance to disintegration is most important. Impact and abrasion are most severe in the top zone. In addition, the brick must be able to withstand infrequent but sometimes rapid temperature change which can result from nonuniform furnace operation.

Inwall: Resistance to the abrasive action of the descending stock is an essential requirement of the refractory in the upper inwall section. Formerly, one of the most severe destructive influences affecting the refractories in the upper inwall and top sections was the tendency of carbon monoxide gas to dissociate into carbon dioxide and solid carbon in the pores of the brick where the temperatures are between about 700°F. and 1200°F. The critical temperature range occurs at different distances from the working face of the lining at the different furnace elevations. Its position at any particular zone depends upon the temperature at the working face of the lining, and upon the temperature drop through the lining. In the top section, the critical temperature range may come close to the working face while in the lower part of the stack, it is well back toward the shell.

Research proved that at temperatures between 700°F. and 1200°F. particles of free iron oxide in the brick are reduced to metallic iron or iron carbide which catalyzes the carbon deposition. Deposition of the carbon can cause internal stresses great enough to disrupt the bond of the brick and cause disintegration. Research also showed that if the brick were fired to a sufficiently high temperature in manufacture, and especially if they were fired under controlled reducing conditions, any iron oxides present combine with alumina and silica to



Typical Modern Blast Furnace

HARBISON-WALKER REFRACTORIES COMPANY

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form iron-alumina silicates which do not have a catalytic effect on the carbon deposition. The high-fired VARNON and H-W 18 brands are recommended for maximum resistance to disintegration. The higher temperature of firing also increases the density, strength, and toughness of the brick. An increasing number of blast-furnace stacks are now lined throughout with these brands.

Temperatures become gradually higher from the top down to the mantle. In the lower inwall section, high refractoriness and resistance to moderately severe abrasion, together with resistance to the penetration of alkalies, are of paramount importance. The ore, limestone, and coke charged into a blast furnace all contain small amounts of alkalies. The alkalies volatilize in the lower portion of the furnace and ascend with the furnace gases to the upper part of the stack where they condense in part upon the furnace lining and upon the descending stock. The remainder of the alkalies is carried away by the gases leaving the furnace top. The alkalies deposited upon the stock are again carried down to the combustion zone and revolatilized. The effect is thus cumulative.

Any gas which penetrates the brickwork carries with it volatilized alkalies, which at moderate or high temperatures exert a strong fluxing action upon the brick and reduce their refractoriness. At lower temperatures the alkalies condense in the pores. Under some conditions, alkali pickup results in the formation of alkali silicates which may disrupt the refractories because of the increase in volume which accompanies their formation, or because of differences in thermal expansion. The absorption of volatile alkalies can be minimized by the use of refractories having lowest possible permeability to gases.

Bosh: In the bosh section, the lining is exposed to a slag which at high temperatures is one of the most corrosive furnace slags. The brick must be highly refractory, and of low permeability and porosity. Because of the extremely high temperatures involved, water cooling the bosh is exceedingly important.

Hearth: Temperatures are highest in the hearth and lower bosh sections; consequently, corrosion by slag action is most severe. Hearth refractories should not only have high resistance to corrosion by the slag, but should also possess high refractoriness, low porosity, and stability of volume in service to resist penetration by metal. The merit of these properties in Harbison-Walker bottom blocks is demonstrated by their splendid service over many years. VARNON BF blocks have come to be widely preferred because of their properties of higher refractoriness and density, together with lowest porosity and negligible shrinkage.

In building the hearth wall and bottom, bricklaying should be as nearly perfect as possible. The thin tight joints necessary are obtainable only with brick of superior workmanship and uniformity in size. It is important that the wall be of ample thickness and that it be properly cooled.

H-W BLACK PATCH is used successfully around the tapping holes and also for lining the troughs.

Piping: For lining offtakes and downcomers, the brick and mortar must be capable of resisting the abrasive action of dust-laden gases moving at high velocity. For this service, the refractories must be strong and tough. High-duty fireclay brick having the desirable properties serve best for this purpose.

High strength and resistance to spalling are the most important requirements for the lining of the hot-blast main system. High-duty fireclay brick laid with an air-setting high-temperature bonding mortar are generally used.

For both new installations and emergency repairs, appreciable savings in time of installation have resulted from the use of H-W EXTRA STRENGTH CASTABLE as a lining material for the piping. Satisfactory installation can be accomplished by casting, tamping, or gunning.

General: The shapes generally used in blast-furnace linings are standard 9″ x 6″ x 3″ straights and keys, 13½″ x 6″ x 3″ straights and keys, and standard bottom blocks, 18″ x 9″ x 4½″. Special shapes may be used over lining coolers, at tuyere coolers, and at the iron and cinder notches.

Harbison-Walker also furnishes all-key type lining brick which have the advantage of eliminating all straight brick. This results in a more uniform layup and the theoretical considerations for a sounder construction are excellent.

Mortars: Adequate refractoriness and minimum shrinkage are essential in mortar materials for blast-furnace linings. The mortar should be finely ground and have excellent workability, as thin, accurate joints are necessary for best results in every part of the furnace. Heat-setting fire clays of the same refractory quality as the brick are generally preferred. H-W SPECIAL MORTAR and H-W WEATHERED BOND B CLAY combine these desirable properties in high-heat-duty material. H-W SUPERDUTY MORTAR is properly matched with the properties of superduty fireclay brick when used in the inwall. For best construction in the hearth, ANKORITE 65 bonding mortar offers the required additional margin of refractoriness and volume stability, combined with resistance to slag attack and metal penetration.

Air-setting mortars have been advantageously employed in top locations for many years and more recently their use has been extended to other parts of the furnace. Air-setting mortars are particularly helpful in resisting abrasion and making the entire lining more impermeable to the various gases and volatiles. In top locations and for bricklaying in piping where highest refractoriness is not required, PENSEAL serves very satisfactorily. HARWACO BOND and H-W SUPER HARBOND are used for bricklaying in the other parts of the furnace lining above the tuyeres which are exposed to higher temperatures.

Maintenance of Linings: Castables and gunning mixes are used for maintenance of blast-furnace linings in areas of localized wear. Such a procedure is deemed economical when it has become necessary to take a furnace out of service for reasons other than general lining wear and subsequent inspection has shown non-uniform thicknesses.

Most experience with gunning monolithic materials to date has been in the lower inwall areas. The bosh and the upper inwall are other locations which have been brought out to uniform thickness by gunning. In some cases the entire stack lining has been repaired in this manner in order to give assurance that the furnace would perform satisfactorily for a greater length of time when again blown in.

For gunning, a hydraulic-setting material is generally preferred because of its best strength development through a wide temperature range. Special low-iron types of gunning mixes should be used to minimize danger from disintegration by carbon monoxide. Castables have the added advantage of minimum permeability. Naturally, adequate refractoriness is necessary depending upon the particular furnace zone where applied. Of significant importance are proper procedures for installation and drying out.

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BLAST-FURNACE STOVES

Efficient operation of the large modern blast furnace requires a means of supplying tremendous volumes of adequately heated air. The temperature of the air may have to be raised from atmospheric to the range of 1000 to 2000°F., depending upon the nature of the furnace burden and other furnace engineering features. The trend is toward appreciably higher temperatures in the future. In normal practice, the air is heated by passage through a tall column of hot brick checkerwork, which has been previously heated by the combustion of cleaned waste blast-furnace gases having a heating value of about 100 Btu's per cubic foot.

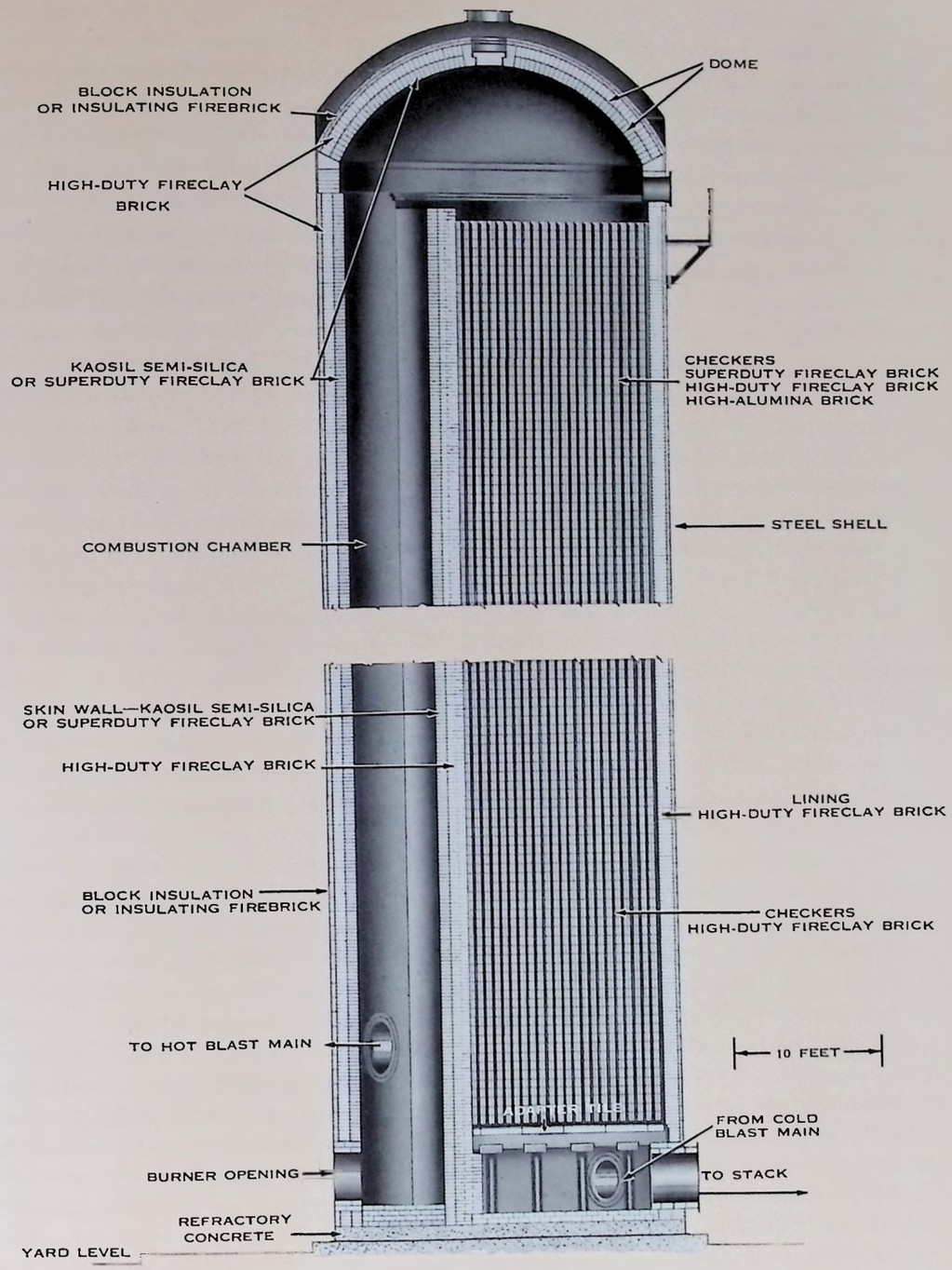
Stoves for large furnaces are 26 to 28 feet in diameter and about 125 feet high from the bottom to the top of the dome. Naturally, design considerations will vary, depending not only on the volume of air necessary but also upon the hot-blast temperature desired. On the basis of 500 square feet of checker heating surface per ton of iron produced per day, a 1500-ton blast furnace would need 750,000 square feet of heating surface, which would be furnished by a normal complement of three stoves. Each stove is put "on the furnace" in sequence, supplying the heated air for a period of from one to two hours, and in turn, being reheated for a period of two to four hours.

Modern stove practice calls for the use of temperature control equipment to promote best combustion, to provide the most desirable temperature distribution through the stove, and to protect the refractories from localized overheating of the combustion chamber and the top, the hottest portions of the stove. The operator must know the temperature in the bottom section of the stoves in order to be sure that they are functioning properly, that the flues are not becoming blocked through the use of improperly cleaned gas, and as a further check on the temperature distribution.

Because of the ever-increasing demands upon hot-blast stoves, the refractories for lining them must more than ever possess a definite combination of superior properties. Essential qualities for stove brick are capacity to absorb heat readily from the hot gases, and ability to impart this heat rapidly to the air blown through the stove. Properties which are necessary for maximum durability are good mechanical strength both cold and at high temperatures, and high resistance to deformation, to chemical action of fumes and dust of high alkali content, and to the spalling effects of rapid temperature change.

Stove brick are not subjected to temperatures as high as those which prevail in the melting zone of the blast furnace, and their normal life is longer. However, they do not have the benefit of outside cooling effects usually afforded blast-furnace refractories. The refractories in all parts of the stove lining and checker setting should have an ample margin of refractoriness, as gradual deterioration from vitrification may take place during the long period of time they are in service.

Highest temperatures prevail in the combustion chamber and dome and in the uppermost section of the checker setting. Brick used for the linings of combustion chambers and domes should have high refractoriness and resistance to spalling. Harbison-Walker superduty fireclay brick Alamo, Boone, and Dean have long been recognized as having the required properties. The semi-silica fireclay brick Kaosil has shown even greater stability under load, together with high spalling resistance. These properties are



Typical Blast-Furnace Stove

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retained in service because of the development of a thin surface glaze which greatly retards penetration by alkalies.

The refractories used in the uppermost checker sections must withstand fluxing by volatile alkalies at high temperatures on both sides of the thin checker walls which usually measure from 1¼ to 2 inches in thickness. At slightly lower temperatures, the alkalies tend to be absorbed by the brick, with formation of such minerals as kaliophilite ($K_2O \cdot Al_2O_3 \cdot 2SiO_2$), leucite ($K_2O \cdot Al_2O_3 \cdot 4SiO_2$), nephelite [$(Na, K)_2O \cdot Al_2O_3 \cdot 2SiO_2$], and others, with resultant increase in volume and thermal expansion of the portion of the brick affected. Recent developments resulting in increased density and lower porosity of ALAMO, BOONE, and DEAN represent significant strides toward reduction of alkali penetration.

In the future, higher blast temperatures than ever before achieved may become the practice, resulting in a greatly increased demand upon the stoves. Higher temperatures throughout the entire structure will result and many of the refractories which have served adequately for years may need to be succeeded by others further specialized for the purpose.

Where higher than normal checker temperatures are contemplated, the exceptionally high-fired and dense superduty brick VARNON and KENMORE offer an added resistance to deformation under load together with minimum porosity for brick of such high refractoriness. Semi-silica fireclay brick are frequently used for intermediate courses of stove checker brick and offer much in volume stability.

In the lower and middle stove construction or for entire stoves where operations do not require that maximum temperatures exceed approximately 2100°F., H-W STOVE brick give exceptionally good results. These brick are dense and strong, and possess the proper combination of properties. The records made by Harbison-Walker stove linings—some of which have been in continuous service for twenty years or more—demonstrate how successfully the company's products meet the requirements.

Not only must stove refractories have suitable chemical and physical properties to meet exacting service conditions, but they must meet close tolerances as to size. In many cases where greatly increased heating surface is necessary it has been attained by the adoption of thinner checkers, and in others by the utilization of special shapes, which are often of intricate design. Close size tolerances are rigid requirements for checker brick of the several special types which are designed for close interfitting to contribute to the stability of the masonry construction. Through many years of experience, Harbison-Walker has perfected methods of processing by means of which excellent workmanship is obtained in the manufacture of checker shapes of every type.

Harbison-Walker insulating materials provide the most desirable selections for the intermediate lining between the refractory ring wall lining and the steel shell, and between the dome and the shell, and are of special value for insulating the combustion chamber section.

Paralleling the advances made in the manufacture of refractory brick, there has been a corresponding development in the production of superior high-temperature bonding mortars. H-W HIGH-DUTY FIRE CLAY, H-W WEATHERED BOND B CLAY, and KAOSIL FIRE CLAY heat-setting mortars are recommended for use in laying brick in the domes, ring walls, and flash walls. Under most conditions the high-temperature bonding mortars HARWACO BOND and PENSEAL, which are air-setting, are preferred for laying brick in the arches and connections.

BOILER FURNACES

THE types, designs, and makes of boilers are numerous. They vary in size from the huge installations of some power-generating stations to the very small units of domestic heating plants. On the basis of construction, there are two principal types of industrial boiler furnaces: (1) those with water walls, and (2) those with refractory walls. Some furnaces are a combination of the two. Most of the development in industrial boiler design over the past several decades has been with the water-wall type, and most of the newer large-size boilers are of this class.

On the basis of function, boilers may be classified (1) as those used in power-generating plants where the steam produced is used to generate electric power, and (2) those used in plants producing steam for use as such. Most of the largest boilers belong in the first group, and have water-wall construction.

The functions of refractories in boiler furnaces are various. They serve to confine and radiate heat, to promote combustion, to help maintain combustion gases at proper temperatures, to create turbulence, to direct hot gases into desired paths, and to seal the setting against infiltration by outside air. Refractories are used for lining combustion chambers, for backing of water tubes, for construction of suspended walls and arches, for baffles, seals, and burner blocks, for building walls beyond the combustion chamber, for lining slag-tap bottoms, for lining sidewalls and bottoms of chemical-recovery boilers in the paper industry, for stack linings, and for ash-handling equipment.

The service conditions to which the refractories are exposed depend upon their place in the furnace, as well as upon the size, design and type of boiler, the kind of fuel used, and the uniformity and other conditions of operation. Among the factors which affect the life of the refractories are the amount and character of the fuel ash, the rate of heat release, the furnace temperature and atmosphere, and the rapidity of temperature changes. Other factors include the position of the burners with reference to the walls, the length of the flame, and the amount of mechanical abuse.

Harbison-Walker refractory materials are used in power-plant boiler settings of all types, from those in the largest central stations to those in manufacturing plants of every kind and size, and in marine-type boilers. Harbison-Walker materials are used also in numerous industrial steam-generating plants and in steam-heating plants of many thousands of buildings, ranging in size from those in large public buildings to those in small dwellings.

At many of the company's plants, Harbison-Walker manufactures and carries in stock numerous special boiler furnace shapes, including many for suspended arches and walls, as well as tube-backing, tube-protecting and baffle tile, and burner blocks. Included also among the products are various monolithic refractory materials which may be used to advantage for the construction and maintenance of sidewalls, arches, baffles, burner blocks, slag-tap bottoms, and insulated sections of boiler furnaces.

The refractories needed for the many different types of boilers comprise practically all the many commercial classes. In addition to the products most commonly used, Harbison-Walker supplies special high-alumina brick for resistance to the severe slagging action of oil ash, silicon carbide for some difficult coal ash conditions, and basic refractories for highest resistance to chemically basic corrosion.

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POWER-PLANT BOILERS WITH WATER WALLS

In the settings of water-wall boilers, refractories are used for backing the water tubes, for baffles and seals, and for the walls beyond the furnace proper. When the tubes are closely spaced or tangent, the side of the tubes away from the fire is generally covered with a layer of castable refractory such as H-W Lightweight Castable 22, or with a nonshrinking high-temperature mastic such as Harwaco Mastic, 1 to 1½ inches thick. This in turn may be backed with H-W Block Insulation. The castable material is usually anchored by metal studs on the tubes, or by wire mesh or expanded metal attached to studs which are welded to the tubes. In the case of pressurized boilers, a light steel casing generally is installed between the castable or mastic and the block insulation.

Where there is an appreciable space between the tubes, the exterior portions of the walls are built of close-fitting refractory tile, with a backing of insulating firebrick, lightweight castable, or block insulation. The tile are made of high-duty or superduty fireclay materials, or of high-alumina material, depending on the severity of the operating conditions. Good workmanship of these tile is highly important.

In some stoker-fired water-wall units, a suspended ignition arch built of firebrick, directly exposed to the furnace atmosphere, is necessary to promote combustion. While the area of this section is relatively small, both the quality of the brick and proper installation are of great importance. High-duty or superduty fireclay brick usually are adequate.

The walls beyond the furnace proper are often of suspended construction. They are built of fireclay brick, of insulating firebrick, or of monolithic refractory material.

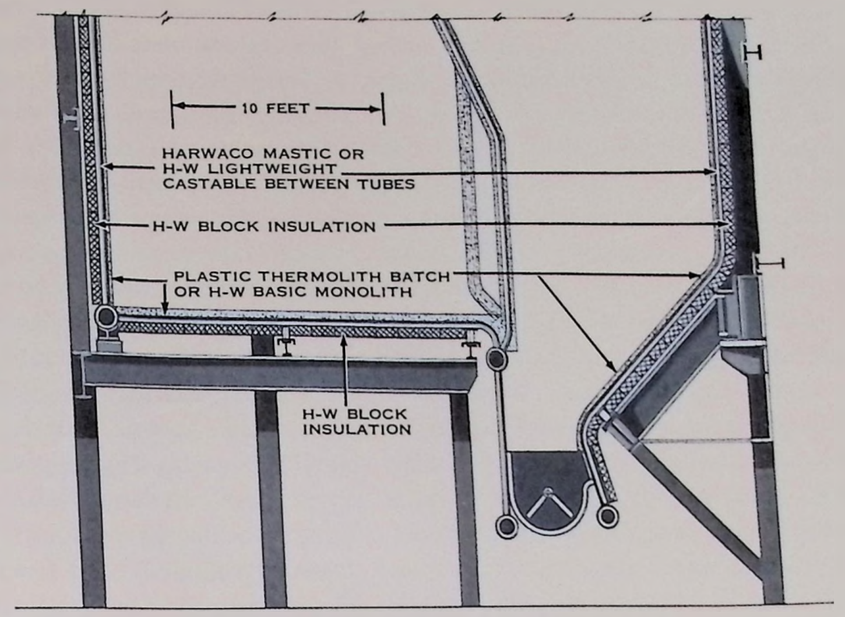
Ash disposal problems are minimized by means of slag-tap and hopper bottoms. For slag-tap bottoms of boilers fired with pulverized coal, the tubes in the bottom and for several feet above it are sometimes covered with a plastic chrome-base ramming mix, or other basic monolithic material. Harbison-Walker products used advantageously for this purpose are Plastic Thermolith Batch, H-W Chrome Castable, or H-W Magnamix. The floors beneath the tubes generally consist of fireclay tile and block insulation.

In bottoms of the ash-hopper type, it has been the practice to use dense fireclay brick for the linings. More recent installations have been either entirely of refractory castable or a combination of castable and brick. Service conditions are especially severe in some hoppers where water for cleaning is introduced through jets in the bottoms. H-W Extra Strength Castable is resistant to the abrasion and rapid temperature changes, and has given excellent service under these rather severe conditions in the absence of acidic water.

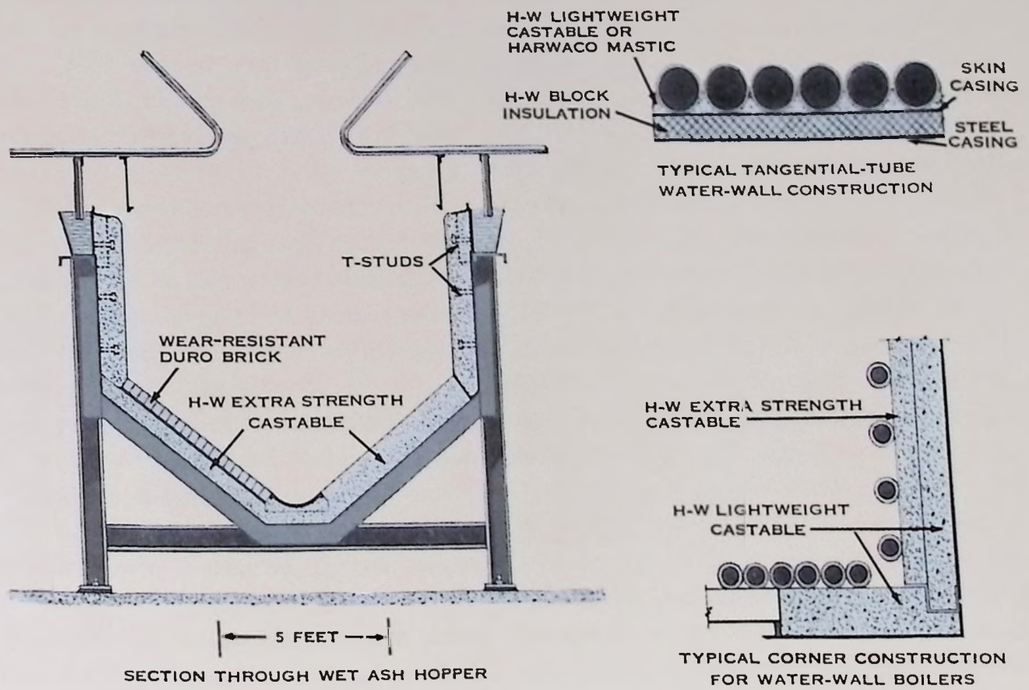
POWER-PLANT BOILERS WITH REFRACTORY WALLS

Few of the more recent power-plant boilers have complete refractory settings. However, thousands of older boilers are still in service, in which the combustion chambers and other parts of the settings are enclosed in solid or air-cooled walls built entirely of refractories.

The combustion chamber walls of some boiler furnaces rest directly upon the foundations; others are sectionally supported. The furnace walls are usually built of high-duty or super-



SECTION THROUGH A SLAG-TAP BOTTOM



TYPICAL TANGENTIAL-TUBE WATER-WALL CONSTRUCTION

SECTION THROUGH WET ASH HOPPER

TYPICAL CORNER CONSTRUCTION FOR WATER-WALL BOILERS

Boiler Furnace Sections

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duty fireclay brick, 9 inches or 13½ inches thick, with an outside backing several inches thick of less refractory fireclay brick, insulating firebrick, or block insulation.

There are some definite advantages in the use of sectionally supported walls and arches in various applications, and several designs are available. This construction generally consists of high-duty or superduty fireclay shapes of special design, held in place by steel hangers attached to supporting steelwork. The backing may be medium- or low-duty fireclay brick, insulating firebrick, or block insulation. In the hotter portions of the setting, the sectionally supported walls are usually cooled by means of horizontal or vertical air ducts between the hot-face refractory and the less refractory backing. A suspended tile arrangement for the ignition arch and front wall is often used in conjunction with solid sidewalls.

For some boilers, especially the smaller units, the settings are made either partially or entirely of monolithic construction. H-W Standard or H-W Super Plastic Firebrick serve for those portions of the linings where the prevailing temperatures are high enough to develop a ceramic bond, as in walls of fireboxes and combustion chambers. Either air-setting plastic refractories or prefired refractories may be used for the balance of the setting.

Castables are of particular value in providing insulating backing for walls of combustion chambers and ash pits, and for baffles, tube decks, and rear arches. They may be used for service throughout the complete range of temperatures up to their temperature limits.

For linings which are exposed to the direct action of both flame and fuel ash, selection of the most suitable refractory is of special importance. High-duty fireclay brick are generally used in this service. For conditions too severe for this class of refractory, superduty fireclay or high-alumina brick may be used.

In boiler settings with limited combustion space and operated at high ratings, even superduty fireclay brick may give relatively short life. High-alumina brands provide an additional margin of quality beyond that of superduty fireclay brick. Harbison-Walker manufactures Dialite in the 50 per cent alumina class, Anchor Dash and Alcor XX in the 60 per cent alumina class, and Korundal in the 90 per cent alumina class. These brands in the order named are increasingly resistant to severe operating conditions. When the temperature of coal-fired boilers is increased by auxiliary oil firing, the coal ash slag may become very fluid. For this condition, Chromex brick are sometimes used to advantage in the combustion chamber lining.

It is common practice to use superduty fireclay or high-alumina brick along the grate line of coal-fired boilers. Silicon carbide brick also are used along the grate line when ash of some compositions is present. Materials used for patching small sections of a lining include plastic refractories, ramming mixes, and castables.

MARINE BOILERS

Steam-power plants for marine service have been developed to a high state of efficiency to meet a definite combination of requirements. The power must be developed in units which are light in weight, and which require the minimum of space. The refractory linings of the boiler settings must be capable of withstanding not only the operating conditions normal to boiler furnaces having high heat release per cubic foot of furnace volume, but also vibration and the heavy stresses and shifting of stresses caused by the rolling and pitching of the vessels. The cold-face temperatures of the refractory walls must be lower than is usual in other boiler settings, both to conserve heat and to avoid overheating the air in boiler rooms.

Most marine boilers are fired with oil; however, some are still fired with coal, either by means of stokers or by hand. The furnaces may have either refractory walls or water walls. The latter are more general.

For the high-temperature portions of settings with refractory walls, common practice favors the use of walls 9 inches thick built with superduty fireclay brick such as Alamo or Varnon, or high-alumina brick of the 60 per cent alumina class, such as Anchor Dash or Alcor XX. The refractory brick are anchored to the steel casing, and adequately insulated by means of insulating firebrick and other high-temperature insulating materials.

For the walls of the furnaces beyond the combustion chambers, it is customary to use high-duty fireclay brick, backed by several inches of insulation, or insulating firebrick with a backing of block insulation. Baffles generally are of high-duty fireclay tile.

Some Harbison-Walker brands widely used in marine service are Walsh XX, Woodland, H-W Crown, Western, Alamo, Varnon, Zenith, Anchor Dash, and Alcor XX.

For the portions of the settings where monolithic refractories are applicable, the following materials may be used, depending upon the location in the setting and the specific service requirements: Plastic Thermolith Batch, H-W Standard Plastic Firebrick, H-W Super Plastic Firebrick, H-W Standard Castable, H-W Super Castable, or H-W Lightweight Castables.

STEAM-PLANT BOILERS

Many boilers are operated primarily for the generation of process-steam or steam for space-heating. Process-steam is widely used in the chemical, petroleum, paper, and other industries; steam for heating is used in manufacturing plants, public buildings, and residences. In the larger steam plants, the refractories used are generally about the same as for units of similar size in power-generating plants.

Medium- and Small-Sized Boilers: Most of the medium- and small-sized boilers presently being installed are of the "package" type. Such boilers are factory-assembled, and as shipped are ready to operate as soon as they are placed on a base and connected with fuel, water, electric, and steam lines.

Oil- and gas-fired fire-tube package boilers generally have a small amount of refractory material in the furnace or combustion chamber. Usually, the rear combustion or baffle chamber is lined with fireclay tile or castable material, backed up with lightweight castable or other insulating material.

In coal-fired fire-tube package units, the combustion chambers usually are lined with fireclay brick or tile, with a backing of insulating firebrick.

In water-tube package steam generators, refractories are used in walls and baffles. In the zones of highest wall temperature, the linings back of the tubes usually consist of 2 inches of fireclay tile backed with insulating firebrick or lightweight castable and block insulation. In the cooler zones, insulating castable is gener-

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ally used, with a backing of block insulation.

Many small to medium-sized boilers in use are not of the package type. For gas- and oil-fired installations, the lining materials include fireclay brick or high-alumina brick, usually backed with insulating firebrick; insulating firebrick alone; plastic refractories, or precast shapes made of castable material.

In medium-sized stoker-fired boiler furnaces, the lining at the clinker line may consist of high-duty or superduty fireclay brick, or high-alumina or silicon carbide brick, depending on the severity of the slagging action. Insulating firebrick are used as backing. In small stoker-fired furnaces, the fireboxes are generally lined with fireclay brick, or with plastic refractories.

REFRACTORY LININGS AS RELATED TO FUELS

Coal, oil, and gas are the most common boiler furnace fuels; however, a wide variety of other combustibles is used also. Coke-oven gas and blast-furnace gas are employed with good economy. Lignite has been used for a great many years in certain areas. By-products or waste fuels such as wood refuse, bark, bagasse from sugar mills, black liquor concentrate of the paper industry, and food processing wastes are burned in boiler furnaces for the production of power or steam. Waste-heat boilers obtain their energy from the hot combustion gases of industrial furnaces.

For every type of burner used for firing gaseous, liquid, or powdered fuels in boiler furnaces, Harbison-Walker supplies brick shapes in the various classes of fireclay and high-alumina refractories, as well as plastic refractories and castables.

Harbison-Walker castables are used advantageously for the construction and maintenance of baffles, burner blocks, and insulated sections.

Stoker-Fired Boilers: Many of the settings of stoker-fired boilers are subjected to erosion and corrosion by slag, and to spalling influences. Walls and arches adjacent to the fireboxes are generally built of superduty fireclay brick or of high-alumina brick of the 60 per cent alumina class such as ANCHOR DASH. The ignition and combustion arches of chain-grate stokers and the ignition arches of spreader stokers are generally suspended. Refractories forming these arches must resist erosion and spalling.

With some types of stoker-fired boilers, clinker adhesion to sidewalls and bridge walls is a problem of major importance. This difficulty is largely overcome by the use at the clinker line of several courses of air-cooled fireclay brick blocks or of KORUNDAL high-alumina brick or HARBIDE silicon carbide brick, to which most clinker does not adhere strongly.

Oil-Fired Boiler Furnaces: For oil firing, the settings may have water walls, solid refractory walls, or suspended air-cooled walls. The refractories selected for the linings will depend upon the type of setting and upon the severity of service conditions. They must be able to withstand localized high temperatures and reducing atmospheres. Harbison-Walker brands of high-duty and superduty fireclay brick, high-alumina brick, monolithic refractories, and high-temperature insulations are used in the linings of oil-fired boiler furnaces.

The ash of some fuel oils is very corrosive and promotes vitrification of the brick, particularly if the ash is relatively high in vanadium and sodium oxides. Petroleum ash containing much vanadium oxide is very destructive to fireclay brick at high temperatures. High-alumina brick, especially those of the 70 per cent to 90 per cent alumina classes, have high resistance to vanadium oxide in such ash.

Gas-Fired Boiler Furnaces: The most common industrial gaseous fuels are natural gas, blast-furnace gas, and by-product coke-oven gas. Natural gas is practically free from ash-producing constituents; the others, except when cleaned by thorough washing, may contain varying amounts of ash-producing dusts as well as tarry substances. Washed blast-furnace gas contains uncombined alkalies.

Operating temperatures in gas-fired boilers may range from relatively moderate to extremely high. Rapid changes in temperature may cause refractory linings to crack or spall. Rapidly moving gases laden with dust may cause mechanical erosion and in some cases, molten ash deposited on the brickwork, causes corrosion. Impinging flames may result in localized hot spots and overheating of small areas.

In general, high-duty fireclay brick are used in building side, front, and bridge walls of boilers with refractory walls. However, for the most severe conditions, superduty fireclay brick or even the more refractory high-alumina brick may be required for the more vulnerable parts of the setting.

Wood-Fired Furnaces: For the burning of slabs, sawdust, bark, or hogged fuel (shredded mill refuse), an extension type of furnace is generally used, and the fuel is fed through chutes in the furnace arch to stationary grates. The temperature may be high enough to melt the ash into a corrosive slag, especially when the wood fuel is supplemented by oil. For the furnace linings, Harbison-Walker high-duty and superduty fireclay and ANCHOR DASH high-alumina brick meet the service requirements.

Bagasse-Fired Boiler Furnaces: In bagasse-fired furnaces, grates or brick hearths are provided for combustion. However, because of its lightness, much of the bagasse is carried along by the draft and burned in suspension. Carbon monoxide, water vapor, alkali hydrates, and alkaline dust, present in practically all parts of the furnace, impose extremely severe conditions upon the refractory linings. In the average bagasse-fired furnace, rapid temperature changes add thermal shock to the other damaging influences which the brick must withstand.

Harbison-Walker superduty fireclay brick, H-W KALA, ZENITH, DEAN, VARNON, or ALAMO, are recommended for the linings of those portions of the furnace which serve as the combustion zone at times when oil or gas fuel is burned. The high density, strong resistance to the effect of alkaline slags, high softening points, and low spalling tendencies of superduty fireclay brick adapt them for this service. High-duty fireclay brick such as WOODLAND, WOODLAND X, WALSH, WALSH S, COLEMAN XX, or H-W CROWN are generally used in other parts of the furnace. HARWACO BOND, when used for laying the brick, assists materially in excluding reducing gases and sublimed basic fluxes from the joints, and in preventing erosion by dust-laden gases. Plastic refractories and castables are used to advantage in certain parts of bagasse-fired boiler furnaces.

Waste-Heat Boilers: In various industrial furnace operations, waste-heat boilers are used to recover the heat from exhaust gases. While the temperatures ordinarily are not very high, the refractories in the boiler furnaces frequently are required to withstand severe destructive factors such as spalling, attrition by dust, and corrosion. For the most economical service, the refractories used will be those best suited to withstand the specific conditions of the particular furnace. ALAMO and corresponding brands of H-W superduty fireclay brick satisfactorily meet a wide range of severe requirements.

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BRASS AND BRONZE

Brasses and bronzes comprise a large variety of copper alloys. In general, the brasses consist primarily of copper and zinc, and the true bronzes contain principally copper and tin.

Furnaces of greatly diversified types are employed in the production of brass and bronze. These furnaces include large reverberatories, rotary furnaces having a wide range of capacities, relatively small tilting furnaces, electric-arc furnaces of various types, induction furnaces, and crucible furnaces.

The classes and types of refractories used for lining these furnaces are numerous. The operating conditions are influenced by the type and size of furnace used, the composition of the alloy being melted, and the condition and composition of any scrap in the charge.

Reverberatory Furnaces are used for melting brasses of every composition. The invert-arch bottoms may be built of Star silica brick, H-W Magnesite brick, or alumina-silica refractories of any of the various classes. In the lower sidewalls, H-W Magnesite and Chromex B brick are widely used. Chromex B is generally preferred to other basic refractories if the brick are exposed to considerable thermal shock. In the upper sidewalls and roofs, Varnon and Alamo superduty fireclay brick give excellent service. Star silica brick, Vega superduty silica brick, and Anchor Dash and Alusite high-alumina brick are also commonly used in roof construction.

Rotary Furnaces, both gas- and oil-fired, are usually lined with radial or arch-type brick in the barrel section. The conical ends may be lined with special shapes or with plastic refractories, since cutting and fitting standard brick sizes would be exceedingly difficult. For melting various brasses and bronzes, Alamo S superduty fireclay brick for the barrel section and Alamo special shapes or H-W plastic refractories such as H-W Super Plastic CS or H-W Mullite Plastic Refractory for the conical ends are excellent lining materials. In very large furnaces, the working lining of superduty fireclay brick may be backed with high-duty fireclay brick. Under especially severe conditions, brands such as Alusite 70 per cent alumina, Coralite XD 85 per cent alumina, or even Korundal of 90 per cent alumina content, are used with good results.

Induction Furnaces, Crucible Furnaces, and Small Tilting Furnaces, which are often used for melting brasses and bronzes of wide variation in composition, are generally lined with refractories of the high-alumina type. For induction furnaces, a monolith-forming refractory material such as Korundal Ramming Mix is frequently preferred. In crucible and tilting furnaces, Alamo superduty fireclay brick, Anchor Dash 60 per cent alumina brick, and Alusite 70 per cent alumina brick, and Korundal Ramming Mix are among the best refractory materials.

Electric-Arc and Resistance Furnaces: Harbison-Walker supplies all the different kinds of brick and monolith-forming refractories needed for the several types of these furnaces. Alusite brick, in the 70 per cent alumina class, make durable linings for many brass furnaces.

Bonding Mortars: Korundal Bonding Mortar or Coralite Bonding Mortar in many cases serve best for laying the superduty fireclay and high-alumina brick. Thermolith, with a chrome ore base, is generally used for laying the basic brick, and is used also for laying the fireclay and high-alumina brick in some alloy furnaces.

CARBON-BAKING FURNACES

While carbon products of many types find commercial application, the product used in largest quantities consists of electrodes of various sizes and shapes. In manufacture, the electrodes are necessarily subjected to relatively high-temperature heat treatment in order to make them mechanically strong and stable at high temperatures, and to impart the most desirable degree of electrical conductivity.

Electrodes of large size are used in greatest quantities. Most of these are baked in multiple-pit furnaces, commonly called ring-type furnaces because they are built in a series of units which function in close relation to each other in a cycle of preheating, baking, and cooling. The fuels ordinarily used are producer gas, natural gas, and oil; these are burned in narrow flues about 7 inches wide. The heat is conducted through 4½-inch walls of refractory brick to the carbon shapes embedded in green or calcined petroleum coke, or a mixture of pulverized coke and silica sand.

Various systems of baffles are used to achieve the most uniform heating. Some of the ring-type furnaces are built with a combustion space beneath the floor of the pit, while others are insulated with a course of insulating firebrick between the exposed high-duty fireclay brick and several similar courses beneath. Outside walls also are insulated with H-W 20 or H-W 23 insulating firebrick.

The walls of the flues for the most part are built of 9-inch straight brick 2½ or 3 inches thick, having longitudinal tongues and grooves in the middle of the 9 x 4½-inch faces. Harbison-Walker special shapes having the over-all dimensions of 9″ x 4½″ x 2½″ or 9″ x 4½″ x 3″ with the central sections reduced to 2 11/16 inches in width are used for both partial and complete flue walls. By this wall construction, which is illustrated on the following page, the rate of heat transfer is increased about 20 per cent as compared with that of walls having a uniform thickness of 4½ inches.

The desirable properties of the refractories best suited for this purpose are high thermal conductivity, stability of volume and texture at high temperatures, resistance to reducing atmospheres and fluxing by volatile alkalies, and good strength over the entire range of baking temperatures.

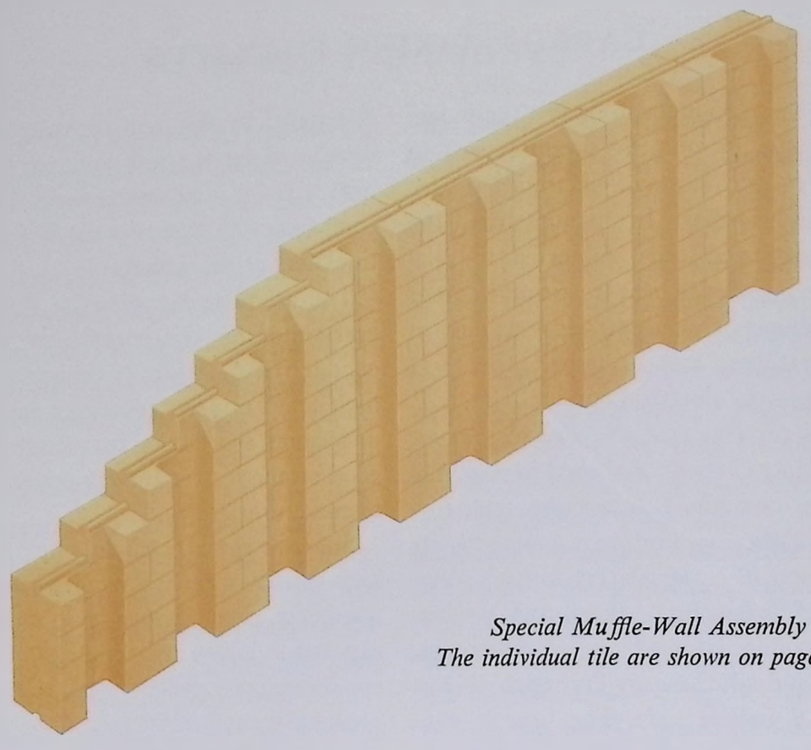
Superduty and high-duty fireclay brick of high density meet the requirements most economically. For various vulnerable positions exposed to higher temperatures, severe fluxing conditions, and greatest load, refractories high in alumina content are used to advantage. Star silica brick are used in the walls of some carbon-electrode-baking furnaces in which unusually large electrodes are baked at higher temperatures. These brick are superior in their ability to sustain load in soaking heats and have higher thermal conductivity at high temperatures than most fireclay brick.

Because of the intricate design of the flue systems, baffles, and end walls, the best workmanship of the refractories used is of utmost importance.

Continuous tunnel kilns are used to some extent for baking various carbon shapes. In their operation it is necessary to maintain reducing atmospheres. Varnon superduty fireclay brick fulfill the requirements very satisfactorily. They have a high degree of immunity to disintegration by carbon monoxide gas over the critical temperature range.

At some plants, such as aluminum electrolytic reduction plants, the availability of ample

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Special Muffle-Wall Assembly
The individual tile are shown on page 507.

electric power makes it feasible to bake the carbons in electric-resistance furnaces. These usually are large rectangular furnaces heated by current flowing through the carbons and the petroleum coke in which they are embedded. H-W castables or hard dense fireclay brick highly impervious to penetration by volatiles serve satisfactorily for the linings. Furnaces of similar design, but smaller, are used for graphitizing various carbon shapes, and for these, high-alumina refractories are needed.

Small electrodes for arc lights, batteries, motor brushes, and various other carbon products are baked in saggers made of highly refractory H-W brands of bond and calcined flint clays.

Many designs of single-unit baking furnaces are used for firing a wide variety of kinds and shapes of carbon products. These may be heated electrically or with such fuels as gas or oil. Superduty fireclay brick are most commonly used for the linings. Various high-alumina refractories are required for withstanding the more severe conditions which prevail in some of these furnaces.

Insulating firebrick of several classes are used for the exterior walls of carbon-baking furnaces.

Mortars: The use of heat-setting mortar for laying the flue-wall brick is considered best practice. This type of mortar material permits expansion adjustment as the temperature is raised initially, and develops a ceramic bond at the soaking heat of furnace operation. The tendency of the walls to develop cracks is thus kept to a minimum.

HARWACO BOND air-setting bonding mortar is used for laying parts of the solid brickwork, and for securing the desirable added strength in several of the top courses of the flues.

CASTING AND MOLDING IN FOUNDRIES

THE service requirements of the various refractories used in the casting of metals in the foundry are so specialized that every step in their manufacture must be carefully controlled for best results. Refractories for this service must be strong and resistant to spalling and to corrosion and erosion by slags and metals.

Ladles: In foundry practice, the ladles used are of many types and sizes. The lining materials commonly used include high-alumina brick, high-fired superduty fireclay brick, high-duty fireclay brick, high-alumina plastic refractories, fireclay plastic refractories, and mixtures of ground quartzite (ganister) with plastic clay.

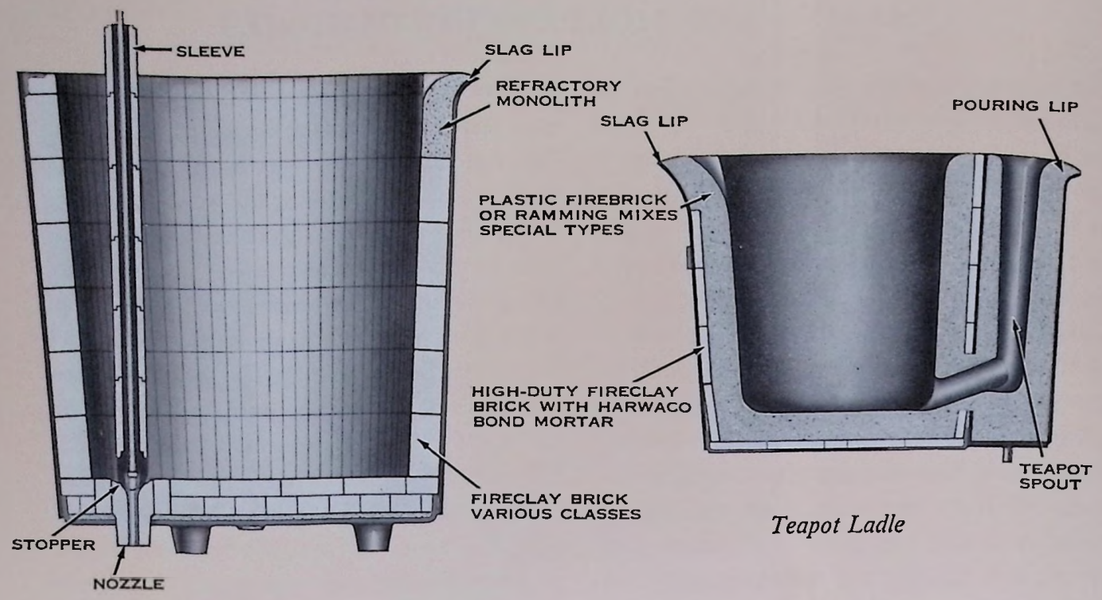
In the steel foundry, the molten metal is usually tapped from the furnace into receiving or mixing ladles, where deoxidizing agents and alloys are added. When large steel castings are poured, the receiving or mixing ladle, which usually is of the bottom-pour type, serves also for pouring the metal directly into the molds. When small castings are poured, the metal may be transferred from the receiving ladle into shank ladles of lip- or teapot-pour types for filling the molds.

The large receiving, transfer, or pouring ladles are generally lined with either superduty or high-duty fireclay brick. The linings of the smaller shank or pouring ladles may consist of H-W GROUND QUARTZITE with H-W WEATHERED BOND B CLAY, H-W SUPER PLASTIC FIREBRICK, or APACHE PLASTIC REFRACTORY. For use in contact with basic slags at extremely high temperatures, a mixture of H-W WASHINGTON DEAD-BURNED MAGNESITE GRAINS with H-W WEATHERED BOND B CLAY or a ramming mix such as H-W MAGNAMIX or H-W C-MIX is used.

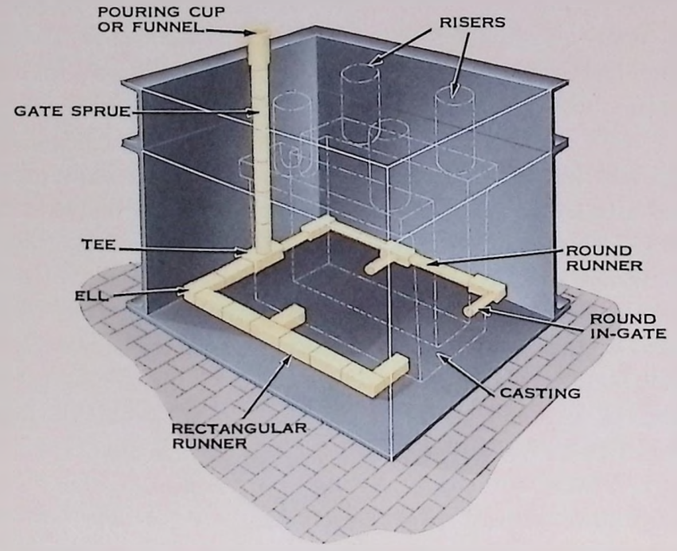
In the iron foundry, the molten metal is generally tapped from the furnace into a forehearth or receiving ladle interposed between the furnace spout and the transfer or pouring ladle. The functions of the forehearth are: (1) to serve as a means of mixing the metal or leveling out metal composition; (2) to serve as a holding ladle for the temporary storage of metal; and (3) to permit an intermediate treatment of metal, such as desulfurizing or the addition of ferroalloys or inoculants. The type of refractory material used for the lining will depend on the primary purpose of the forehearth. For functions (1) and (2), a high-duty fireclay brick lining is adequate if the temperatures are not high. When high-temperature metal is involved, or when desulfurizing with soda ash, a dense superduty fireclay, high-alumina, or basic brick may be needed. Superduty fireclay refractories in plastic form are also extensively used for lining forehearths.

Transfer ladles and pouring ladles are of three general types: (1) lip-pour, (2) teapot-pour, and (3) bottom-pour. The larger ladles of all types usually are lined with refractory brick and the smaller ones, mostly of the lip-pour or teapot-pour types, with a monolithic refractory. Fireclay brick are generally used in the subbottoms of the ladles even when the rest of the lining consists of monolithic material. Lip-pour and teapot ladles of medium size may be lined with H-W SUPER PLASTIC FIREBRICK, with APACHITE PLASTIC REFRACTORY, a high-alumina plastic refractory containing graphite, or with a mixture of H-W GROUND QUARTZITE and H-W WEATHERED BOND B CLAY. The pouring spouts of the teapot ladles are built either of special fireclay shapes or of plastic refractories containing graphite. A large bottom-pour ladle is usually lined with fireclay brick, and is equipped with a fireclay pouring nozzle and a stopper-rod

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Bottom-Pour Ladle *Teapot Ladle*



Typical Arrangements of Gate and Runner Brick

assembly, which normally consists of a graphite stopper head and fireclay sleeves.

The sides of shank-pouring ladles may be lined with H-W SUPER PLASTIC or H-W STANDARD PLASTIC FIREBRICK, H-W BLACK PATCH, or with ramming mixtures of ground quartzite and fire clay. The bottoms generally are lined with special brick shapes but may be lined with the same material as the sides.

FIREBOND, THERMOLITH, HARWACO BOND, CORALITE, H-W SILLIMANITE BONDING MORTAR, and ANKORITE 65 high-temperature bonding mortars are used for laying ladle linings.

Gate and Runner Brick: In foundry practice, sand inclusions are a common cause of defective castings. Gate and Runner Brick have greater resistance to erosion by flowing metal than molding sand, and their use greatly reduces sand inclusions. Harbison-Walker Gate and Runner Brick are made of high-duty fireclay material, and meet the rigid requirements for refractoriness and resistance to thermal shock and erosion demanded by this service.

Harbison-Walker Gate and Runner Brick are supplied in a variety of sizes for proper gating of castings of any weight. They are made with plain or interlocking ends, with projections at both ends or with recesses at both ends. Crosses, tees, and ells are available, together with suitable pouring cups or funnels.

Highly Refractory Molding Media: The production of ferrous castings and of heavy castings in general taxes the refractoriness of silica sand molds to their utmost. To meet these severe conditions, Harbison-Walker offers several highly refractory molding materials, including CALAMO, H-W FLINTGRAIN and FLOUR, H-W FLINT-MULL GRAINS, H-W MULLITE GRAINS and FLOUR, H-W FORSTERITE GRAINS and FLOUR, and H-W MAGNAMOLD. (See page 170.)

CERAMIC KILNS

CERAMIC ware is fired in kilns under widely varying conditions, involving differences in kiln design, type of fuel, kiln atmosphere, and temperature and rate of firing. Downdraft periodic kilns and continuous tunnel kilns constitute an overwhelming majority of present-day units, with a strong trend toward tunnel kilns.

Periodic Kilns: For kilns used in firing sewer pipe, hollow tile, face brick, other building brick, and some types of refractory brick, Harbison-Walker brands of superduty, high-duty, and medium-duty fireclay brick are widely used with excellent results. In salt-glazing kilns, insulating brick are sometimes used with considerable saving in fuel consumption. The classes of Harbison-Walker insulating brick used comprise a wide range for substantially all operating temperatures. Harbison-Walker brands of superduty fireclay and high-alumina brick provide excellent service in the more vulnerable locations.

In the construction of kilns operated at high temperatures, ALCOR XX, H-W MULLITE, and ANCHOR DASH high-alumina brick are used. For very high operating temperatures, H-W CORUNDUM, KORUNDAL, and CHROMEX B are recommended. KORUNDAL burner blocks are standard with many companies, especially those using residual oils having a highly corrosive ash. KORUNDAL RAMMING MIX is used for burner-block bushings and inserts and for complete burner blocks. KORUNDAL brick have become well established for the construction of piers and muffles.

For many years, the company has specialized in the manufacture of floor and riddle tile.

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Tunnel Kilns: Continuous tunnel kilns are widely used for firing nearly all types of ceramic ware. Harbison-Walker products comprise all commercial refractories for the entire construction of every design of tunnel kilns. Included among the various high-alumina brick, and superduty, high-duty, and medium-duty fireclay brick are several which are particularly adapted for use under conditions of soaking heat, as in heavily insulated crowns. KAOSIL, VARNON, H-W MULLITE, and KORUNDAL XD are examples.

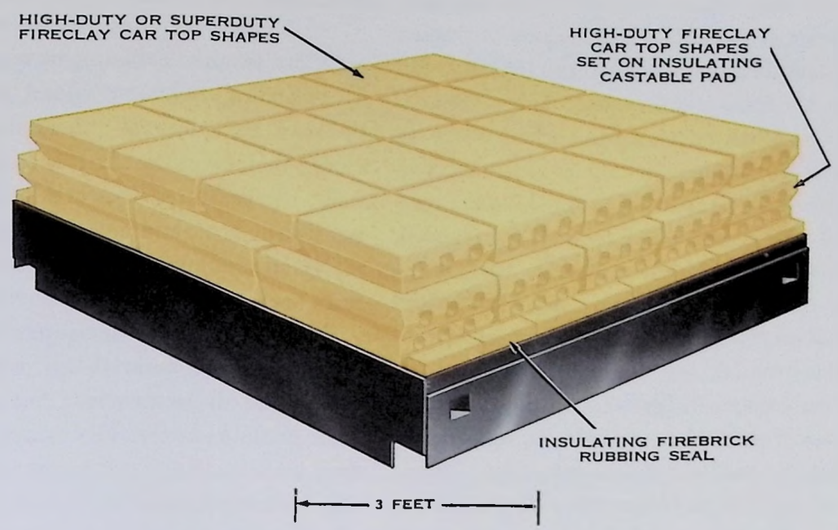
In the parts of kilns subjected to temperatures of 2100° to 3000°F., as for example in sidewalls and crowns of the firing zone, the use of STAR and VEGA silica brick is very advantageous. These brick are of especial value in kiln sections where arches built of other refractories would tend to sag, and walls would tend to shrink and lean. Factors which are especially important with silica brick construction are proper design, sufficient allowance for thermal expansion, and correct technique in laying. VEGALITE the unique insulating silica brick is used with special benefit at temperatures up to 2900°F. The glazing zones of tunnel kilns used for salt-glazing brick and tile usually are built with very dense fireclay brick of the high-duty or superduty classes.

For extremely high temperature service, the use of KORUNDAL in walls and crown of the burning zone and for burner blocks is best practice. This is especially important in tunnel kilns firing residual oils having a highly corrosive ash. Important savings in fuel result from the judicious use of H-W insulating firebrick, H-W BLOCK INSULATION, and H-W MINERAL FIBER COATING for walls and crowns.

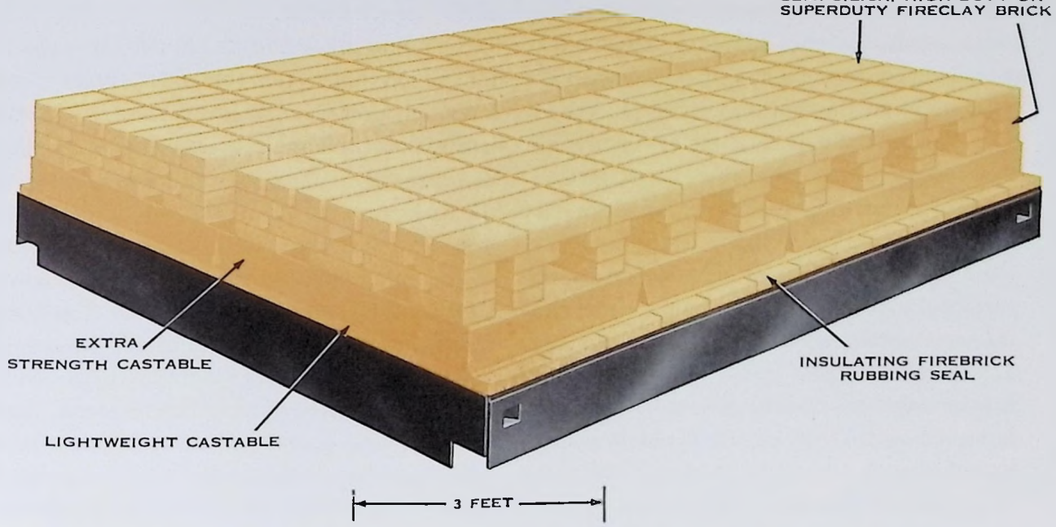
Based upon experience in its own and many other tunnel kiln plants, Harbison-Walker has developed car-top refractories of superior quality. Two types of tunnel kiln cars are in general use—the overdeck-fired and the underdeck-fired. For the overdeck-fired tunnel kiln car, the base may be built of H-W LIGHTWEIGHT CASTABLE 22 or H-W LIGHTWEIGHT CASTABLE—EXTRA STRENGTH. In the main deck, H-W car-top high-duty and superduty fireclay brick are widely used. These are supplied in a wide variety of special shapes.

Underdeck-fired tunnel kiln cars require two kinds of special refractories. The piers must be capable of withstanding both high compressive loads and the severe thermal shock of rapid changes in temperature. The deck tile must possess good hot transverse strength and must support the load without undue sagging or cracking or breaking. They must also be highly resistant to spalling. High-duty fireclay brick of merit for service in the piers are H-W SAVAGE DOT, WOODLAND DOT, and WALSH XX. Brick which are widely used for the deck include KAOSIL, H-W SAVAGE, and COLEMAN XX. Other refractories of special merit in certain applications are the superduty fireclay brick VARNON and the high-alumina brick H-W MULLITE.

Harbison-Walker HARBIDE brand of silicon carbide kiln furniture is manufactured in many sizes and shapes, including various designs of setter tile and posts, and fulfills the widest range of tunnel kiln requirements. KORUNDAL XD, the 90 per cent alumina brick consisting of stabilized corundum bonded with mullite, possesses unique physical properties especially desirable for extremely high temperature use. The unusual combination of spalling resistance and high-temperature strength commend it for tunnel kiln accessories and for use in parts of ceramic kilns which are operated under the most severe conditions.



Typical Overdeck-Fired Tunnel Kiln Car Built with Special Shapes



Tunnel Kiln Car Top for Underdeck-Fired Kilns Built with Standard Rectangular Brick

HARBISON-WALKER REFRACTORIES COMPANY

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COKE OVENS

THE manufacture of coke in the United States began almost a century ago. For almost 50 years, coke was made only in beehive ovens. In 1893, by-product ovens were first introduced in the United States, and began gradually to supersede ovens of the older type. In early 1958, by-product coke-oven plants in the United States had a total production capacity of about 80 million tons annually, as compared with about 5 million tons for beehive plants. The chemicals obtained from the coal have gradually assumed greater relative importance, as compared with the coke, and the term "chemical-recovery ovens" has come into general use, without completely replacing the older term of "by-product ovens."

Chemical-Recovery Coke Ovens: The development of refractories for these complex structures has been a large factor contributing to the rapid growth of the giant chemical-recovery coke-oven industry. The most desirable characteristics and qualities of the refractories needed in the 500 to 1,000 different special shapes for a battery of coke ovens have been achieved through many years of experience. Among the important factors involved in this accomplishment have been sustained research, special manufacturing facilities and techniques, and rigid quality control.

In the construction of a modern chemical-recovery coke oven, the refractory most extensively used is silica brick. However, large quantities of high-, medium-, and low-duty fireclay brick are needed also, as well as insulating material. In Harbison-Walker's modern manufacturing plants, all brands of brick have their own specific mixes, grain sizing, and firing temperatures to meet the particular service conditions. H-W BLOCK INSULATION is used with excellent results in this application.

STAR silica brick are used in positions where the brick are subjected to load at high temperature, including the first section of pinion walls, regenerator walls, corbels, oven and flue walls, oven roof, and in some cases, inspection walls and crossovers. In some batteries, silica brick are used also for oven floors.

Harbison-Walker's development of power-pressed silica liner brick for oven walls and other parts of the structure has been of great value to the industry. The company has developed new machines and improved techniques that have made practicable the manufacture of a major percentage of the silica shapes by precise machine methods. The accuracy of dimensions and the high mechanical strength of these brick make possible the construction of smooth oven walls which are highly resistant to abrasive action. Their thermal conductivity is somewhat higher than that of hand-made liners of the same material.

High-duty fireclay brick are used in parts of the pinion walls, the sole flues, regenerator faces, checkers and, in most cases, in the jambs, floors, charging holes, offtake openings and inspection walls, as well as in the top of the battery.

Medium-duty fireclay brick are used in parts of the pinion wall, in the parapet walls above the lintels, and in parts of the waste-heat flues. Low-duty fireclay brick serve as a fill above the oven roof and for top paving, where strong hard-burned brick of this class are required. Regenerators, doors, and oven tops are insulated with suitable materials.

H-W COKE OVEN SILICA FIRE CLAY or FIREBOND is used for laying the silica brick, and H-W HIGH-DUTY FIRE CLAY for the fireclay brick. HARWACO BOND serves advantageously for laying special shapes in the doors.

Monolithic door linings made with such materials as H-W EXTRA STRENGTH CASTABLE have come into extensive use. For maintenance of the ovens, the economy of Harbison-Walker's patching mixes has been established.

Beehive Ovens: The beehive coke oven is essentially a vertical cylinder with a domed roof. It is charged with coal through an opening in the roof and the coke is withdrawn through a large door opening extending from the lowest level of the sloping floor up to the skew which supports the dome. The refractories which are best suited for these ovens as built today are wear- and spall-resistant fireclay brick of the high-duty class for the bottoms and sidewalls; KAOSIL semi-silica fireclay brick and STAR silica brick are widely regarded as standard for construction of the crowns. KAOSIL and STAR are capable of sustaining the load and thrust of the crown to the maximum degree, and the former is also highly resistant to spalling resulting from temperature changes over a very wide range. In some ovens the crowns are built of high-duty fireclay brick which have adequate strength at the operating temperatures for sustaining the imposed load, which is not excessive. These brick are best suited for use in ovens which are operated intermittently.

A modification of the beehive ovens, commonly referred to as the Belgian-type oven, provides some advantages in that it has two opposite openings which facilitate the unloading of the oven by means of a pusher. This results in an appreciable conservation of heat. The same kinds of refractories are used in these ovens as in beehive ovens of other design.

COPPER

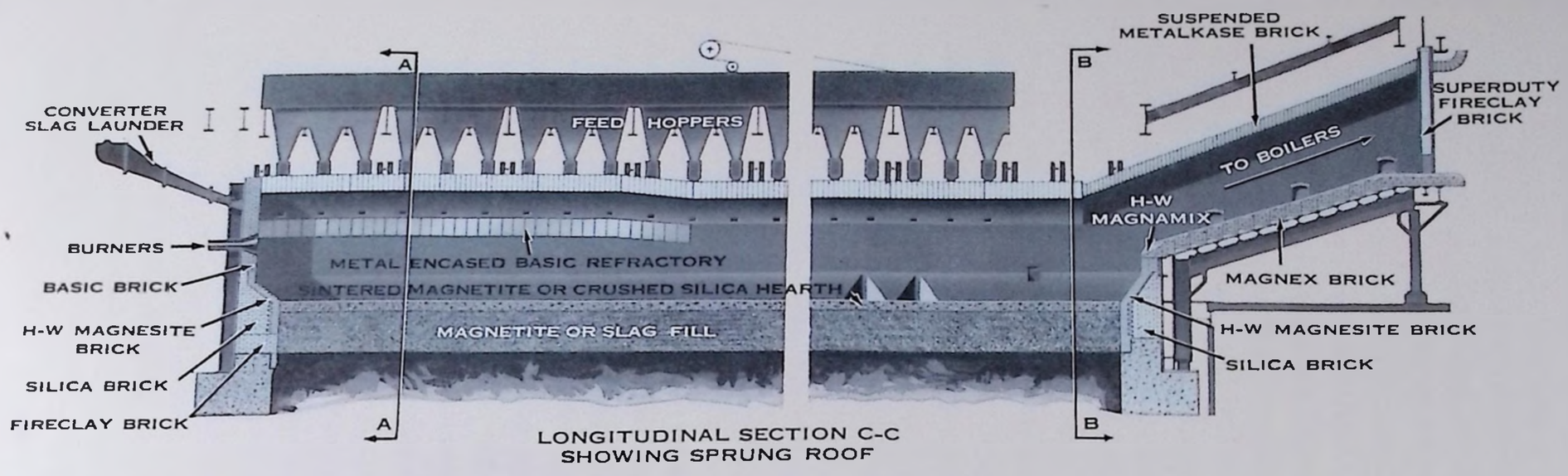
THE rapid progress of metallurgical science has brought about many changes in the design and operation of furnaces used in the production of copper. Increased rates of production have been accompanied by higher operating temperatures, increased activity of chemical reactions, and larger volumes of metal, slag, and gases. All of these have imposed increasingly severe conditions upon the refractories of which the furnaces are built. Continuous research on the complex problems involved has enabled Harbison-Walker to supply refractories best suited for service in each application.

Roasters: Frequently copper sulfide concentrates are roasted to remove excessive sulfur before charging into the smelting furnaces. Refractories for the multiple-hearth roasting furnaces are discussed on page 443.

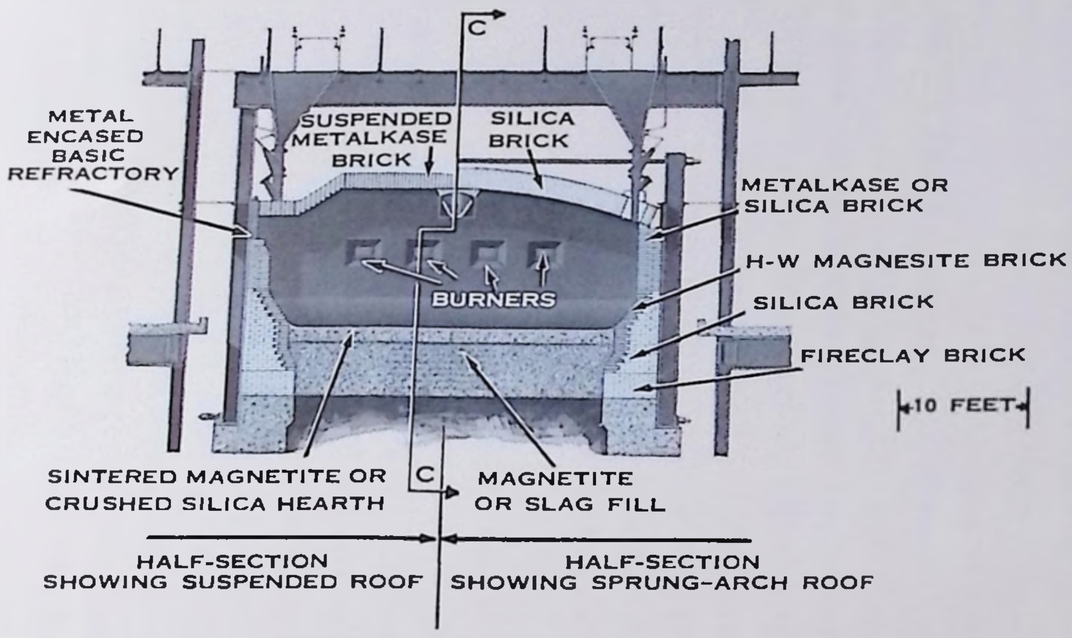
Reverberatory Smelting Furnaces: Reverberatory furnaces used for smelting copper ores are about 115 feet, more or less, in length and vary in width from 25 to 35 feet. In general, the charge consists of roasted or unroasted concentrates in wet or dry form, and at intervals, molten slag from the converter plus suitable fluxing materials. The fuel may be natural gas, oil, or powdered coal depending on availability and cost. Temperatures will range from 2700°F. to 3000°F. in the smelting zone, and at least 2000°F. to 2300°F. at the skimming end. The product of the furnace is copper matte, which consists mainly of cuprous sulfide, with appreciable proportions of ferrous sulfide, and small proportions of other sulfides.

At one time, silica brick were used almost to the exclusion of all other refractories for the

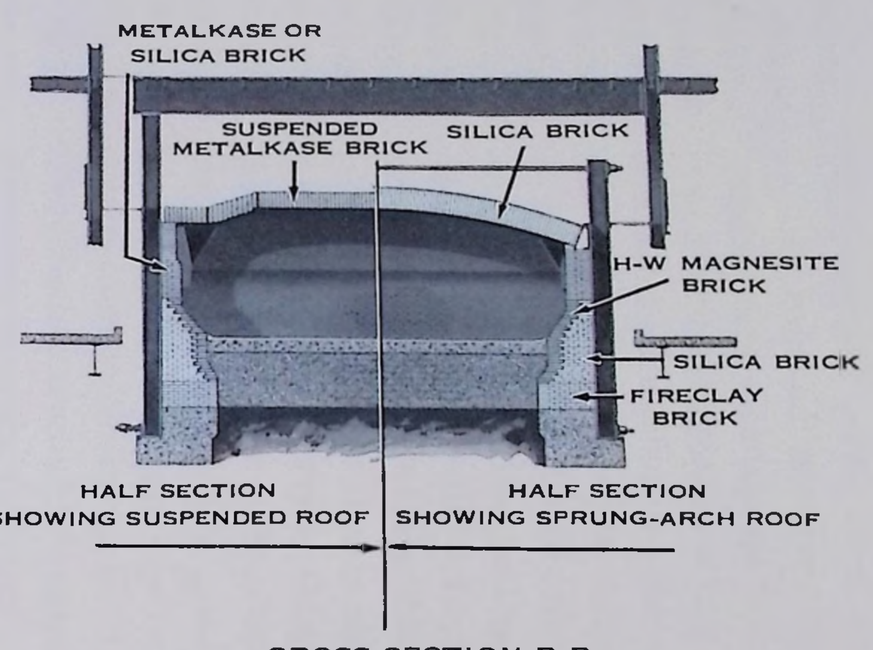
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LONGITUDINAL SECTION C-C
SHOWING SPRUNG ROOF

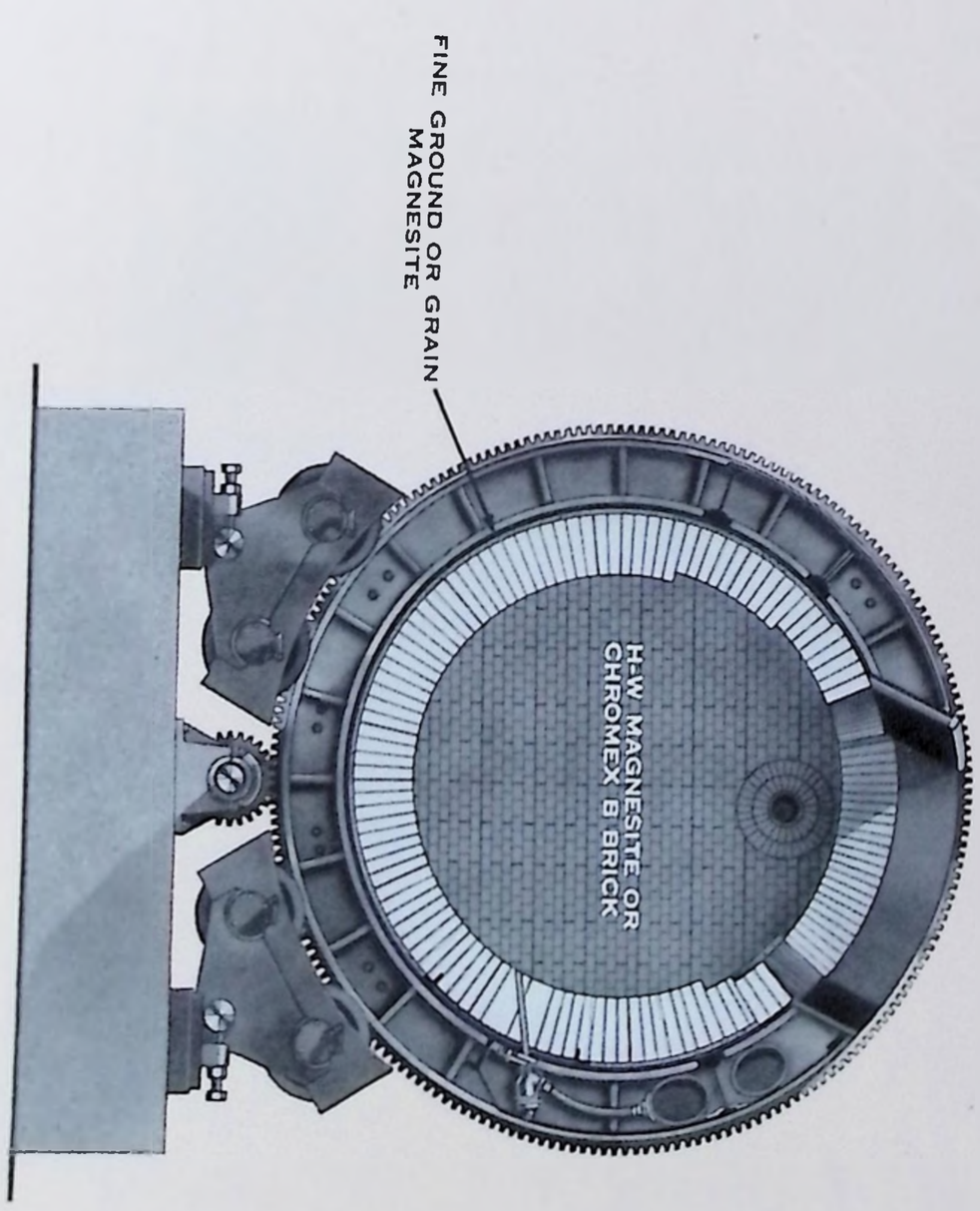


CROSS SECTION A-A

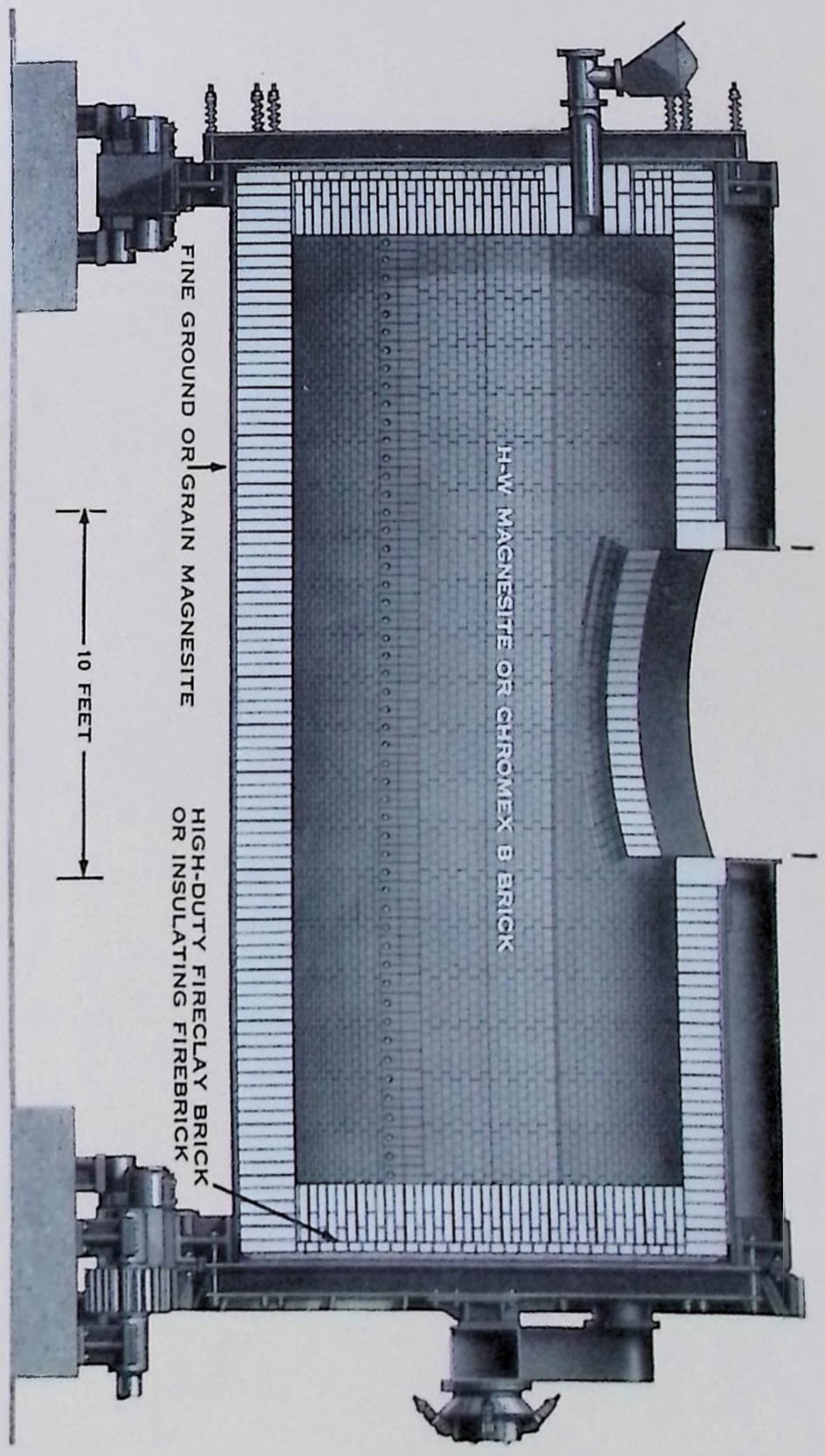


CROSS SECTION B-B

Typical Reverberatory Copper-Matte Smelting Furnace



Typical Copper Converter



complete construction of copper reverberatory furnaces. Higher production rates have imposed increasingly severe conditions on the refractories and now silica brick are frequently inadequate, particularly in more vulnerable positions of the furnace. This has led to the increased use of basic brick for the entire furnace structure.

Sprung-arch roofs are commonly built entirely of silica brick. STAR brand has long been a standard of quality for this application. In more recent years, the use of VEGA superduty silica brick has resulted in measurably longer and more economical service. A roof construction which has been used to advantage consists of silica brick in the major portion of the roof with shoulders of MAGNEX (chemically-bonded magnesite-chrome brick) laid with steel plates. The basic brick shoulders extend inward from the skewbacks for a distance of 54 inches or less on both sides of the furnace for the length of the smelting zone.

Suspended-arch construction is employed for roofs built entirely of basic brick. METALKASE MAGNEX or METALKASE MAGNEX XXP brick (illustrated on page 103) are used for this construction. At furnace operating temperatures the metal at the exposed ends oxidizes and combines with the magnesia of the brick to form a magnesioferrite bond, producing a monolithic surface. The steel casings reduce the tendency of the brick to spall and greatly increase the life of the roofs.

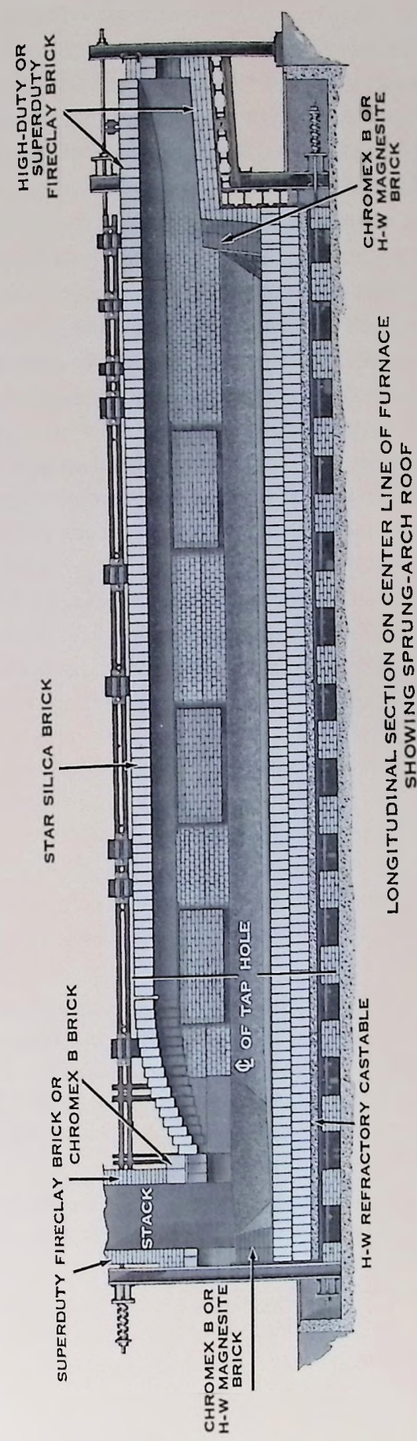
When wet concentrates are charged, spalling or hydration of the basic brick around the fettling holes may be a matter of concern. In some such cases high-alumina brick serve advantageously. The use of H-W PERIKLASE, a high-magnesia burned brick which has appreciable resistance to hydration on initial heating, often leads to improved results.

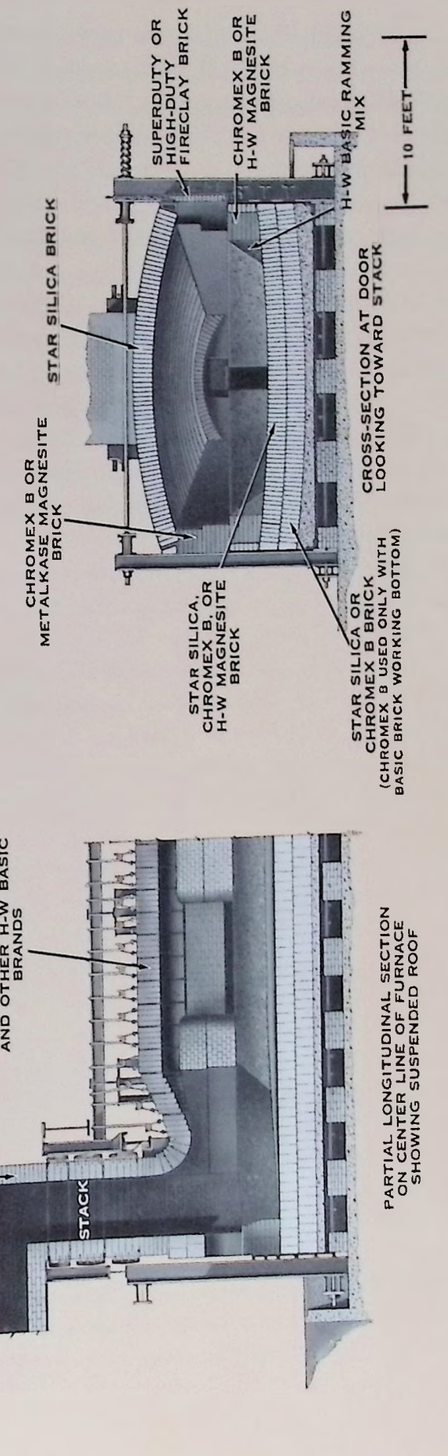
The furnace walls above the slag line are advantageously built entirely of MAGNEX or METALKASE MAGNEX brick. The walls below the slag line are built of CHROMEX B or H-W MAGNESITE brick backed with silica brick or high-duty fireclay brick. Where service conditions are moderate, STAR or VEGA silica brick may be used for the entire wall thickness.

The reverberatory furnace bottom usually consists of several feet of converter slag or magnetite tamped into place, with a working hearth of sintered magnetite, crushed silica rock, or high-silica slag. Basic refractory hearths of grain magnesite or crushed chrome ore are used in some furnaces.

Converters: In the converter, matte from reverberatory furnaces, generally containing about 20 per cent to as much as 50 per cent copper and in a few cases even more, is converted to blister copper of 96 to 99 per cent purity. The charge consists of molten matte, a siliceous or other flux as required, and sometimes raw concentrates or scrap copper. Air is introduced through the tuyeres. The slag formed, containing mainly iron oxide and silica plus several per cent copper, is returned to the reverberatory furnace. The product of the converter, blister copper, must be further refined.

Temperatures in the converter range from 2100°F. to 2400°F. The lining of the bottom and the tuyere zone, which is the zone of greatest wear, is usually 18 inches thick, while a lesser thickness generally is adequate for the remainder of the lining. Frequently, grain magnesite to a thickness of 1 to 2 inches is used between the brick lining and the shell, to supplement expansion joints provided between the brick. Some operators prefer laying the brick against a welded shell with adequate expansion allowance between the brick and at the ends of the courses.





Typical Copper Refining Furnace

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Hard-burned basic brick are used for converter linings. H-W MAGNESITE brick and CHROMEX B chrome-magnesite brick are the standards of quality at many copper smelters.

Thermal spalling can contribute to consumption of refractories in the tuyere section. The use of HARWACO MASTIC or THERMOLITH for sealing the space between the tuyere pipe and the brick moderates this condition. CHROMEX B brick are less basic and more resistant to spalling than are burned magnesite brick. Several modified basic refractories, which are especially adapted for certain converter operating conditions, are produced by Harbison-Walker. They are of spinel-bonded periclase and chrome-periclase compositions.

At some plants, it is the practice to patch the tuyere sections with a basic monolithic material installed by ramming or by gun application. H-W C-MIX, H-W MAGNAMIX, and H-W CHROMEPAK, all of which are described in other chapters, may be used for this purpose.

Holding Furnaces: Holding furnaces in which molten blister copper from the converter is kept hot for casting into slabs and cakes may be either barrel-type tilting furnaces or stationary reverberatory furnaces. In the tilting furnace, CHROMEX B or H-W MAGNESITE may be used for the entire working lining with one or two courses of superduty or high-duty fireclay brick, or insulating firebrick as a back-up lining against the shell to conserve heat. In the reverberatory-type furnace, the sidewalls and bottoms may be CHROMEX B or H-W MAGNESITE; the roof may be H-W MAGNESITE, CHROMEX B, METALKASE MAGNEX, or STAR silica brick depending upon service conditions and the design of the furnaces.

Steps in Refining: Blister copper which contains a sufficient amount of precious metals to warrant their recovery is first refined in a furnace of the reverberatory type. Since the metal is cast into anodes, the refining furnace is known as an "anode furnace." The anodes are placed in electrolytic cells, where pure copper is deposited upon the cathodes. The precious metals gold, silver, platinum, palladium, and others collect on the bottom of the cell, forming a sludge or "slime." This is recovered and the various metals are separated. The cathodes are melted down in a wirebar furnace and cast into ingots, or they may be further processed in an electric furnace to yield oxygen-free copper or phosphor copper.

Blister copper low in its content of precious metals is refined in a furnace of the same design and method of operation as the anode furnace, and cast into ingots.

Anode and Other Refining Furnaces: These furnaces may be either tilting or stationary. The tilting furnaces may be lined throughout with CHROMEX B or H-W MAGNESITE hard-fired basic brick.

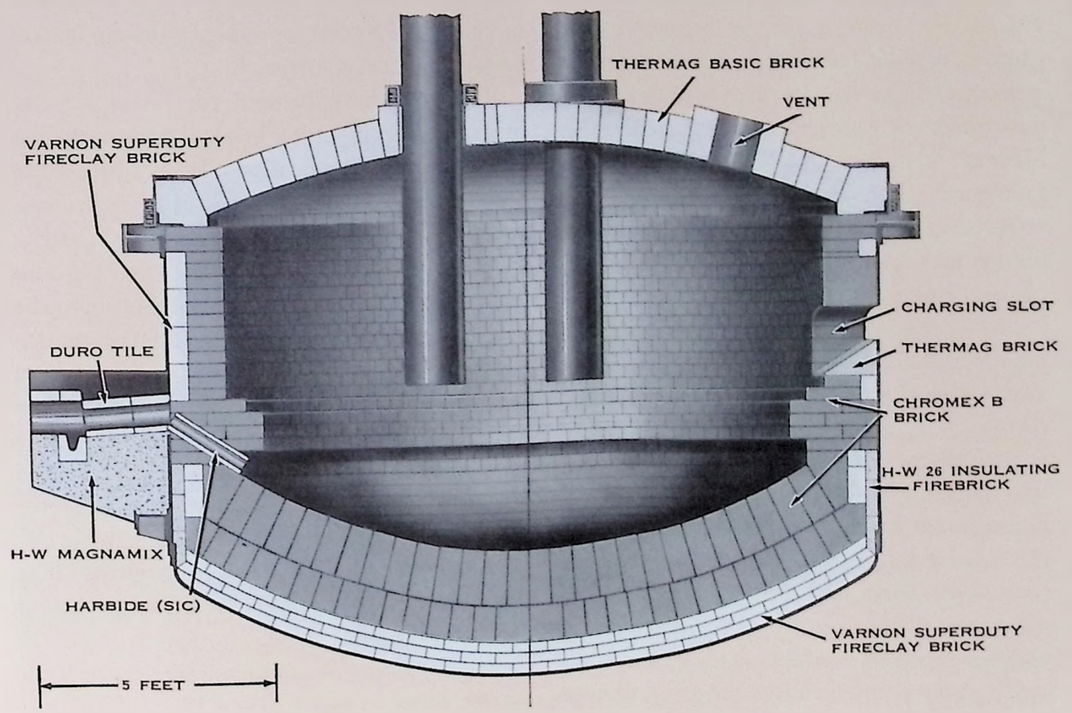
In stationary anode furnaces, the lower walls are advantageously built of CHROMEX B or H-W MAGNESITE brick and the upper walls of CHROMEX B or METALKASE MAGNEX. VEGA and STAR silica brick are used with good economy in sprung-arch roofs at many refineries. Where basic brick can be used advantageously, CHROMEX B serves well in sprung-arch roofs and METALKASE MAGNEX and METALKASE MAGNEX XXP in suspended roofs. For use in contact with molten metals and slags, hard-fired basic brick are preferred to chemically-bonded or metal-encased brick.

Wirebar Furnaces: Wirebar furnaces are used for melting the pure copper cathodes from the electrolytic cells. These furnaces are usually reverberatories 25 feet to 40 feet long by 16 feet to 18 feet wide. Selection of refractories will vary somewhat depending on the furnace design and operating conditions. The invert-arch bottoms generally are built of two courses of silica brick. In some cases the working bottom is constructed of H-W MAGNESITE or CHROMEX B brick with an undercourse of STAR silica brick. A double course of H-W MAGNESITE or CHROMEX B is preferred at some plants. The lower sidewalls are customarily built of H-W MAGNESITE or CHROMEX B to a point above the slag line, and the upper sidewalls may be built with either CHROMEX B or METALKASE MAGNEX brick, particularly where spalling conditions are a factor in the operation.

In sprung-arch roofs, VEGA and STAR silica brick are widely used. In some cases CHROMEX B brick are so employed to advantage. In roofs of the suspended type METALKASE MAGNEX and METALKASE MAGNEX XXP brick offer definite advantages.

The verb arch to the uptake is usually constructed of CHROMEX B basic brick, which is extended into the uptake for a distance depending on operating conditions. Frequently, VARNON superduty fireclay brick are used to advantage in the uptakes. High-duty fireclay brick give good results where service conditions are moderately severe.

Secondary Metal-Melting Furnaces: In general, the furnaces used for melting secondary metal are reverberatories of the same design as



Electric Copper Melting Furnace

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anode and wirebar furnaces, but of smaller size.

Electric-Arc Furnaces: These are becoming used to an increasing extent for the production of oxygen-free copper and phosphor copper. The bottoms and lower sidewalls are most economically constructed of hard-burned basic brick such as CHROMEX B or H-W PERIKLASE. The sidewalls above the metal line may be CHROMEX B, H-W PERIKLASE, THERMAG, or MAGNEX. For the roofs, THERMAG is the choice at some plants. Use of the spinel-bonded basic refractory THERMAG H is sometimes preferred where spalling is an important factor in the ultimate life of the roof.

Auxiliary Furnace Parts: For offtakes and connecting flues of copper smelting and refining furnaces, the type of refractory having the most economical balance between first cost and service will depend upon the conditions that prevail. For example, if the refractories are exposed to high temperatures, and the gas is moving at high velocity with entrained basic dust, the brick which should be considered are MAGNEX, CHROMEX B, H-W MAGNESITE, or FORSTERITE. For service of less severity the refractories which will give most economical service may be brick of the 60 per cent or 70 per cent alumina class, superduty fireclay brick, high-duty fireclay brick, or silica brick, depending upon particular furnace conditions.

Waste-Heat Boilers: The increasing output by reverberatory matte-smelting furnaces, together with the modern practice of locating waste-heat boilers close to the furnaces, results in higher boiler furnace temperatures and greatly increased rates of evaporation. To meet these conditions, there has been a trend toward wider use of superduty fireclay brick for the settings. Harbison-Walker brands of superduty and high-duty fireclay brick meet the requirements satisfactorily. Boiler furnace refractories are further discussed on page 351.

Acid-Resisting Structures: For flues and stacks exposed to acid vapors, acid-proof brick should be used. These brick fulfill the need also for lining acid tanks and for copper electrolytic tank insulators. DURO or W-ACID brands of acid-proof brick are used.

Insulation: The economies resulting from insulation have been demonstrated in many nonferrous metallurgical furnaces especially in plants where the cost of fuel is high. The practicability of insulation in any particular case will depend upon the combination of conditions that prevail. Harbison-Walker insulating brick, insulating castables, block insulation, and bulk insulation meet a wide range of service requirements. (See pages 124 to 132.).

Mortar Materials: For each type of refractory brick there is a corresponding Harbison-Walker refractory mortar material.

HARWACO BOND is used for laying fireclay brick and high-alumina brick. THERMOLITH has a wide range of applications. It may be used to advantage for laying all types of basic brick as well as high-duty fireclay, superduty fireclay, high-alumina, and silica brick. It is used also as a filler or tamping material between the round converter tuyere pipes and the rectangular brick shapes. In cases where the design of the brick conforms to the contour of the tuyere, THERMOLITH or HARWACO MASTIC is recommended as a seal or grout between the brick and the tuyeres. FIREBOND is used for laying silica brick and high-duty fireclay brick.

STARBOND and VEGA BOND heat-setting silica bonding mortars are especially suited for laying and grouting silica brick.

Additional data on refractory mortar materials are given on pages 138 to 146.

CUPOLAS

IN foundry practice, the cupola furnace is used mainly for melting gray iron. It is also employed in duplex operations for the initial melting of iron which is to be processed subsequently in converters or other furnaces to make steel, or in the air furnace for conversion into malleable iron. In recent years, the production of nodular iron and certain special irons has appreciably increased the importance of the cupola lined for basic-slag practice.

Fireclay brick are so generally used for cupola practice that they may be regarded as standard for this service. Their adoption has come about as a result of their combination of desirable physical and chemical properties, and their relatively low cost.

The thickness of the stack lining is generally 4½ inches. Below the stack, the thickness of cupola linings is rarely less than 6 inches, and ranges from this up to 12 inches or more. The inner or working lining is generally built of standard 9″ x 6″ x 4″ cupola blocks. The backing between the working lining and the shell may consist of 9-inch splits, 9-inch 2″ splits, or straights, set on end; or more frequently of a combination of 9-inch arch brick and straights, laid to form a back-up lining 4½ inches thick. Standard 9-inch circle brick also are frequently used to form a 4½-inch lining. Under some conditions of service, especially with continuous melting practice, the backing is advantageously built with 9″ x 6″ x 4″ cupola blocks.

Some of the smaller cupolas are lined with standard 9-inch circle brick, or with standard 9-inch arch brick in combination with 9-inch straights. However, a lining composed of cupola blocks has fewer joints and is therefore preferable, since joints are more vulnerable to attack by slag.

H-W Universal Cupola Blocks have two important advantages over the standard radial cupola blocks. First, the curvature of the ends insures the maintenance of tight joints, and thus retards penetration by metal and slag. Second, only one shape is needed for lining any cupola in which the diameter inside the brickwork is 2′-6″ or larger; consequently, use of this block eliminates the necessity for carrying a stock of many different sizes for cupolas of different diameters. See illustration page 483.

Factors influencing the life of the refractory linings of cupolas are the nature of the charge, the method of charging, the character of the flux, the ash content of the fuel, the velocity of the blast, duration of the heat, temperature of tapping, and continuity of operation.

Stack: In the stack, the operating temperatures are low. For the lining, Harbison-Walker high-duty or medium-duty fireclay brick are used to good advantage. It is good practice to lay the brick with HARWACO BOND, PENSEAL, or FIREBOND mortar to seal joints effectively and to give the masonry a strong durable bond.

Charging Zone: In the charging zone, the lining must resist the abrasive action of the descending charge. The requirements of the usual practice are met by strong, dense, and tough cupola blocks made by the deaired extrusion process. However, in some cases, service conditions tend to cause spalling, and wear-resistant power-pressed brick are preferred. In many cupolas, this section is lined to advantage with refractory castable material such as H-W EXTRA STRENGTH CASTABLE applied with an air-placement gun. This product has remarkable resistance to abrasion and impact.

Preheating Zone: In this zone also, the lining is subjected to abrasion by the moving burden.

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The temperature, while moderate, increases considerably between the top and the bottom of the zone, and is high enough to calcine the limestone added as a flux. In general, the same refractories are used as in the melting zone, as described below, but the service conditions are much less severe, and the normal life of the refractories is considerably longer. The air-setting bonding mortars HARWACO BOND and PENSEAL serve well for laying the brick. Under severe conditions, such as those prevailing in the continuous melting of charges having a high content of steel, the back-up lining should be built of cupola blocks of the same refractoriness and high quality as those of the blocks used for the melting-zone linings.

Melting Zone: Melting zones of some cupolas are provided with a boshed lining. This is accomplished by placing an additional 9-inch split or straight brick against the shell, back of the first few courses of cupola blocks above the lower tuyeres; above these courses, the lining is sloped back to the normal diameter. The purpose of this arrangement is to provide a slight overhang, which will help to keep the coke and the molten metal and slag away from the tuyeres.

Service conditions in the melting zone are severe. The refractory lining is required to resist high temperatures, corrosion, erosion, and penetration by slag and metal. High-duty fireclay brick made by the extrusion process or vacuum power-press process are generally used. The hard-burned superduty fireclay brick VARNON and KENMORE are being used to an increasing extent for the melting-zone linings.

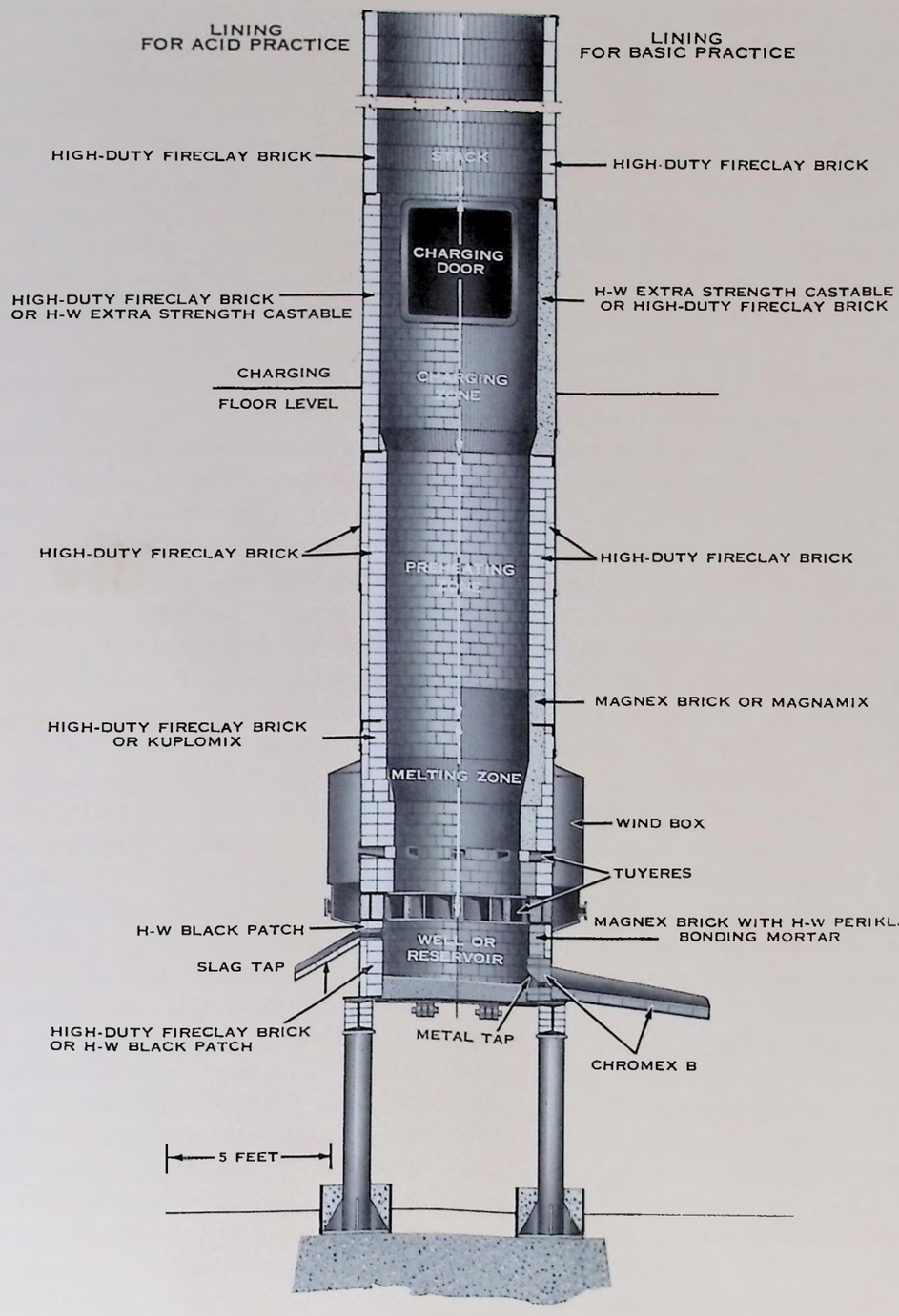
H-W SUPERDUTY MORTAR is well adapted for laying either high-duty or superduty fireclay brick in the melting zone.

STAR silica brick are used in a relatively small number of cupolas in which continuous melting practice is followed, and in which the service conditions are especially severe. Provision for thermal expansion must be made when silica brick are used. For laying the silica brick, the heat-setting mortar VEGA BOND or STARBOND is recommended.

Proper maintenance of the melting-zone lining is exceedingly important. Care in chipping away slag and slagged areas and in the installation of patches results in longer life. Adhering slag should be chipped away completely before patching; otherwise, softening of any remaining slag will cause the patches to loosen and be carried away, exposing the brickwork to further attack. For daily maintenance of the melting zone, KUPLOMIX, a prepared dry mixture of ground quartzite (ganister) and high-duty fire clay, generally is applied by means of an air-emplacement gun. For hand patching, a special KUPLOMIX is provided. In some small cupola operations, patching is done with 9-inch standard fireclay brick of the high-duty class, cemented in place with HARWACO BOND or FIREBOND air-setting bonding mortar.

The Well: Harbison-Walker high-duty fireclay brick, either extruded or power pressed, are well suited for use in lining the well. HARWACO BOND air-setting mortar and H-W HIGH-DUTY FIRE CLAY mortar may be used advantageously for laying the brick. In cupolas operating at high temperature and melting large tonnages of iron, chemically-bonded EBONITE cupola block shapes often give improved service. These brick contain graphite and are formed under very high pressure. They have high resistance to wetting by molten iron or slag. They should be laid with EBONITE MORTAR which is heat-setting and has the same composition as the brick.

Basic Operation: Above the melting zone, the cupola lining is the same for either acid or basic operation. When the slag is kept contin-



Section of Typical Cupola

HARBISON-WALKER REFRACTORIES COMPANY

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uously basic by metallurgical control, the refractory lining of the melting zone and well is built of basic brick. For production of nodular iron, the choice is between a chrome-free, chemically-bonded magnesite brick, MAGNEX CF, and high-fired magnesite brick, H-W MAGNESITE. For certain special irons a fired magnesite-chrome brick, MAGNEX B, has given excellent results. Between the basic brick and the shell there is usually a back-up lining of fireclay brick 1¼ to 6 inches thick.

CHROMEX B, a high-fired chrome-magnesite refractory, is noteworthy for its successful use for forming a breast around the taphole as well as for the taphole block itself. Continuous operation is possible with CHROMEX B in this critical zone. H-W PERIKLASE BONDING MORTAR, an air-setting high magnesia mortar, is recommended for laying all the basic brick used.

Basic brick have a reversible thermal expansion of approximately ⅛ to 3/16 inch per foot at cupola operating temperatures. In the melting zone, expansion strips can be used in the basic lining and an allowance of ⅛ inch per foot both circumferentially and vertically is common practice. In the well, which contains the molten metal and slag, expansion joints cannot be used between the basic brick. Provision for expansion can be made, however, by allowing a space between the basic brick and the back-up lining against the shell. The necessary width of the space can be calculated, based on the outside diameter of the annular ring of basic brick and a rate of expansion of about ⅛ inch per foot. H-W calcined clay of coarse grind is used for filling the space.

For daily maintenance of the melting zone, H-W MAGNAMIX, a prepared dead-burned grain magnesite material having an air-set bond, is recommended for basic operation. It can be applied by hand or with an air gun.

Hot-Blast Cupola Operation: This practice continues to increase as the advantages resulting from the use of preheated air becomes realized. The recuperative and regenerative hot-blast systems, accessory to the cupola, necessitate the use of several kinds of refractories for best performance. H-W dense high-duty fireclay brick and insulating firebrick and castables are especially suited for most requirements, and VARNON superduty fireclay brick are used with benefit for the most severe conditions.

Tapping Arrangements: Metal from the cupola is tapped into a ladle or forehearth. The slag may be tapped by means of a front-slagging device or a rear-slagging arrangement, such as that illustrated on the drawing of a typical cupola on page 377. For rear slagging, the taphole and slag-hole blocks are either of the same quality as the brick in the melting zone, or of higher quality. HARBIDE silicon carbide slag-hole blocks give excellent service. KORUNDAL XD, high density 90 per cent alumina brick, maintain the openings in slag and taphole blocks of proper size for long continuous operation.

In front slagging, both metal and slag flow through the same taphole into a forehearth. A trough and dam arrangement controls the height of the metal and the level of the slag in the well of the cupola. For acid practice, EBONITE brick or H-W BLACK PATCH plastic refractory is recommended for lining the entire forehearth. KORUNDAL, a 90 per cent alumina brick, is used as the skimmer to separate the metal from the slag. For basic practice, CHROMEX B brick, laid with THERMOLITH air-setting mortar, are used for the entire slagging trough including the skimmer.

ELECTRIC FURNACES

MANY metals, ores, and minerals are commercially processed in electric furnaces of different types. Various metals are melted, refined, and alloyed, and both iron and nonferrous ores are reduced in electric furnaces under diverse operating conditions. Steel and iron are the principal products treated in electric furnaces and the amounts of nickel, copper, aluminum, zinc, and other nonferrous metals and alloys add up to large tonnages. Other important products are ferroalloys, calcium carbide, abrasives, elemental phosphorus, fused-cast refractories, and graphitized carbon.

Commercial production of electric furnace steel in the United States began on a small scale in 1906. The demand for accurately controlled steels of various analyses to meet modern metallurgical requirements has brought about a steady growth in the development of the electric furnace, and today there is a wide range of individual units varying in holding capacity from a few pounds to almost 200 tons.

Five types of electric furnaces are in general use. These are: (1) the three-phase direct-arc furnace generally used in the melting and refining of steel, iron, copper, and nickel, and the smelting of various ores; (2) the single-phase indirect-arc furnace of relatively small size most frequently used in the melting of steel, iron, copper, and copper alloys; (3) the single- or three-phase submerged-arc furnace employed in the production of ferroalloys, nickel matte, abrasives, calcium carbide, phosphorus, titanium, and elemental iron; (4) the resistance furnace used for the graphitizing of carbon, the heat treating of various metals, and the melting of nonferrous metals and alloys; and (5) the high- and low-frequency induction furnaces used for melting ferrous and nonferrous metals and alloys.

THREE-PHASE DIRECT-ARC FURNACES

In Steel Plants and Steel Foundries

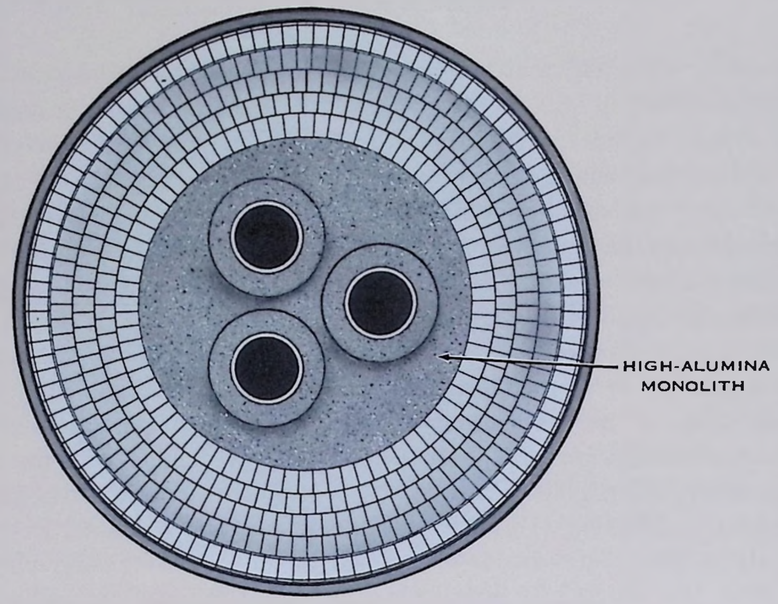
In general, electric furnace steel for ingots is produced in furnaces lined for basic practice, while iron and steel for castings may be produced in furnaces lined for either basic or acid practice. The capacities of the furnaces used range up to 200 tons in ingot shops, and up to 25 tons in foundries.

The furnaces may be either door-charged or top-charged. The life of the refractories in the roof, door arches, and jambs is influenced by the method of charging, which largely determines both the amount of mechanical abuse to which the lining is subjected by the charging equipment, and the extent to which the brick are exposed to thermal shock through chilling by cold air and by rapid heating.

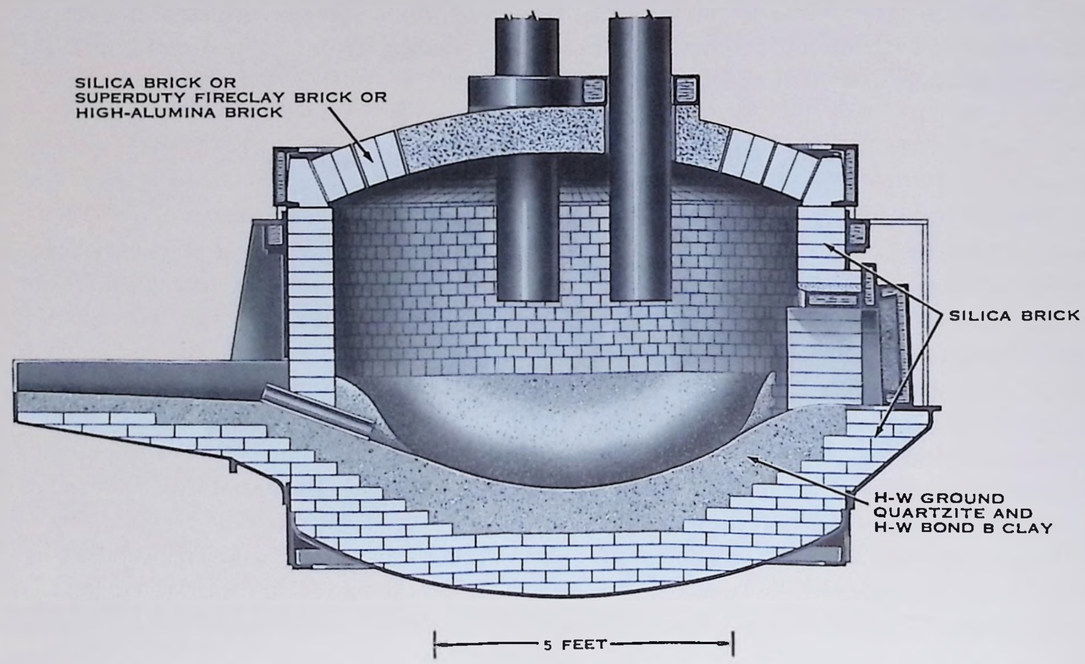
Roofs: For both basic and acid practice, silica brick are widely used in roof construction. The life of such roofs normally may vary from about 30 heats to as many as 600 heats, depending upon the size of the furnace, operating conditions, and whether the practice is basic or acid. Electric furnace roofs built of silica brick remain rigid at operating temperatures. STAR and STAR DASH silica brick meet the requirements for most such roofs. For operating temperatures which exceed the safe range for STAR, a margin in refractoriness is provided by VEGA or VEGA HP superduty silica brick.

The roofs may be built of large special shapes designed to lay up in a prearranged pattern with

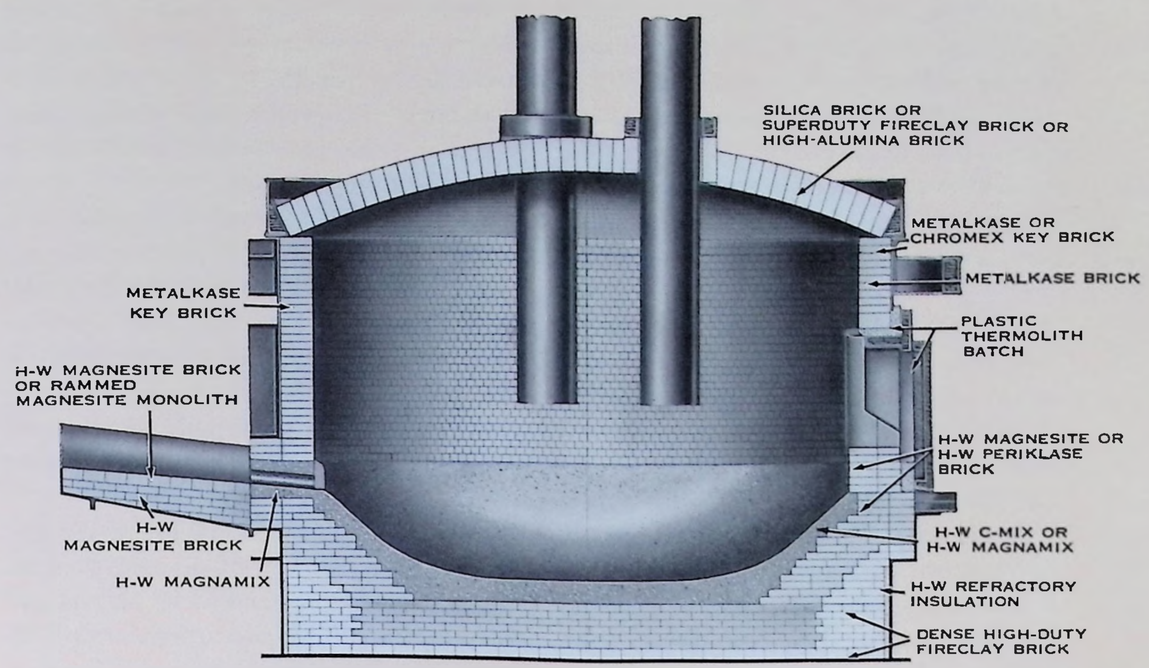
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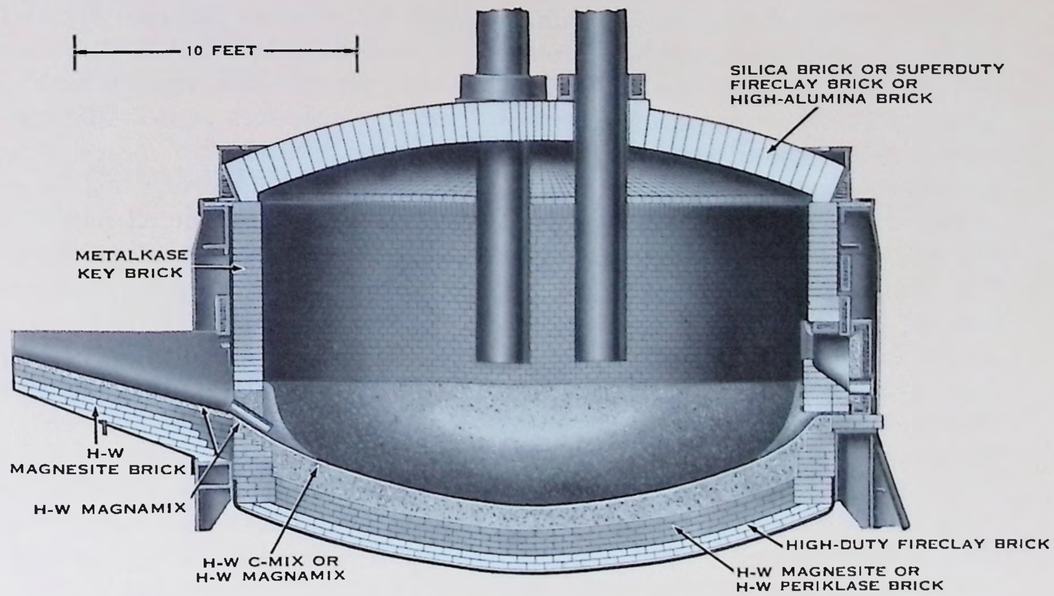
ROOF PLAN



Typical Electric Steelmelting Furnace
(*Acid Practice*)



Typical Electric Steelmelting Furnace
(*Basic Practice*)



Typical Electric Steelmelting Furnace
(*Basic Practice*)

HARBISON-WALKER REFRACTORIES COMPANY

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relatively little cutting, or they may be built of smaller brick, consisting of standard sizes or modifications of standard sizes, some few of which must be cut to fit, particularly around the electrode openings. The reasons for using the smaller sizes are their lower cost as compared with the larger special shapes, and the fact that division of the roof brick into these sizes is generally desirable for best workmanship in installation and resistance to spalling.

In the roofs of many furnaces the entire central section is built with H-W MULLITE or CORALITE PLASTIC REFRACTORIES, or other H-W monolith-forming products, resulting in best balanced service.

For the roofs of furnaces which are operated intermittently, and in which spalling conditions are unusually severe, the superduty fireclay brick brands ALAMO, H-W KALA, BOONE, DEAN, ZENITH, or H-W SUPER SAVAGE may be preferred to silica brick.

In the production of alloy steels at exceedingly high temperatures, the use of high-alumina brick such as ANCHOR DASH, ALUSITE, H-W MULLITE, and KORUNDAL in the roofs frequently is most economical. While a single brand may be employed for the entire roof, generally two or more brands are used in various combinations. ANCHOR DASH is excellent for the annular ring section and either H-W MULLITE or KORUNDAL contributes to a balanced roof life when used in the central section. To avoid cutting around the electrode rings, monolith-forming materials such as H-W MULLITE RAMMING MIX or KORUNDAL RAMMING MIX are used to fill the small spaces adjacent to the rings.

Some measurable progress in the use of basic brick roofs holds promise of becoming an economical reality. METALKASE basic brick fabricated with a special alloy are becoming successfully used in roofs of furnaces operated at very high temperatures with exposure to severe fluxing conditions. Some other H-W basic brick without the metal casings offer promise of giving good service, particularly in the electrode ring sections.

Upper Sidewalls: In basic-lined furnaces it is standard practice to use METALKASE MAGNEX brick in the upper sidewalls from a level two courses above the slag line. For especially severe conditions, METALKASE PERIKLASE brick, either chemically bonded or hard burned, are recommended. In the sidewalls of acid-lined electric furnaces, excellent results are secured from STAR and VEGA silica brick.

Door Arches and Jambs: Harbison-Walker high-alumina brick are often used advantageously in door arches and jambs. METALKASE, CHROMEX B, and the high-magnesia brick H-W PERIKLASE or one of its modifications also give excellent service in these positions, in some basic-lined furnaces.

Lower Sidewalls and Bottoms: In the basic electric furnace the lower sidewalls and subbottoms are generally built of hard-burned magnesite brick, such as H-W MAGNESITE or H-W PERIKLASE. Both the stadium construction, built with standard sizes, and the invert-dome construction, built with Harbison-Walker EFR shapes, are commonly used. One or more courses of superduty or high-duty fireclay brick may be used directly against the steel shell in the bottom. The hard-burned basic brick CHROMEX B may also be used in this position. The working bottom immediately above the subbottom is generally built by ramming into place such basic materials as H-W MAGNAMIX or H-W C-MIX to the desired working contour. H-W MAGNAMIX is an air-setting ramming mix with a high magnesia content. H-W C-MIX is an exceptionally refractory air-setting ramming mix made from synthetic magnesite of a high degree of purity. H-W WASHINGTON DEAD-BURNED MAGNESITE GRAINS, sintered into place, also provide durable furnace bottoms. For daily maintenance and repiping tapholes, H-W MAGNAMIX, which sinters at lower temperatures, is used with excellent results.

In acid electric steelmelting furnaces, silica brick are used in the lower sidewalls and subbottoms. One or two courses of Harbison-Walker high-duty fireclay brick sometimes are placed beneath the silica brick directly against the steel pan. The working bottom is advantageously formed of a mixture of H-W GROUND QUARTZITE and H-W WEATHERED BOND B CLAY. Usually, the bottom is rammed into place to its final contour, and then given a permanent set by sintering with the electric arc.

Mortars: Either CORALITE BONDING MORTAR or ANKORITE 65 high-temperature cement may be used to advantage in electric steelmelting furnaces for laying high-alumina or superduty fireclay brick. VEGA BOND is excellent for grouting silica brick roofs. THERMOLITH high-temperature bonding mortar is preferred for some requirements.

In Iron Foundries

The service conditions in electric furnaces used for the melting of gray iron or the superheating or holding of iron for malleable castings are similar to those in electric steelmelting furnaces operating on acid practice. Usually, the operating temperatures are lower and the furnaces are kept in more continuous operation. The refractory linings are generally the same as those in electric steelmelting furnaces used in acid practice.

In Nonferrous Metallurgy

In nonferrous metallurgy, the refractories used for the linings differ widely. For melting copper in direct-arc furnaces, the most successful results are generally secured from linings made of basic brick of various classes. CHROMEX B is used in bottoms and complete sidewalls in a number of furnaces with good service records. H-W PERIKLASE may also be used in bottoms and lower sidewalls. MAGNEX, a chemically-bonded magnesite-chrome refractory, also serves well in upper sidewalls of some furnaces. THERMAG, a spinel-bonded magnesite brick, is especially suited for the roofs. Refractory linings for copper electric furnaces are discussed in some detail on page 374.

Direct-arc furnaces used for melting nickel and its various alloys are lined to best advantage with H-W PERIKLASE and H-W MAGNESITE brick in the bottoms and sidewalls with alumina-silica brick in the roofs.

INDIRECT-ARC ELECTRIC FURNACES

The indirect-arc furnace is of the single-phase type and varies in capacity from about six pounds to several tons. The two electrodes are diametrically opposite along the horizontal axis of the furnace.

Small indirect-arc furnaces which range in capacity from 6 pounds to 35 pounds or more are used in the precision-casting industry for melting special steels and alloys. Except for a steel case and supporting trunnions, the furnace consists of a two-piece refractory crucible. The two halves are cemented together to form a spherical enclosure complete with electrode holes and a charging and pouring spout. H-W PERIKLASE shapes serve this purpose with splendid results. H-W PERIKLASE BONDING MORTAR

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or THERMOLITH, a chrome-base mortar, is used to cement the two halves together. For some alloys the 99 per cent alumina brick H-W CORUNDUM is employed for the crucibles, and KORUNDAL BONDING MORTAR for cementing the two halves together.

The larger indirect-arc furnaces have some important applications for melting cast iron, nodular iron, copper-base alloys, and to some extent alloy steel. The basic brick H-W MAGNESITE, H-W PERIKLASE, and CHROMEX B, together with the basic ramming mixes H-W MAGNAMIX and H-W C-MIX, are used to line these furnaces. For copper-base alloys, the 70 per cent alumina brick ALUSITE, or H-W MULLITE in combination with H-W MULLITE RAMMING MIX and H-W MULLITE PLASTIC REFRACTORY, are used more generally than basic brick. For door openings and pouring spouts, Harbison-Walker furnishes both brick shapes of special design and ramming mixes which best withstand impact and abrasion.

RESISTANCE FURNACES

In resistance-heating furnaces, the resistor may be metallic, carbon, or graphite. In general, this type of heating requires the most efficient utilization of the energy developed. Harbison-Walker insulating refractories of various classes, alumina-silica refractories, and high-alumina refractories of several classes are being successfully used for the linings.

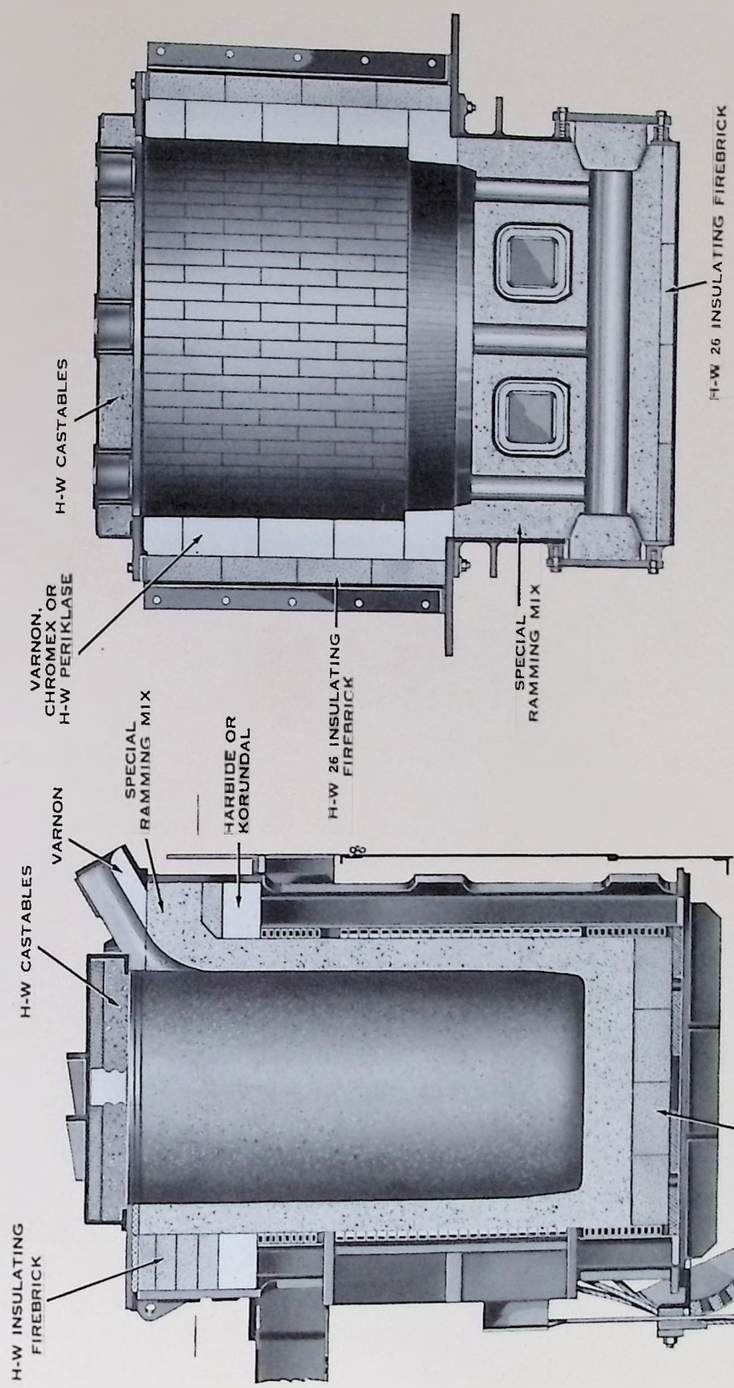
INDUCTION FURNACES

In general, induction furnaces can be divided into three classes: (1) the coreless high-frequency induction furnace, (2) the core-type low-frequency induction furnace, and (3) the coreless low-frequency induction furnace.

Coreless High-Frequency Furnaces: The coreless high-frequency induction furnace consists of a primary (the furnace coil), and a secondary (the molten metal). When a high-frequency alternating current is applied to the primary a current is induced in the secondary. The induced current rapidly heats the metal bath and melts any scrap or other solid metal in the charge. Furnaces of this type are generally used in the production of stainless and other highly alloyed steels. The refractory lining of such furnaces may be either acid or basic. The latter are more common in the United States.

The first step in lining the furnace is to coat the coil with a good troweling mortar of either the high-alumina type such as CORALITE BONDING MORTAR or the chromite type, such as THERMOLITH. In the smaller units, the furnace lining usually consists of a fired crucible of siliceous fire clay for acid practice, and high-purity magnesia, such as H-W PERIKLASE, for basic practice. In the larger furnaces the lining material consists of coarsely ground quartzite ganister mixed with a small percentage of fire clay or H-W ZIRCON RAMMING MIX for acid practice, and a high-purity magnesite ramming mix, such as H-W C-MIX or H-W INDUCTION FURNACE MIX, for basic practice.

Core-Type Low-Frequency Furnaces: The core-type low-frequency induction furnace contains a primary coil surrounding a laminated core. The secondary consists of molten metal in a channel surrounding the primary coil. Furnaces of this type are commonly used for



Core-Type Low-Frequency Furnace

Typical Induction Furnaces (Ajax Magnethermic Corp.)

Coreless Low-Frequency Furnace

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melting brass and other copper alloys, high-purity aluminum and aluminum alloys, zinc, and in some cases high-purity iron. The type of refractory lining depends upon the metal being melted. A monolithic lining is generally preferred in the inductor box because of the difficulty of fitting brick in this section of the furnace. The upper or holding portion of the furnace is lined with either brick or monolith-forming refractories.

For linings of furnaces melting nonferrous metals, monolithic materials such as H-W Castolast, Coralite Ramming Mix, and Korundal Ramming Mix are used. Depending upon various operating conditions, the basic materials such as H-W Induction Furnace Mix, H-W C-Mix (modified), and H-W Magnamix or H-W Zircon Ramming Mix are used with good results in linings of many ferrous alloy furnaces. H-W Periklase and Chromex B, or high-alumina, superduty, and high-duty fireclay brick serve best for parts normally lined with brick.

Coreless Low-Frequency Furnaces: The coreless low-frequency induction furnace is becoming more extensively used for melting iron, steel, and aluminum. The linings are rammed into place with monolithic refractories, the compositions of which are governed by the metals which are melted. For melting iron, a very highly siliceous composition is used for temperatures up to 2600°F. For higher temperatures, the lining is substantially quartzite ganister with a suitable bonding constituent.

For the melting of steel, the quartzite ganister mix is prepared with a minor percentage of a special bond. For basic linings, H-W C-Mix, a ramming material of high periclase content, may be used.

FERROALLOYS

Ferroalloys comprise a group of important addition agents which are used in the production of various alloy steels and alloy cast irons. Included among the more common ferroalloys are ferromanganese, ferrosilicon, ferrochromium, ferrotungsten, ferrovanadium, ferromolybdenum, ferrophosphorus, ferrotitanium, ferrocolumbium, and ferroselenium.

Ferroalloys generally are produced in electric furnaces. Some of them, such as ferromanganese, ferrophosphorus, low-grade ferrosilicon, and a few others, are made in large tonnages in blast furnaces, and some low-carbon ferroalloys are made in so-called reaction vessels.

The selection of refractories for lining the furnaces and auxiliary equipment is governed largely by the kind of alloy that is being produced as well as by the type and size of furnace used for the purpose. Consultations on any problems concerning the refractories are freely offered by Harbison-Walker sales engineers.

Blast Furnaces: In general, the same refractory lining materials are used in blast furnaces producing ferroalloys as in those producing the usual grades of iron. (See page 343.)

Electric Furnaces: Both submerged-arc and direct-arc electric furnaces are used for the production of ferroalloys. Various refractory materials are used for lining the furnaces as determined by the particular service conditions.

Some furnaces are lined with basic refractories, as for example in the production of low-carbon and in part high-carbon ferrochromium. H-W Magnesite and H-W Periklase brick are being used with good results in this service. The hearth and the front wall are frequently formed by a magnesite ramming mix, such as H-W Magnamix 85 or H-W C-Mix.

In the production of ferroalloys such as ferrosilicon, ferromanganese, and others, Harbison-Walker high-duty fireclay brick are used as a backup for carbon blocks. In some cases the fireclay brick are used for the working lining of the upper sidewalls, and carbon blocks are used to form the well. In some of these furnaces, the gases are collected in tightly fitting hoods and concentrated carbon monoxide gas may accumulate. For the working linings, maximum resistance to disintegration by carbon deposition is provided by H-W 18 hard-burned high-duty or Varnon superduty fireclay brick, or low-iron H-W castables.

Reaction Vessels: Some low-carbon ferroalloys are produced by exothermic reaction in cylindrical vessels at very high temperatures. In the processing, large volumes of high-lime slags are produced. The vessels usually are lined with a basic ramming mix of high magnesia content. H-W Magnamix 85 gives good results.

Ladles: The ladles which are used for transferring molten ferroalloys generally are lined with refractory materials having similar chemical characteristics to the ones used for lining the furnaces. The materials used extensively include high-duty and superduty fireclay brick; the monolith-forming refractories H-W Black Patch, a superduty fireclay plastic refractory containing graphite; Apachite Plastic Refractory, a graphitic high-alumina product; and Kuplomix, a siliceous granular material.

H-W Magnamix 85 forms an excellent working lining for ladles in which alloys of high-melting temperatures are transferred.

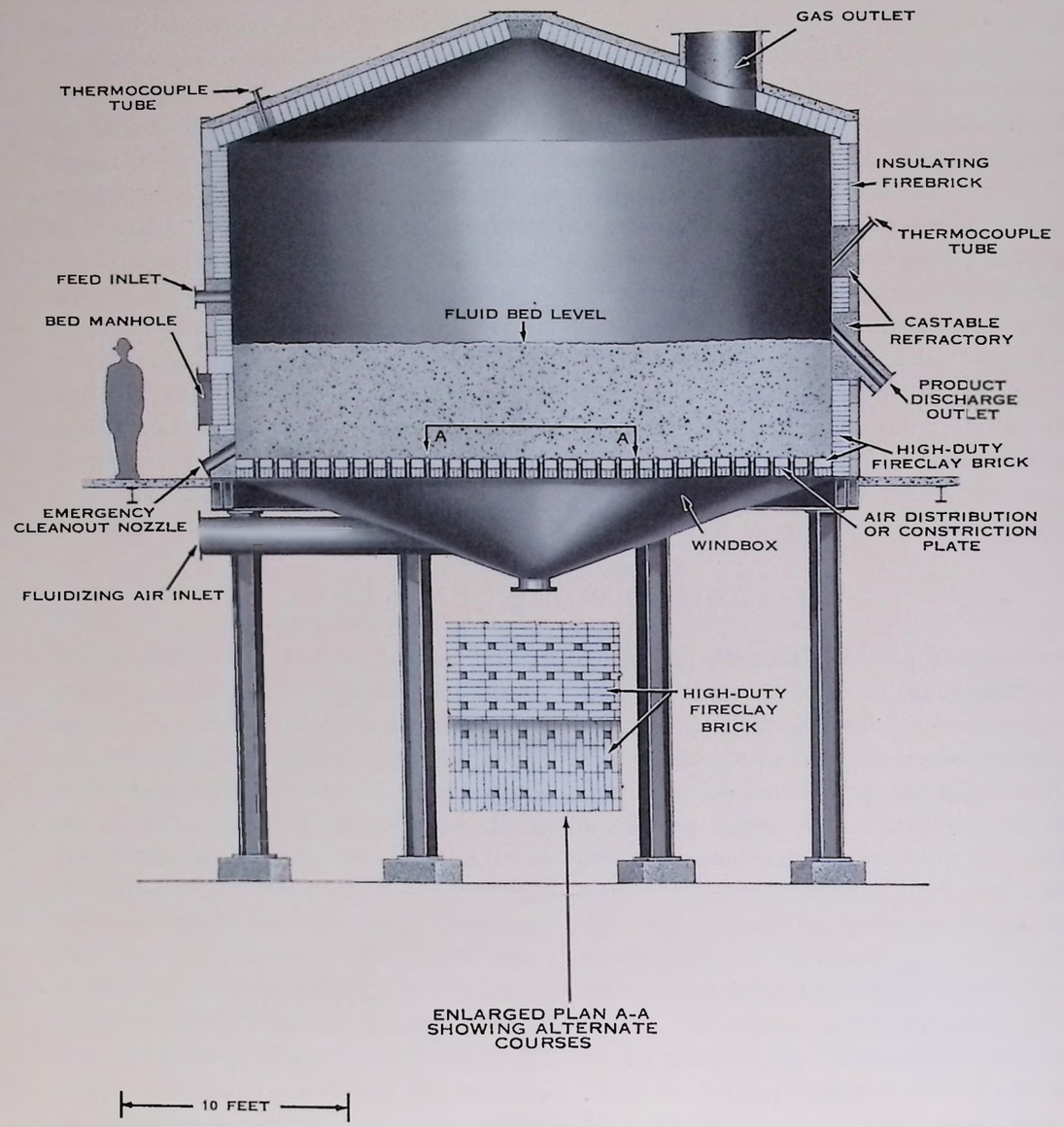
Bonding Mortars: For laying the high-duty and superduty fireclay brick, Harwaco Bond bonding mortar is recommended. For laying the H-W Magnesite and H-W Periklase brick, H-W Periklase Bonding Mortar is used.

FLUIDIZED-SOLIDS REACTOR

An important process used in effecting certain heat treatments of a variety of materials is the dry fluidization of finely divided solid particles by their suspension in an upward-moving stream of air or gas. Fluidized-solids reactors are used for such diverse applications as the drying of ground cement rock, limestone, dolomite, fine coal, blast-furnace slag, various chemical compounds, and ilmenite; the roasting of arsenopyrite, pyrite, pyrrhotite, chrome ore, zinc and copper concentrates and ores; the calcining of limestone, aluminum hydrate, phosphate rock and clay; the reducing of iron ore; and the reactivating of carbon.

A fluidized-solids reactor consists basically of a vertical cylindrical furnace, containing one or more perforated hearths or constriction plates. Thus, the reactor may have one or several compartments in which the desired treatment is effected. The charge, of proper particle sizing, is fed onto the perforated hearth, and is maintained in a fluid state by suspension in an upwardly moving stream of air or gas. The difference in pressure in the spaces above and below the hearth is such that the entire bed of charged material can be kept in suspension. The pressure of the air or gas below the perforated hearth or constriction plate is precisely controlled and is determined by the size and density of the solid particles. The fluidized bed is kept in turbulent motion similar to that of a boiling liquid. As charging continues, the bed overflows, and the excess material is either fed onto the hearth of the next lower compartment or discharged from the reactor. The operation generally is contin-

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Typical Single-Compartment Fluidized-Solids Reactor

uous. In processes which are endothermic, gas, oil, or powdered coal may be used as fuel; the roasting of sulfide ores and concentrates is exothermic and usually requires no fuel once the reaction is started.

The primary requirements of the refractories used in fluidized-solids reactors are adequate refractoriness and strength, low porosity, good spalling resistance, a high degree of immunity to the action of reducing gases, and good workmanship. Various brands of Harbison-Walker refractories fulfill all these needs.

Walsh XX, Woodland, and various other Harbison-Walker brands of high-duty fireclay brick are used for the reactor linings and perforated hearths in most applications. When service conditions are especially severe, particularly at very high operating temperatures, Kenmore or Varnon superduty fireclay brick are commonly employed. Under reducing conditions, such as might prevail during the direct reduction of iron ore by carbon monoxide gas, the maximum resistance to disintegration by carbon deposition is obtained from high-fired high-duty fireclay brick and high-fired superduty fireclay brick such as Varnon and Kenmore. The fireclay brick sidewalls are usually backed with H-W 23 or H-W 26 insulating firebrick to conserve heat and reduce fuel costs.

The best commercial workmanship of the brick shapes which form the perforated hearths is of great importance. Harbison-Walker's extensive experience in making refractories particularly suited for these requirements assures the best in all the different sizes and shapes.

H-W Extra Strength Castable is used for forming monolithic hearths of some single-compartment reactors.

Harwaco Bond air-setting bonding mortar is used for laying the various fireclay brick.

GLASS PLANT FURNACES

The ever increasing progress in glassmaking practice has not only produced glass of superior quality and a wide diversification of kinds, but has also brought about greatly increased production of glass per square foot of melting area and per cubic foot of furnace volume. Developments in the designs of continuous glass-melting furnaces, operating factors, and specialized refractories contribute to these rapid evolutionary advances.

The severity of operating conditions which the refractories are required to withstand continues to become greater. Much higher temperatures are employed and the amount and corrosiveness of the batch carry-over and volatile fluxes are increased. Lime, soda, fluorides, lead oxide, borax, silica, and other glass batch constituents react chemically at high temperatures with various refractories. Volatile alkalies are especially corrosive, since these materials readily penetrate into the pores of the brick. Borax used in the manufacture of certain glasses reacts severely with fireclay and basic brick. Sodium sulfate is an extremely active flux especially in reducing atmospheres. Silica blown over as fine dust into the regenerative system can cause damaging chemical reaction and build-up, resulting in clogging of checkers. Reducing or alternate oxidizing and reducing atmospheres affect basic brick to various degrees depending upon their compositions.

The optimum selection of refractories for a

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glass-tank furnace is that which would give completely balanced life for all parts of the furnace. This requires special attention to vulnerable positions where short service life might cause a shutdown for repairs long before a rebuild of the tank becomes necessary.

Furnace design, composition of the glass batch, and operating conditions vary so widely from plant to plant that no entirely definite rules can apply for the selection of refractories. In each case the choice from the wide range of types and classes now available must be based upon experience and knowledge of the specific conditions which prevail in the different parts of the furnaces.

Furnace Crowns or Caps: For the construction of the caps, silica brick are almost universally the standard. Improvements in the manufacture of STAR silica brick and the development of VEGA superduty silica brick have increased their practical utility at higher temperatures and higher production rates. In general, the power-pressed silica brick now widely used for furnace caps have a lower porosity than the brick available in the past. Even a small decrease in porosity is sufficient to effect an appreciable decrease in the amount of alkali absorbed by the brick. The smoothness of the brick surfaces, their freedom from warpage, and accuracy of dimensions contribute to a uniformly tight fit. It has been considered best practice at many plants to lay the brick with full but thin buttered joints and to grout with a special high-silica bonding mortar such as STARBOND and VEGA BOND. Tight impermeable joints contribute greatly to best service and particularly to the avoidance of boring, induced by penetration and condensation of volatile alkalies in leaky joints.

The usual thickness for silica crowns is 12 inches. However, some caps 13½ inches, 15 inches, and even 18 inches thick now are in service. The thickness of the brick is generally 3 inches. A width of 6 inches is preferable to 9 inches, because thinnest and tightest joints can be secured most readily with brick of the 6-inch width. For some of the smaller tanks making special glasses, high-alumina brick caps are sometimes used.

The silica-brick modifications STAR DASH and VEGA HP (hot patch) have unusually good spalling resistance and are used to advantage especially for making hot repairs.

Insulation of the glass-tank caps continues to become more widely practiced with the benefit of fuel savings and improved uniformity of operation. VEGALITE, the lightweight silica brick having at least twice the insulating value of silica brick of usual bulk density, serves this purpose most advantageously. Its safe-working temperature is 3000°F., and because of its similar chemical composition it does not react chemically with normal silica brick at highest safe-working temperatures. A major benefit derived from the insulation of a glass-tank cap with VEGALITE is the reduction of boring effects of volatile alkalies which penetrate the joints and accumulate in the temperature zone where condensation occurs. The insulation of a glass-tank cap alters the temperature gradient through it, causes the zone of condensation of volatiles to prevail outside the cap proper rather than within it, and therefore tends to retard boring.

In general, insulation should be applied only to new crowns as otherwise at operating temperatures the absorbed volatile fluxes near the hot face of the older crown may cause excessive fluxing. However, some crowns have been insulated with satisfactory results after having been in service for a considerable time. In the operation of a glass-melting furnace, flame impingement upon the roof is always undesirable.

In recent years, it has been general practice to build glass-furnace crowns with lower rise than formerly in order to increase thermal efficiency. While previously all crowns were joined directly to and supported by the breast walls by means of invert arches, many now are supported on steel channels which hold the skews, with the advantage of somewhat better control through ease of operation during the heat-up schedules.

Walls and Ports: At moderate operating temperatures, fireclay brick and more extensively silica brick continue to be used with satisfactory service in walls and ports. However, at the high temperatures now prevailing in many furnaces of both side- and end-port designs, materials of higher refractoriness and more corrosion-resistant compositions are required. The most severe conditions occur in the floors, walls, jambs, burner blocks and necks of ports, the furnace breast walls, and hot end wall.

KORUNDAL brick, containing approximately 90 per cent alumina, and H-W MULLITE brick are used in jambs and other parts of ports, as in burner blocks and in some vulnerable parts of the superstructure. MONOFRAX® H, a fused-cast refractory consisting essentially of beta alumina, was developed especially for use in the superstructure of glass furnaces. It is stable in the alkali-laden atmosphere of glass furnaces, and gives excellent service. Several brands of Harbison-Walker basic brick are used with best economy in port necks exposed to the most severe conditions. VEGA superduty silica brick continue to be used in port locations which are exposed to less severe conditions.

For the port crowns, FORSTERITE L and other H-W basic brick give best service in many cases. These same basic brick also are used in port sidewalls, uptakes, and regenerator walls usually to the lower levels of basic brick checker settings. The kinds of brick which withstand the most severe treatment to best advantage are briefly described under the heading of "Regenerators."

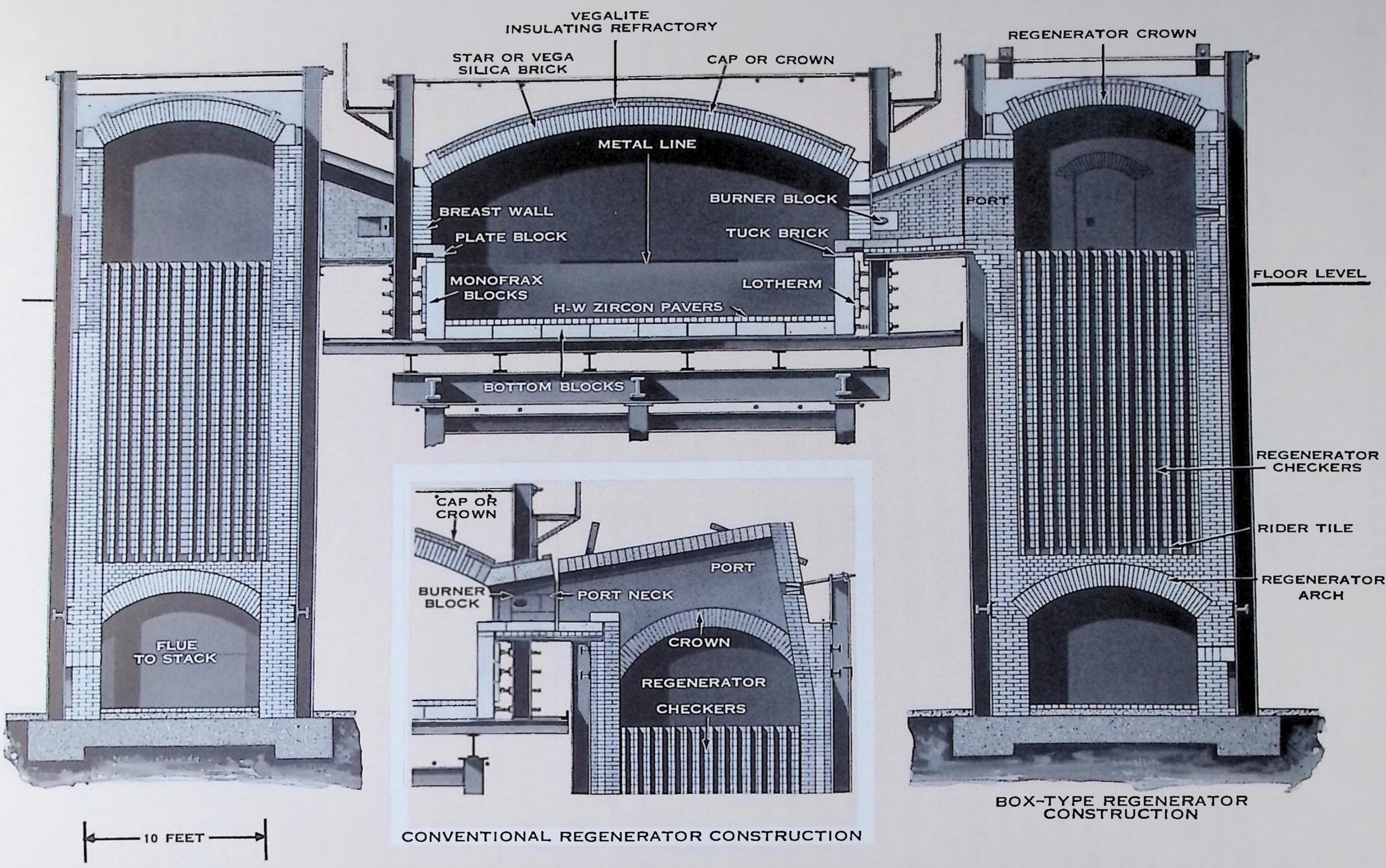
Lower Sidewalls and Bottom Blocks: MONOFRAX® S, a fused-cast zirconia-alumina-silica refractory, best fulfills the most severe requirements for use in contact with molten glass. It serves advantageously in the sidewalls of the melter, bridge wall, throat, and doghouse areas. MONOFRAX® M, a fused-cast refractory containing both alpha and beta alumina, is used mainly in contact with the glass in refiner ends and feed channels. High resistance to corrosion makes MONOFRAX® M an excellent lining material for the refining portions of the glass tank, especially if the possible effects of the refractory on glass quality are of major concern.

For the bottom construction, it is considered good practice at many plants to use H-W ZIRCON 9 x 4½ x 3-inch straight brick for covering the clay bottom blocks. Generally, H-W ZIRCON is bedded in a thin leveling mortar, namely H-W ZIRCON BONDING MORTAR. In some plants, fused-cast pavers of MONOFRAX® S are used in the melter end, and MONOFRAX® M in the refiner end.

Under certain conditions, as for example in the melting of colored glasses, insulation of lower sidewalls is practiced with worthwhile economy because of retarded heat transfer. LOTHERM is a strong insulating firebrick which, as used in this application, withstands the static load imposed by the glass melt at the ends of the jack bolts in the sidewall assembly. Insulation of the bottom, particularly of the refining section of glass furnaces, in a number of cases has resulted in improved operation.

Regenerators: The regenerator checkers are exposed to the action of alkaline dust at temperatures considerably below that of the melt-

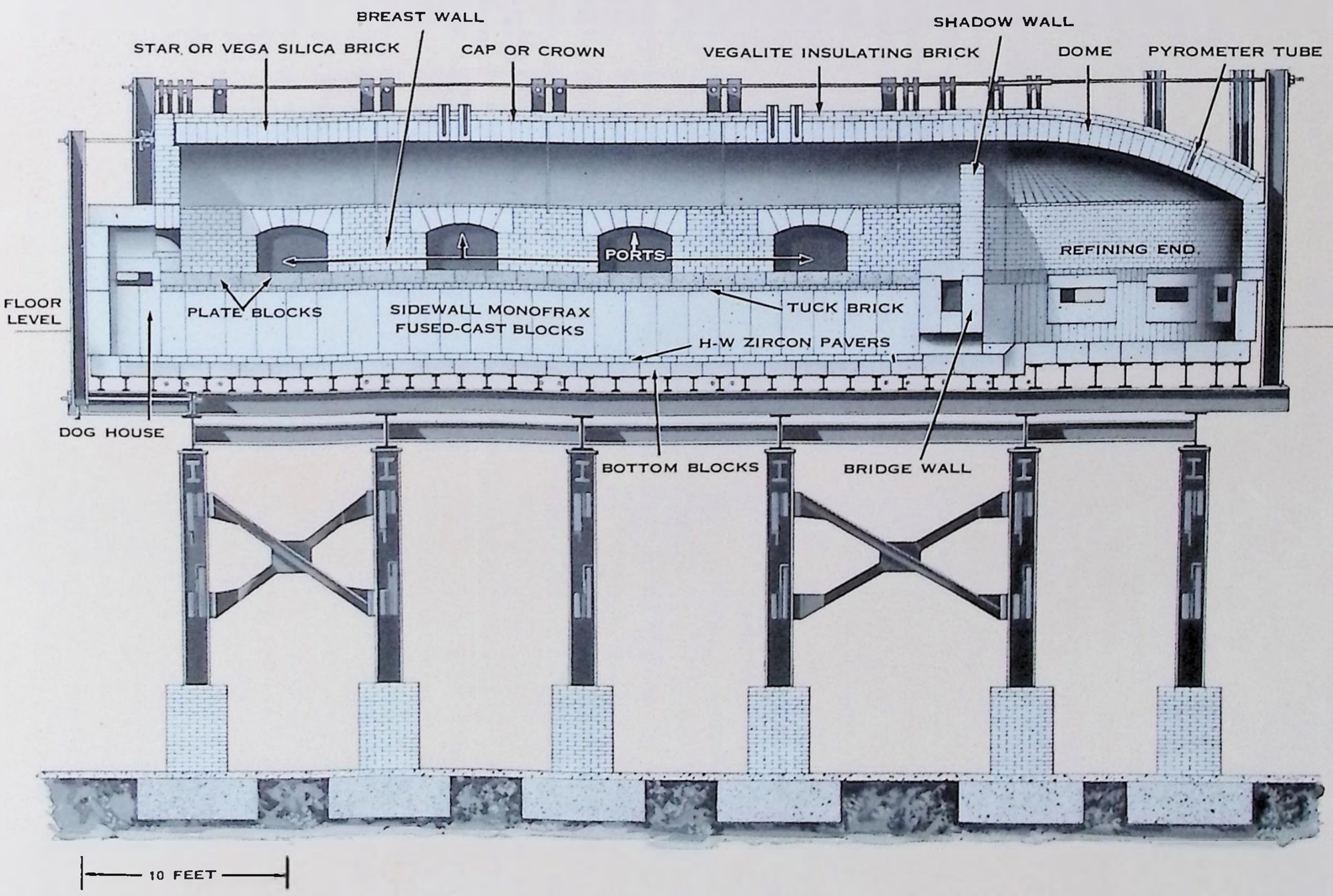
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CONVENTIONAL REGENERATOR CONSTRUCTION

BOX-TYPE REGENERATOR CONSTRUCTION

Typical Side-Port Glass-Tank Furnace



LONGITUDINAL SECTION

Typical Side-Port Glass-Tank Furnace

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ing zone of the tank. At the top of the checkerwork the temperature may be as high as 2500° F., and in some instances appreciably higher. At the bottom of the checkers the temperature is considerably lower and condensation of volatilized alkalies may occur. During clean-out periods the brick are subjected to influences which tend to cause spalling.

The behavior of the checkers depends upon the temperature, the extent and rapidity of the temperature fluctuations, the amount and composition of alkaline dust and fumes in the furnace gases, the amount and composition of slag drip from the arch, the kind of checker brick used, the type of construction, the kind of fuel, and the manner in which the checkers are cleaned. For a given kind of checker brick, the length of service will vary with the temperatures and other operating conditions.

Brick for checker service should stay clean and should not become appreciably encrusted; the openings should remain clear, and the rate of wear should be low. These requirements can be met or closely approached by selection of the brick best suited to the service conditions.

In order to meet the greatly intensified conditions of higher temperatures and higher rates of production, accompanied by increased carry-over of alkali fluxes into the regenerators of soda-lime-silica glass furnaces, basic brick have largely replaced superduty fireclay and high-alumina checkers at the hottest ports in varying depths and in some cases from the top down to the rider arches. In many installations, basic brick are used for the entire checker setting. In regenerators checkered with both basic and clay brick, the former generally are used to a point beyond the hot ports, where the alkaline dust carry-over is much reduced. For securing the best balanced service, experience from previous campaigns can be of best guidance in selecting the kinds of refractories among basic, high-alumina, and superduty fireclay brick and in determining the pattern of setting them in relation to each other.

FORSTERITE and FORSTERITE L, the magnesium silicate refractories, pre-eminently established through the years for checkers, parts of regenerator walls, arches, and ports of many soda-lime glass-melting furnaces, are supplemented by other Harbison-Walker basic brick developed for specific operating conditions. CHROMEX B and CHROMEX S, consisting predominantly of chrome ore, fulfill certain needs most advantageously. Included among leading basic refractories developed by Harbison-Walker primarily for glass-furnace requirements are THERMAG H, a high-periclase brick with a duospinel bond, and other high-periclase brick with a magnesium aluminate bond.

Brands of basic brick embracing different combinations of physical and chemical properties are available to provide adequate resistance to the wide diversity of corrosion factors and destructive regenerative cyclic effects which prevail in the regenerators of various glass furnaces. These refractories are produced as hard-burned brick for maximum stability of mineral constitution and as chemically-bonded brick for the benefit of maximum spalling resistance. For certain wall and arch constructions, they are made with metal casings.

Superduty fireclay brick such as VARNON and KENMORE are preferred for use in regenerators of furnaces in which borosilicate and lead glasses or some special batches are melted. In the regenerators of some glass-melting furnaces producing only borosilicate glasses, STAR and VEGA silica brick checkers are used with splendid results.

The most widely used arrangements for checker settings of glass furnaces include the open conventional system, the open basket-weave setting, and the solid chimney-flue setting in closed basket-weave design. Each method provides certain advantages for different sets of conditions. Basic brick checker settings are favored to an appreciable degree by the basket-weave method, set either tightly closed or open. These basket-weave arrangements provide greater support and relief of transverse stress than does the conventional setting method.

Unit Melter Furnaces and Day Tanks: In general, these furnaces, without regenerative systems, require refractories similar to those which serve best for side-port and end-port tank constructions. For the special glasses produced in some of these, Harbison-Walker brands adapted for the special needs are accepted as standards at many plants.

Lehrs: Insulating refractories of the several commercial classes are commonly used for building most designs of annealing and decorating lehrs. All the different kinds needed for highly satisfactory results are available in Harbison-Walker products. H-W BLOCK INSULATION and H-W lightweight castables serve the most exacting requirements. The special shapes used in some of the constructions are made from several brands of strong Harbison-Walker insulating firebrick along with the kind of mortar for the particular requirement.

Mortar Materials: Both air-setting and heat-setting mortars serve their particular functions to best advantage in various glass-furnace constructions. Harbison-Walker's complete line of mortars is described on pages 138 to 146.

THERMOLITH bonding mortar, which has a chrome ore base, is made with air-setting or heat-setting bonds as desired for the application. It is used extensively for laying the brick in regenerator walls and uptakes. However, it may not be used in furnace ports or other positions in glass-melting furnaces where the chromic oxide might affect the color of the glass. FORSTERITE BONDING MORTAR, either air-setting or heat-setting, is most widely used for laying FORSTERITE brick and in many cases is preferred for laying other basic brick. It is also used with high-alumina brick and alumina-silica brick in port walls and arches. Air-setting HARWACO BOND and heat-setting ANKORITE 65, both of high-alumina base material, are used advantageously for laying fireclay or high-alumina brick in ports and regenerators. Hard-fired superduty fireclay brick laid with ANKORITE 65 are used with excellent results in the crowns of certain glass-melting tanks. THERMOLITH, HARWACO BOND, or FIREBOND are used for laying the brick in lehrs. Other mortars of higher alumina content such as KORUNDAL BONDING MORTAR, consisting largely of corundum and mullite, are also used.

H-W STAR SILICA FIRE CLAY is used economically for laying brick which are not subjected to the most severe conditions. STARBOND and VEGA BOND give best service when used for laying silica brick which are exposed to highest temperatures and greatest corrosive treatment. STARBOND is measurably more refractory than the normal silica clay, and VEGA BOND represents the ultimate in silica mortars.

Castable Refractories: The use of monolithic constructions in various parts of glass furnaces of all kinds has continued to increase throughout recent years. Harbison-Walker castables are described on pages 163 to 167.

Used in the construction of the difficult contours of some glass-furnace flues, castables provide important advantages in addition to their excellent durability. Maintenance repairs with dense castables in worn regenerator positions and port uptakes effect considerable savings in time and materially prolong service life.

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HEATING AND HEAT-TREATING FURNACES

The group of furnaces used for heating and heat-treating covers a wide field in the processing of both ferrous and nonferrous metals. "Heating" or "reheating" furnaces are used in heating metals to the required temperature for changing their shape or form by stamping, pressing, rolling, extruding, shearing, forging, welding, or similar processes. "Heat-treating" furnaces are used for stress relieving and for changing the physical properties of the metal after the product has attained its final shape. In these general classifications are the following types of furnaces:

Heating Furnaces:

Aluminum	Preheating before melting
Axle heating	Plate heating
Bar mill	Seamless tube
Billet heating	Slab heating
Butt- and lap-weld pipe	Structural mill
Copper	Upsetting
Forge	Welding

Soaking pits, which are also classified as heating furnaces, are discussed on page 453.

Heat-Treating and Processing Furnaces:

Aluminum coating	Nitriding
Annealing	Normalizing
Brazing	Stress relieving
Carburizing	Tempering
Hardening	Vitreous enameling

In no other group of furnaces are there such great differences in size, design, and operating conditions. Every gradation in size is found, from small rivet-heating furnaces to the huge billet-heating furnaces illustrated on pages 398 and 399—and from small box-type heat-treating furnaces to the large continuous annealing furnaces several hundred feet long. Heat-recovery units may or may not be provided. The furnace may be any one of several types: hearth, pit, muffle, tunnel, or others. It may be stationary, rotating, stationary except for a rotating hearth —and in some cases even portable. The material under treatment may be heated in batches in an "in-and-out" type of furnace; or it may pass intermittently or in a continuous stream through a furnace having either a stationary or a moving hearth.

HEATING FURNACES

The selection of the type of furnace for any particular operation is governed by the size, shape, kind, and variability of product being processed. Other factors such as available fuel supplies, production demands, and flexibility of the process are necessarily taken into consideration. The operating temperature will depend largely on the type and size of product, the furnace design, and the operating rate. It will usually fall between 2000° and 2800°F. in the hot zone. In some high-tonnage units requiring very high heat release the temperature in the hot zone may be as high as 3000°F.

The factors having the greatest effect on the life of the refractory linings are the continuity of the operation, the type of fuel, the temperature, the furnace atmosphere, the nature of the flame, the rapidity of temperature fluctuations, the corrosive effect of any iron scale or ash, and the amount of physical abuse.

In the preheating and cooling zones of continuous heating furnaces, high-duty fireclay brick and insulating firebrick last almost indefinitely. However, more refractory materials are needed for the higher temperature zones of many types of heating furnaces. In the hotter zones of continuous furnaces and in batch-type furnaces operated at high temperatures, the proper selection of refractories is exacting for keeping costs within an economical limit.

Hearths: Among the factors which determine the kind of refractory material best adapted for service in heating furnace hearths are the temperature, the amount of scale, and the degree of mechanical abrasion. At low temperatures of furnace operation, any iron oxide scale which forms remains dry, and has little tendency to attack the refractory material of the hearth. At higher temperatures, the scale becomes a viscous or molten slag and has a strongly corrosive effect. The degree of mechanical abrasion and impact imposed upon the hearth depends largely upon the kind and weight of the metal shapes being processed.

Under mild temperature conditions the hearths may be built of dense, tough high-duty fireclay brick. With increased operating temperatures, it may be necessary to use superduty fireclay brick or high-alumina refractories. In hearths subjected to unusually high temperatures and very severe abrasion conditions, HARBIDE (silicon carbide), ALUSITE, and KORUNDAL XD, 70 and 90 per cent alumina refractories, meet the different needs.

In many heating furnace hearths, the corrosive action of molten scale is so severe that basic refractories such as H-W MAGNESITE or CHROMEX B are preferred over the fireclay or high-alumina refractories. These brick are strong, highly refractory, and capable of absorbing large quantities of iron oxide with little change in strength or rigidity.

The use of PLASTIC THERMOLITH BATCH, H-W CHROMEPAK, H-W MAGNAMIX 85, or H-W MULLITE RAMMING MIX provides a convenient method of forming the hearth contours with a ramming material which is mechanically strong and highly resistant to abrasion and to penetration by the molten scale.

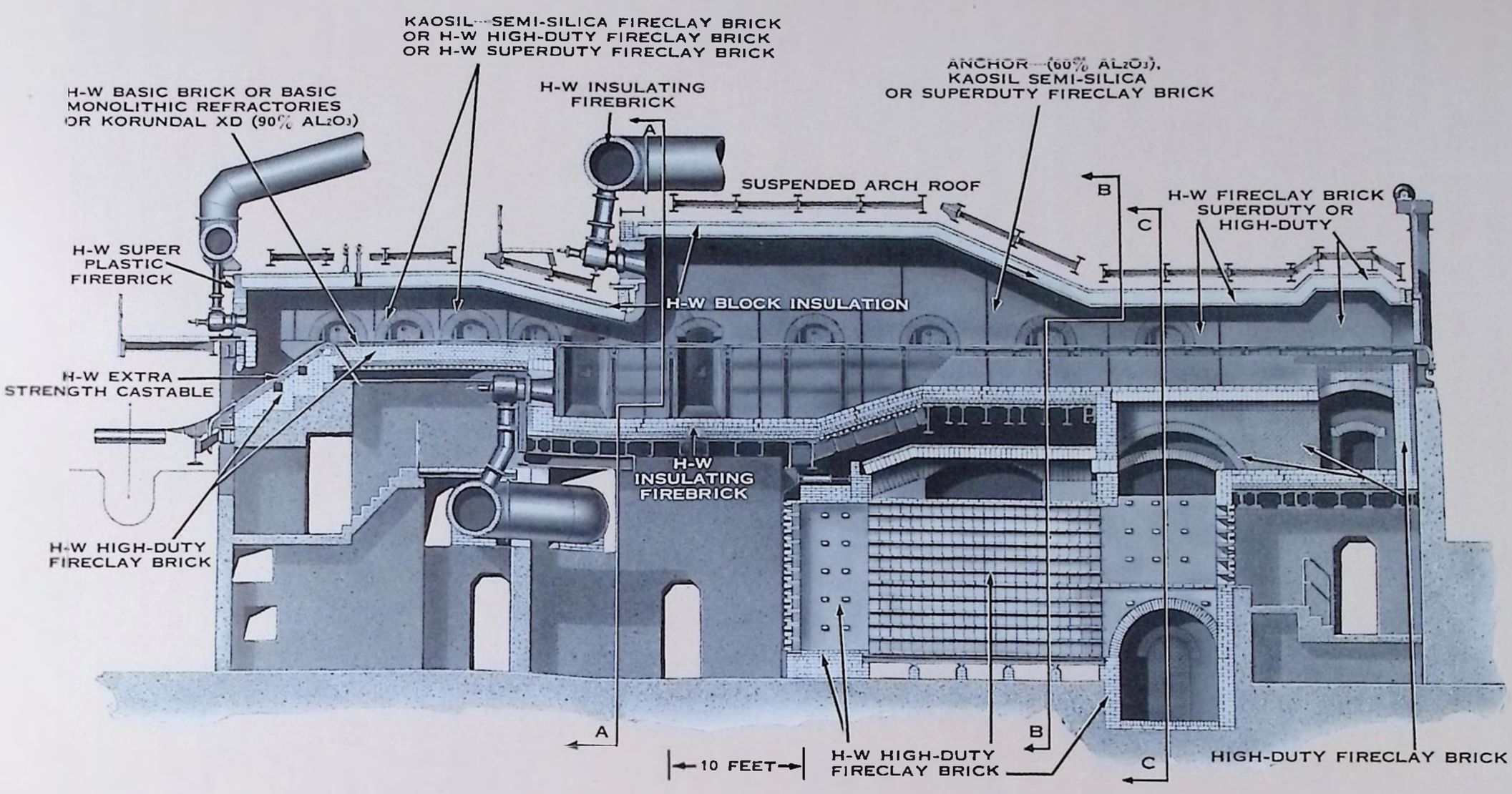
Some furnace hearths which are subjected to unusually severe scale attack are top dressed with ground chrome ore or ground dead-burned magnesite. These materials absorb the iron scale and are removed periodically and replaced with fresh material.

Steel rails, water-cooled pipes, HARBIDE silicon carbide brick, or KORUNDAL XD high-alumina brick are used in some furnaces to withstand the severe abrasion of the moving stock.

Sidewalls: The classes of refractories generally used for sidewalls are high-duty, superduty, and semi-silica fireclay brick. In furnaces operating at temperatures exceeding the maximum limits of fireclay brick, use of the high-alumina brands ANCHOR DASH (60 per cent alumina class), ALUSITE and H-W MULLITE (70 per cent alumina class), or even KORUNDAL XD (90 per cent alumina class) is often an economy. The type of fuel may influence the choice of refractories. In some furnaces using by-product fuels high in alkalies, KAOSIL semi-silica brick give best results. The alkalies and vanadium oxide in the ash of fuel oil may have a strongly corrosive effect. The resistance of high-alumina brick to this action increases with increasing alumina content. Frequently it is advisable to use several courses of H-W CHROME brick along the walls where molten scale comes in contact with the refractories. PLASTIC THERMOLITH BATCH may be employed to protect the sidewalls against slag attack.

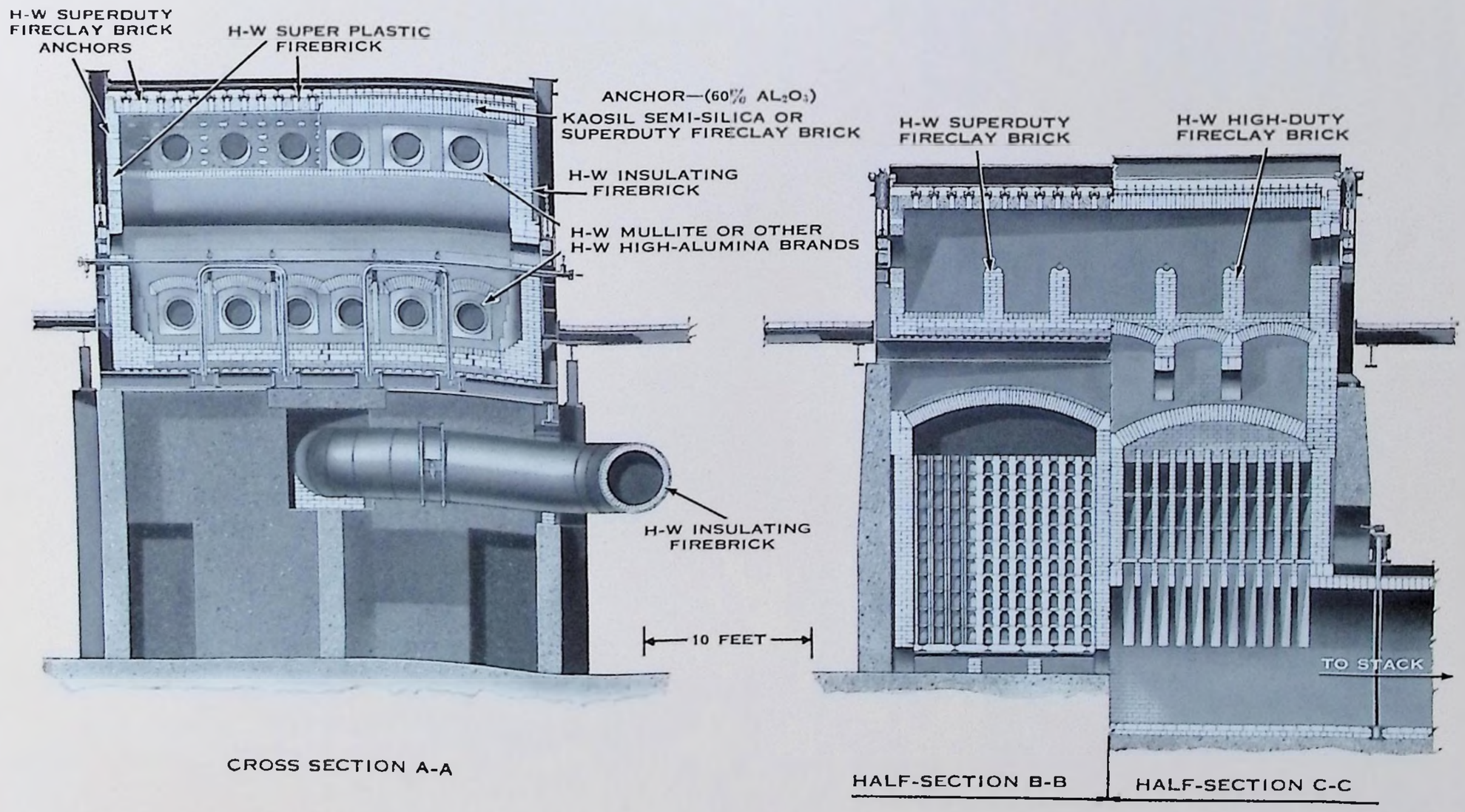
In many instances, it is considered advantageous to build the sidewalls of heating furnaces entirely of monolithic refractories. H-W SUPER PLASTIC FIREBRICK, APACHE PLASTIC REFRACTORY, H-W MULLITE RAMMING MIX, H-W SUPER CASTABLE, H-W HIGH-ALUMINA CASTABLE,

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LONGITUDINAL SECTION

Typical Recuperative Reheating Furnace



CROSS SECTION A-A

HALF-SECTION B-B

HALF-SECTION C-C

Cross-Sections of
Typical Recuperative Reheating Furnace

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and H-W Lightweight Castable 20 are used in this service. It is common practice to provide support for monolithic walls by anchoring them to steel supporting members.

Roofs: In many cases, the roofs of heating furnaces consist of sprung arches; frequently they are of flat suspended construction. The flat arch is widely used on large continuously operated furnaces as well as on smaller furnaces, and usually is of suspended construction.

Generally, the roofs are subjected to service conditions similar to those which the sidewalls must withstand. With sprung arches, an additional factor of importance is the stress from the thrust of the arch.

For any particular zone of a given furnace, the same refractories as those used in the sidewall usually will serve for the roof.

HEAT-TREATING FURNACES

Heat-treating furnaces generally operate in the temperature range of 800° to 1750°F., and are seldom designed for temperatures above 2100°F.

The various heat treatments are accomplished in furnaces capable of heating the product to a specified moderately high temperature for a sufficient time to permit the occurrence of phase and surface changes, followed by a cooling cycle which determines the final physical properties. This final phase may be achieved by controlled rates of cooling or by various quenching procedures.

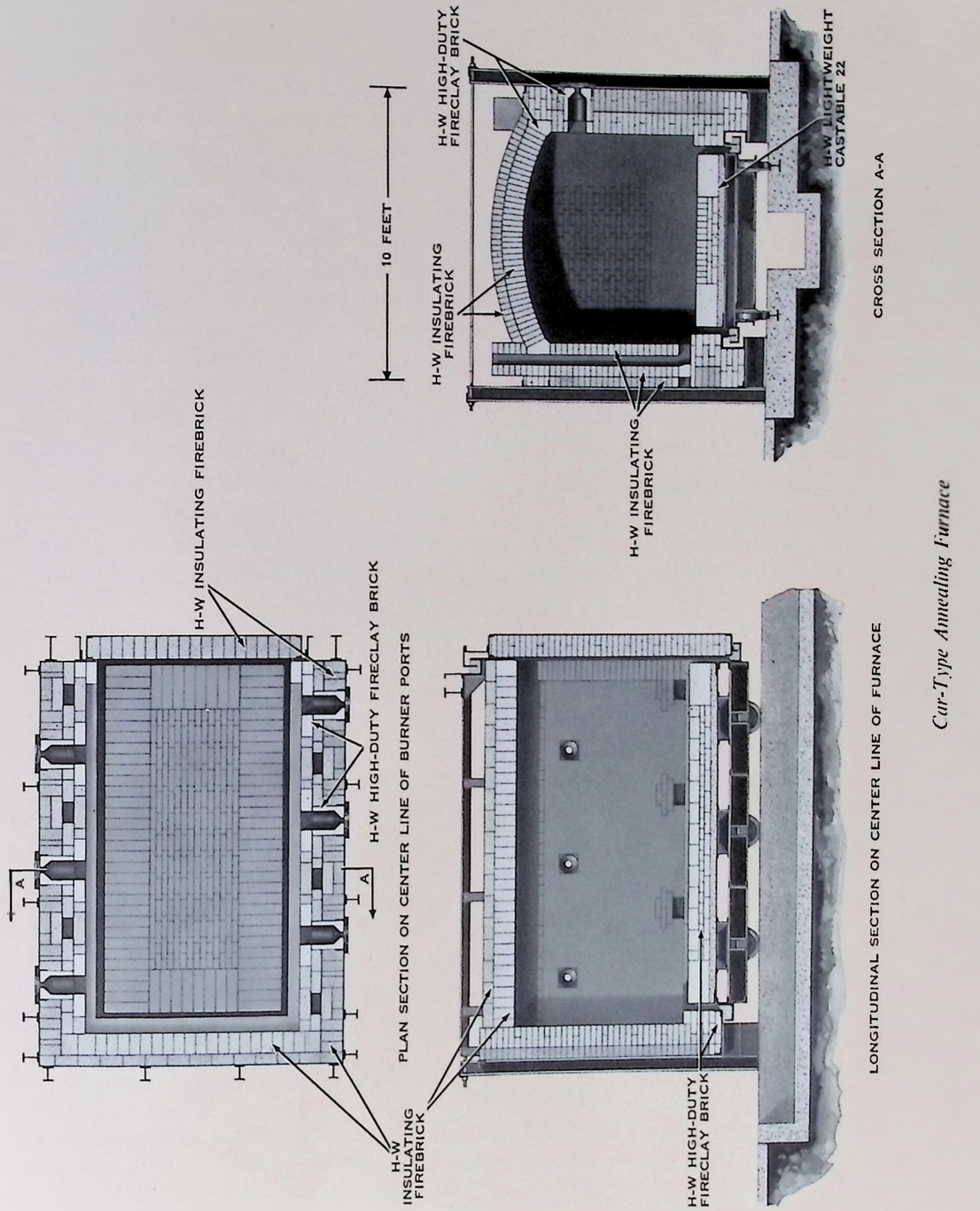
Many heat-treating processes also employ prepared gaseous atmospheres of various compositions. These atmospheres may be used only to prevent oxidation or scaling of the surface, or they may be used to change the chemical composition of the product by adding carbon, nitrogen or other elements, or by removing carbon, as in decarburizing.

If controlled atmospheres, containing appreciable quantities of carbon monoxide or hydrogen, come into contact with the refractory lining, care must be taken to select refractories which have unusually low contents of reducible oxides. This can be accomplished in either of two ways: (1) by selecting refractories containing an absolute minimum of free iron oxide or other oxides which are reducible in their free state, or (2) by selecting refractories which have been so processed that these oxides have been rendered inert by chemically combining them into stable compounds. The low-iron insulating firebrick H-W 23-LI together with H-W 18 Ky, H-W 18 Pa, H-W 18 Mo, H-W Crown XB, and Varnon brick are in these categories.

Combustion chambers or baffles are usually built of high-duty fireclay brick, superduty fireclay brick, or high-alumina material depending on the fuel, temperature and degree of flame impingement, and heat shock.

In furnaces heated by electrical resistance, the rate of temperature change is very moderate. Very dense and strong high-duty fireclay shapes for some furnace designs are used to support the resistors.

Since the operating temperatures are relatively low, and the service conditions such as corrosion, erosion, and abrasion are relatively mild in heat-treating operations, insulating firebrick are widely used in building the furnaces. In the case of continuously operated furnaces, the use of insulating firebrick is especially advantageous, because of the low rate of heat loss through such refractory linings. For intermittent or batch-type operations, insulating firebrick provide a lining with low heat-storage capacity. Thus, a minimum amount of



Car-Type Annealing Furnace

HARBISON-WALKER REFRACTORIES COMPANY

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fuel is wasted in heating up and cooling down the furnaces. Moreover, use of insulating firebrick enables the operator to keep very close temperature control during all phases of the heat-treating cycle. Except where load-bearing capacity or resistance to abrasion must be high, or high porosity is undesirable, insulating firebrick should find increasing use in heat-treating furnaces.

Lightweight castables are used successfully for building some complete heat-treating furnaces. H-W LIGHTWEIGHT CASTABLE 22, H-W LIGHTWEIGHT CASTABLE—EXTRA STRENGTH, H-W LIGHTWEIGHT CASTABLE 26, and other insulating castables are widely used to form monolithic sidewalls and arches. H-W HARCAST and H-W LOW-IRON LIGHTWEIGHT CASTABLE 22 are particularly suited for use in furnaces operating with controlled atmospheres. H-W EXTRA STRENGTH CASTABLE (COARSE) is being used with great success for car tops and pedestals which support the material being treated.

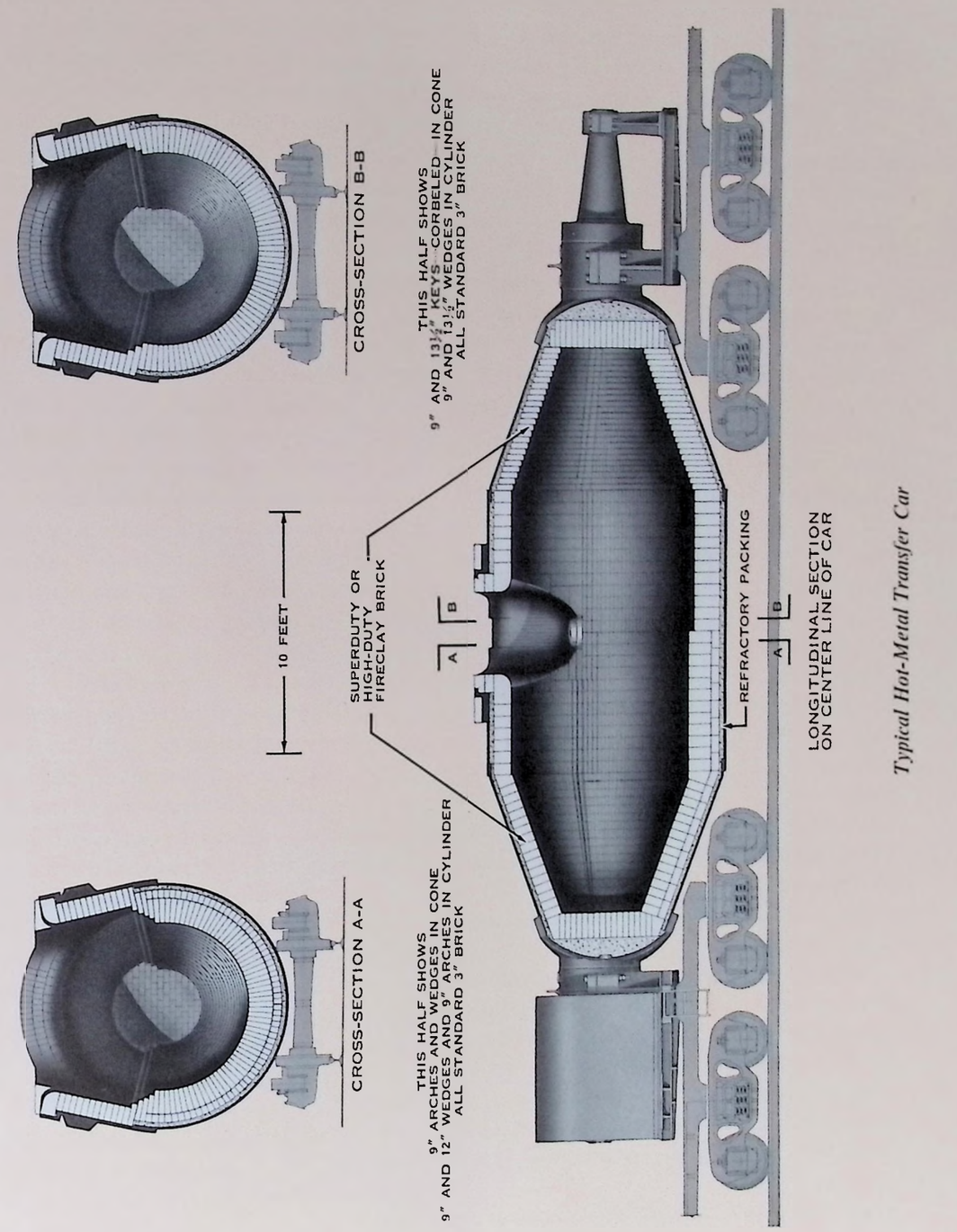
Annealing Furnaces: The hearths of annealing furnaces are generally built of medium-duty or high-duty fireclay brick capable of withstanding the mechanical treatment to which they are subjected. Occasionally, superduty fireclay brick are used for hearths which are subjected to severe thermal shock. For sidewalls and roofs, insulating firebrick may be used wherever operating conditions permit. If the operating conditions are severe, fireclay brick are used for the inner face of the walls, with a backing of insulating firebrick. The quality of the insulating firebrick used depends on the service temperature. Because of the relatively low operating temperatures, it is best practice to lay all brick with air-setting mortars rather than with mortars which require high temperatures to develop a strong bond.

HOT-METAL TRANSFER LADLES AND METAL MIXERS

Hot-Metal Transfer Ladles: Molten iron from the blast furnace is usually tapped into transfer ladles mounted on railroad trucks. The iron in the ladles is then moved by rail to any point desired. Generally, it is taken to an open-hearth or converter plant, where it is stored in hot-metal mixers until needed by the furnaces. Less frequently, the molten metal is carried to a continuous casting machine and cast into pigs.

The capacity of transfer ladles ranges from 50 to 225 tons or even more of hot metal. The smaller ladles of this type are usually of upright cylindrical design and open at the top, although some constructions provide partial top closure for heat retention. The ladles of 125 tons and higher capacity generally are horizontal cylinders with conical ends and are referred to as mixer-type ladles. Pouring the metal into and out of the ladles is accomplished through an opening in the top.

The fireclay brick lining of a hot-metal transfer ladle is usually 9 inches to 13½ inches thick, and an additional 4½-inch safety lining, installed against the shell, has been found to be advantageous in many plants. Dense superduty fireclay brick, such as VARNON, VARNON BF, and ALAMO S are most widely used, although high-duty fireclay brick may give best economy in some instances. Harbison-Walker's blast-furnace refractories, as well as WALSH T, H&B WOODLAND, and other high-duty fireclay brick brands, have the required properties of density and strength. In order to obtain these properties, the brick are preferably made by the vacuum power-press process, or by deaired extrusion and repressed.



Typical Hot-Metal Transfer Car

HARBISON-WALKER REFRACTORIES COMPANY

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In lining the ladles, it is usual practice to tamp a mixture of crushed firebrick and fire clay against the shell. The packing material is usually 1 to 2 inches thick and its purpose is chiefly to avoid contour irregularities which may be caused by lap joints in the steel shell or by rivet heads. Sometimes a backing of 9-inch splits or 2-inch brick is used instead. The brick in the working lining should be laid with the thinnest possible joints and keyed as tightly as possible. The selection of the bonding mortar is as important as is the choice of brick. Minimum shrinkage at service temperature is the first consideration, and many users insist upon an air-setting mortar, which assures adequate strength throughout the joint at all temperatures. H-W SUPER HARBOND and HARWACO BOND are widely used. In cases where especially severe conditions prevail, CORALITE BONDING MORTAR with its higher refractoriness is preferred. When a heat-setting mortar is preferred, ANKORITE 65 may be used.

Among the factors which influence the life of transfer ladle linings are the height of the drop from the metal runner to the ladle, the distance of ladle travel, the length of time the metal is stored in the ladle, the number of pours when emptying, and the degree to which the lining can be cooled between metal casts. Perhaps the most important factor is the character and amount of slag which may be carried incidentally with the iron.

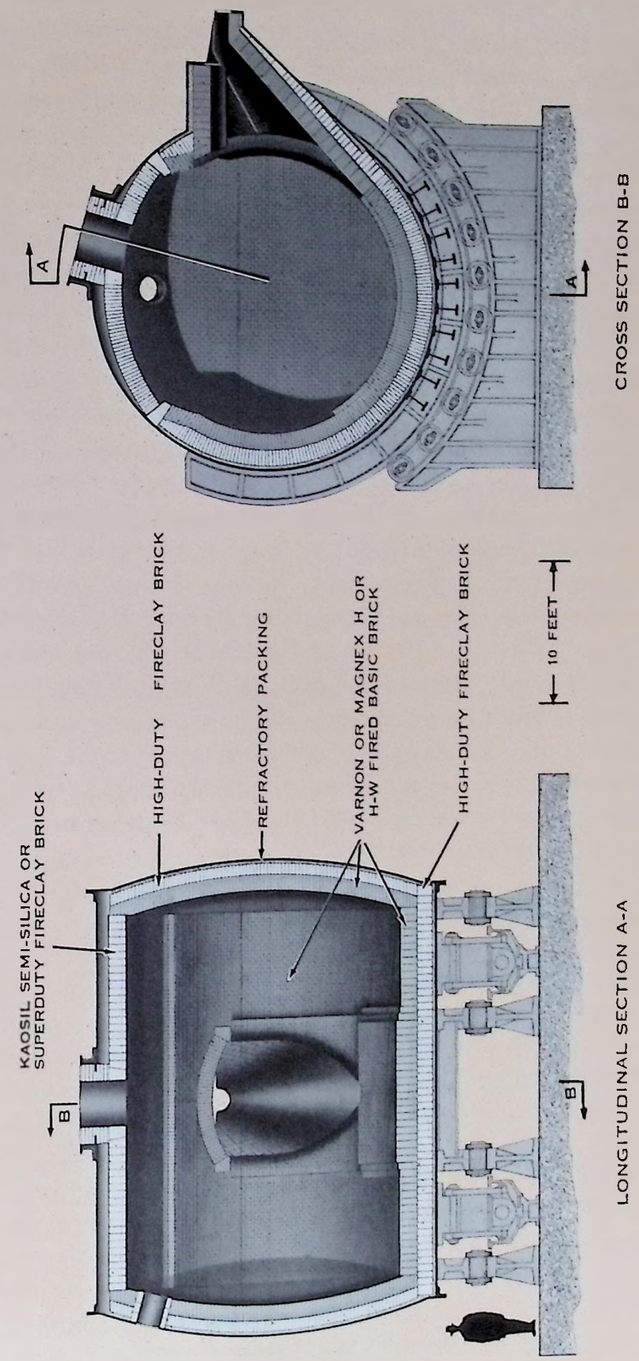
Wear on the linings is much less severe when the number of times the vessel is shifted and tipped is held to a minimum. The life of the lining is generally longest when the ladle is used in conjunction with a continuous pig-casting machine and when the position of the ladle may be reversed for both filling and pouring.

At some plants extra lining thickness is provided immediately under the opening where the metal stream impinges, in order to give a balanced over-all wear pattern. Ladles kept in continuous operation may be cooled somewhat by blowing air into them between trips. This practice lowers the mean temperature of the linings and has a favorable effect upon the life of the refractories.

Metal Mixers: In most steel plants, hot metal from the iron blast furnaces is stored for a time and kept hot in metal mixers, while awaiting the next step in processing and conversion into steel. The mixers are holding vessels of various shapes and sizes ranging up to 1500 tons capacity. They are so mounted that the vessel may be rotated to permit periodic pouring of the hot metal into transfer ladles for transportation to the open-hearth furnaces or converters. Molten iron, with small amounts of accompanying slag, is poured into the metal mixer through an opening usually in the top, and then as required, is poured out through a spout on one side into the transfer ladles.

While the temperature of the metal has a very pronounced effect on the life of mixer linings, the type and amount of slag carried over from the blast-furnace operation is also important. Life of the refractories is affected adversely by extreme variations in metal height and by high frequency of pouring, which increases the number of exposures of the refractory structure to slag. Refractory life around the spout is improved by a smooth flow of the molten metal, which depends upon vessel design and surface contours.

It is common practice to line the body of the vessels below the roofs with two concentric rings of brick, with the ring against the shell being more or less permanent. Many mixers are operated at temperatures as low as about 2150°F. to 2250°F. and dense, hard-burned



Typical Hot-Metal Mixer

HARBISON-WALKER REFRACTORIES COMPANY

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fireclay brick of the high-duty class give excellent service. The various brands of Harbison-Walker's high-duty blast-furnace brick are used, as well as such brands of fireclay brick as Walsh T and H&B Woodland.

It is often advantageous to operate mixers at higher temperatures, either because of the rapid throughput of metal required, or because of the necessity of burning auxiliary fuel to promote proper fluidity so that smooth pouring may be maintained. Moreover, in some cases the metal is now tapped from the blast furnace at a higher temperature than formerly and arrives hotter at the metal mixer. For temperatures as high as 2300°F., the hard-fired superduty fireclay brick brands Varnon or Varnon BF are recommended. A belt of Alcor XX, H-W Mullite D, or Coralite XD high-alumina brick at the metal line gives superior resistance to corrosion by slag.

The sprung-arch roofs may consist either of high-duty or superduty fireclay brick, and generally have very long life. Kaosil semi-silica fireclay brick are favored for this service because of their excellent volume stability in such arches at even the maximum temperatures of mixer service. Glazing of the exposed surface of the semi-silica brick, which occurs in service, is another advantage, as it tends to minimize spalling and penetration by fluxes.

Proper selection of mortar material, and accurate bricklaying, with very thin joints, are essential, since the joints are particularly vulnerable to erosion in contact with moving slag and metal. A high-temperature bonding mortar such as H-W Super Harbond or Harwaco Bond finds most favor. Coralite Bonding Mortar is preferred for laying fireclay and high-alumina brick where more severe service conditions prevail.

When temperatures higher than 2300°F. may be attained, it is best to rely on a basic brick such as Magnex H or H-W fired basic brick for lining all areas that are in contact with the metal or slag. H-W Periklase Bonding Mortar serves best for use with these basic brick.

H-W High-Alumina Castable has proved to be an exceedingly versatile material for making patch repairs to the spout and metal line areas of metal mixers. Applications are made successfully by troweling or casting, or by means of a pneumatic gun.

INCINERATORS

While the great majority of incinerators are used by municipalities for burning garbage, sewage sludge, and other waste material, a considerable number are employed for disposing of industrial waste products. In each class of incinerators, there are a number of well-established designs built by engineering companies which specialize in such construction. The wide range of Harbison-Walker products permits selection of those best suited for each type of incinerator.

Most incinerators are built with solid walls. The interior is built of high-duty or superduty fireclay brick. The walls are self-supporting, and usually have an outside backing of one or two courses of medium-duty fireclay brick or of insulating firebrick with a steel casing. The furnace roofs consist of either sprung or suspended arches. As incinerators become more widely used, there is the increasing tendency to build the roofs with suspended arches. Harbison-Walker maintains stocks of the brick shapes required for the various designs of suspended roofs.

While the temperatures prevailing in most incinerators are only moderately high except in localized areas, the destructive influences to which the brick linings are exposed are severe. Corrosive ash, high in potash, results from the burning of organic materials such as animal or vegetable matter, wood, and paper. Frequently tin, lead, or other metals, and broken glass are present. At the combustion temperatures maintained, the metals may oxidize and have a destructive effect upon the refractories. Usually ash or clinker in a more or less viscous state will penetrate the brick to a slight depth, and fly ash will adhere to the walls and roof. In the removal of this clinker and fly ash the brick are generally subjected to considerable mechanical abuse. Frequently, the brick in the door jambs and charging holes are damaged by the tools used to distribute the bed and to remove clinker adhering to the brickwork.

The refractory linings are exposed alternately to flame impingement and to sudden cooling caused by the charging of damp or wet refuse. This condition is accentuated when refuse varies from highly combustible, almost explosive, wastes such as hydrocarbon or cellulose-type materials, to less combustible refuse such as wet wood and others of low heat content. The presence of an appreciable amount of carbon monoxide, resulting from incomplete combustion, can exert a destructive action over a critical temperature range.

Harbison-Walker refractories recommended for use in incinerator linings have the combination of properties required for greatest resistance to the various destructive influences. The brick supplied for walls and sprung-arch roofs are of the proper texture for resistance both to slag penetration and to thermal spalling conditions. Brick widely used for this service are the high-duty fireclay brands Walsh XX, Woodland Dot, H-W Savage, H-W Crown, H-W High Grade XX, Royal Gorge, and Western. The superduty fireclay brick used when service conditions are especially severe include Alamo, Boone, H-W Super Savage, Dean, H-W Kala, and Zenith.

Harwaco Bond, used for laying the brick in the entire construction, contributes much to good service. For sprung-arch roofs, this mortar material has proved especially advantageous. For suspended roofs, a heat-setting mortar such as H-W High-Duty Fire Clay or H-W Superduty Mortar is generally preferred.

For monolithic refractory linings, H-W Standard Plastic Firebrick and H-W Super Plastic Firebrick are used extensively. The use of H-W Extra Strength Castable and H-W Super Castable for the construction of arches and charging holes, and for making repairs in many instances is the most economical practice. The hearths and shaft linings of some multiple-hearth incinerators used for burning garbage are economically constructed and maintained with H-W castables.

For burning some kinds of refuse of low heat value it is necessary to use auxiliary firing with oil or gas, and heat conservation is very desirable. With the increasing application of insulation in incinerator construction, the choice of the insulating material has become more exacting. The Harbison-Walker insulating materials most commonly used in incinerator construction are H-W 16-20 and H-W 20 insulating firebrick and H-W block and bulk insulations.

Since the majority of incinerators are installed and operated under the jurisdiction of municipalities, the refractories used are generally purchased on definite specifications. Harbison-Walker products satisfactorily fill the requirements of the specifications for all the widely accepted types of incinerators.

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LEAD

The smelting and refining of lead involve a complex series of operations, and refractories especially adapted to the various specific conditions must be selected for each stage. There are numerous variations in detail between the succeeding steps as carried out in different smelters and refineries. The following paragraphs give a greatly condensed outline of the steps which are most important with regard to the usage of refractories.

The concentrated lead ore is first roasted and sintered and then charged to the *blast furnace*, together with fluxing agents and coke. The products of the blast furnace are impure lead, possibly some matte (copper-iron sulfide) and speiss (arsenides of iron, cobalt, and nickel), and slag.

The lead from the blast furnace is charged into *drossing kettles* and agitated by air or steam, or by the insertion of wooden poles. Some of the dissolved impurities come out of solution and form a "dross" which floats on the molten lead and is periodically skimmed off, together with considerable amounts of entrapped lead and lead oxide.

The kettle dross is processed with reducing agents and fluxes in a small reverberatory known as a *dross furnace*. The lead recovered from the dross is returned to the drossing kettle, a matte-speiss product is shipped to a copper plant, the slag is charged to the blast furnace, and the fume is recovered by treatment of the flue gas.

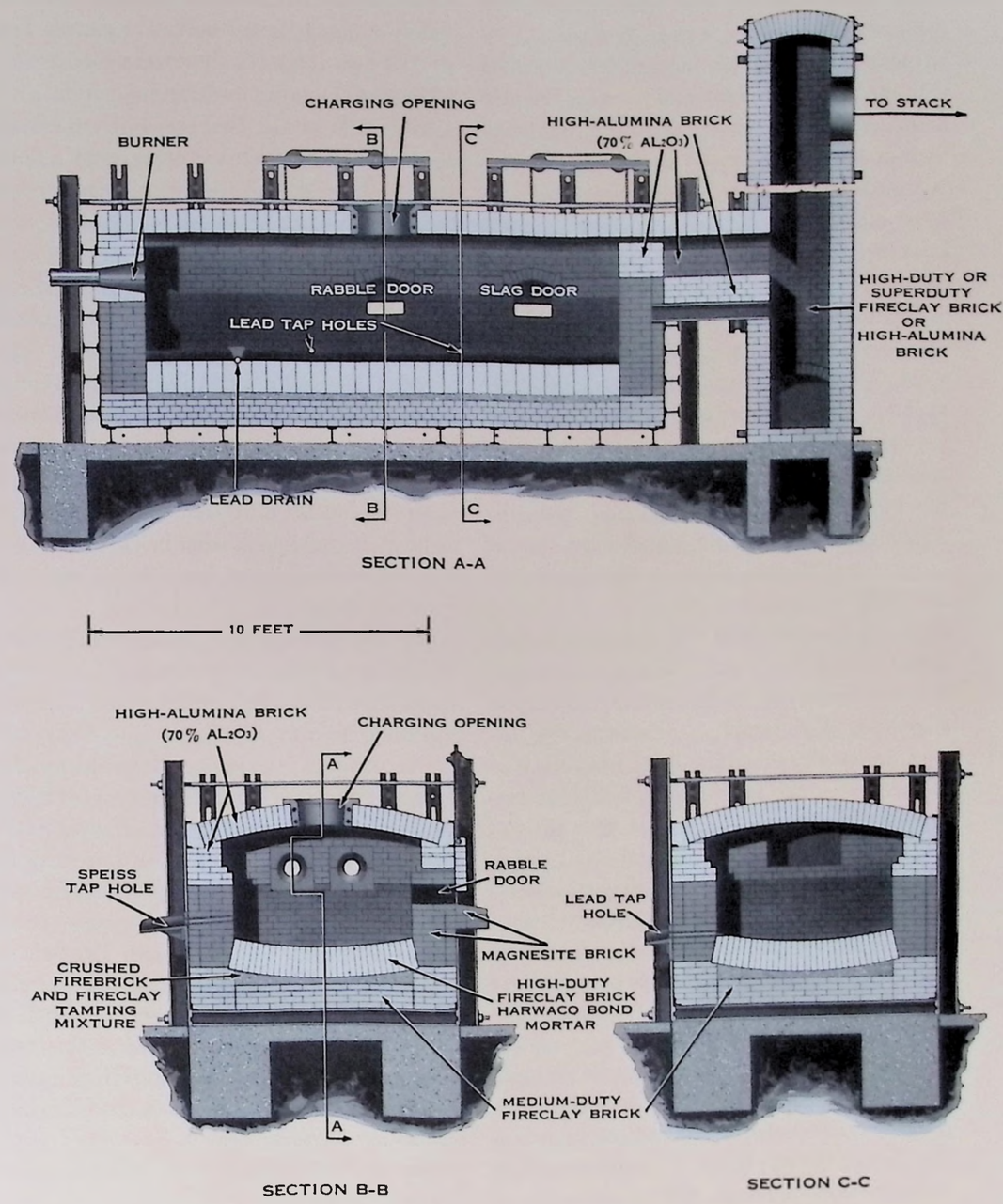
The lead from the drossing kettle contains various impurities including antimony and bismuth which make it hard. Generally, there is enough dissolved silver also to justify its recovery. Removal of the impurities by oxidation precedes desilverization, and is known as "softening." This step is usually carried out in the refinery rather than in the smelter. It is accomplished in a *softening furnace* of the reverberatory type, holding up to 300 tons.

In the Parkes process of refining, the one most commonly used, the softened lead bullion goes directly to a large *desilverizing kettle*, where zinc is added. The zinc combines with silver, forming a rich silver-zinc crust. This is mixed with coal or charcoal and charged into a graphite *retort*. The zinc distills off and a lead bullion high in silver is obtained. This is treated in large *cupels* to drive off the lead and to recover the silver, together with any gold present, in the form of Doré silver. The partly desilverized lead from the kettle is further refined in a reverberatory refining furnace similar to the softening furnace, or in a refining kettle.

Sintering Machines: H-W brands of superduty or high-duty fireclay brick, laid with HARWACO BOND, are recommended for the linings of sintering machine ignition stoves.

Lead Blast Furnaces: The lead blast furnace is one of the units with modest refractory needs but care and judgment are required to obtain optimum performance. Selection of brick for the shaft is based primarily on the toughness and abrasion resistance required to withstand the load conditions. High-duty or medium-duty fireclay brick made by either the extrusion or the power-press method of manufacture are used. WALSH T gives excellent service in this application.

Some furnaces, particularly those with short water jackets, use a band up to about 3 feet high of fired basic brick such as H-W MAGNESITE or CHROMEX B, laid with THERMOLITH, to resist the corrosive conditions above the crucible walls.



Typical Lead Drossing Furnace

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The crucible of the blast furnace must hold the molten metal, and it must resist attack by hot slag and the oxides and sulfides associated with the bullion. It is desirable that the crucible be impervious. For most conditions, linings of high or superduty fireclay brick may be used. WALSH T brick render outstanding service. In some plants, CHROMEX B or H-W MAGNESITE brick laid with THERMOLITH are used to advantage for the top courses or for the entire crucible.

Tapholes and spouts handling lead should be lined with impervious, jointless material of great resistance to erosion. H-W CHROME CASTABLE and PLASTIC THERMOLITH BATCH are good for this purpose.

Deleading Kilns: In the linings of zinc deleading kilns operated in connection with the treatment of lead blast-furnace slag at a number of smelters, WALSH T rotary kiln blocks are used with good results.

Drossing Kettles: High-duty and medium-duty fireclay brick laid with HARWACO BOND are standard materials for lining the combustion chambers. With proper provision in the furnace design to relieve the brick from the load of the kettle, the use of H-W insulating firebrick exposed to direct contact with the hot furnace gases is very economical.

Dross Furnaces: In the reverberatory dross furnace the invert-arch bottom is subjected to physical and chemical attack during the charging and operating cycles. The brick should have considerable strength to resist abrasion and crushing, they should be dense and of low porosity, and they should be accurately made in order to minimize joint thickness. The joints should be completely filled with an impermeable, dense, strong mortar which resists wetting and erosion by the bath. The requirements for the service are competently met by WALSH T fireclay brick and other dense highly impervious brands of high-duty fireclay brick from widely situated Harbison-Walker plants. THERMOLITH and HARWACO BOND mortars are best for laying the brick in this application.

The walls of the furnace a short distance above the invert arch are exposed to a fluctuating bath level, and within this narrow band the corrosive action of the bath is at a maximum. To resist the corrosive action, the use of hard-burned basic brick such as H-W MAGNESITE or CHROMEX B laid with H-W PERIKLASE BONDING MORTAR or THERMOLITH is good practice. To resist excessive spalling action, ALUSITE high-alumina brick are recommended.

The upper sidewalls of the furnace are sometimes built of superduty fireclay brick such as ALAMO S, but for maximum resistance to corrosion ALUSITE high-alumina brick, or CHROMEX B or H-W MAGNESITE basic brick may give improved results.

The roof of the dross furnace is subjected to conditions which, on the whole, are more severe than those affecting the upper sidewalls. Superduty fireclay brick may give acceptable service in some cases, but widespread practice recognizes the need in most instances for a high-alumina brick such as ALUSITE. For extremely corrosive conditions, particularly around the center charging hole, CHROMEX B may be used to resist chemical attack. Under some conditions, CHROMEX B brick laid with THERMOLITH are used advantageously around the charging holes. In some smelters, alternate courses of ALUSITE and CHROMEX B are used in this area.

Scorifying Furnaces: The scorifying furnace is operated in connection with lead drossing furnaces to upgrade matte to be shipped to the copper smelters. CHROMEX B brick laid with THERMOLITH are used for the lining.

Softening Furnaces: The refractories used in the softening furnace are similar to those of the dross furnace. High-duty fireclay brick which are dense and strong are generally used for the invert-arch bottom, which may be 9 to 18 inches thick. Wedge brick are generally used for the construction. WALSH T and other Harbison-Walker brands of dense high-duty fireclay brick give very satisfactory service in this application. ALUSITE 70 per cent alumina brick are used at the metal line in many furnaces, when spalling conditions are severe. The presence of considerable amounts of corrosive oxides strongly commends the use of the basic brick H-W MAGNESITE or CHROMEX B. ALUSITE or CHROMEX B or combinations of the two are particularly suited for use in the roof of softening furnaces.

Retort Furnaces: The rich silver-zinc crust obtained in the desilverizing kettle is charged into a graphite retort, together with a small amount of coal. Heating to a temperature of about 2200°F., distills off the zinc into a condenser. The retort is enclosed in a rectangular furnace usually lined with high-duty fireclay brick or high-alumina brick. WALSH T and ALUSITE are widely used.

Cupels: Lead bullion containing gold and silver is cupeled to separate the lead. To provide low absorption of precious metals, the cupel bottoms may be lined with H-W EXTRA STRENGTH CASTABLE rammed into place to form an impervious lining. However, for maximum service life, the bottom should be made of high-alumina brick, such as ALUSITE. This brand is used also in the walls of the cupel, but for maximum resistance to corrosion in this area H-W MAGNESITE laid with H-W PERIKLASE BONDING MORTAR is preferred. High-duty or superduty fireclay brick are recommended for the arches or tops.

Lead-Recovery or By-Product Furnaces: Secondary lead may be recovered by smelting the scrap material in a blast furnace or in a reverberatory furnace. In the case of the blast furnace, the shaft above the water jacket should be lined with a strong and tough fireclay brick like WALSH T to resist impact and abrasion.

In reverberatory lead-recovery furnaces, conditions are similar to those in the softening furnaces, and the same type of refractory construction is used for corresponding parts of the furnaces. ALUSITE or H-W MAGNESITE give excellent service in the upper sidewall. Because of the extremely corrosive conditions caused by the use of various fluxes, some furnaces are water-cooled at the slag line. ALUSITE, a 70 per cent alumina brick, renders good service in the roofs.

Lead Oxide Furnaces: Dense high-duty fireclay brick satisfactorily serve as lining materials in furnaces used for the production of the lead oxides known as red lead and litharge. WALSH XX, WALSH T, and other Harbison-Walker brands of high-duty fireclay brick perform very satisfactorily in this application.

Lead oxides for some applications are manufactured in furnaces operating at temperatures above the melting points of the oxides. Brick such as H-W PERIKLASE and H-W MAGNESITE in the hearths, sidewalls, and arches of such furnaces have proved to be the most satisfactory of all refractories for this service, not only because of their greater resistance to attack by molten lead oxide, but also because the use of these brick prevents contamination by impurities from the refractory materials.

Monolithic Refractories for Lead Furnaces: Among the many kinds of Harbison-Walker monolith-forming refractories, H-W EXTRA STRENGTH CASTABLE and H-W CHROMEPAK are particularly suited for use in certain parts of the different lead-reduction and refining furnaces.

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LIME KILNS — VERTICAL

There are great variations in the size and design of the vertical shaft kilns which are used so extensively for the production of agricultural, chemical, and building lime. Small kilns may have a diameter of only 3 to 5 feet and a height of 10 to 15 feet; large kilns may be over 25 feet in diameter and 80 feet or more in height.

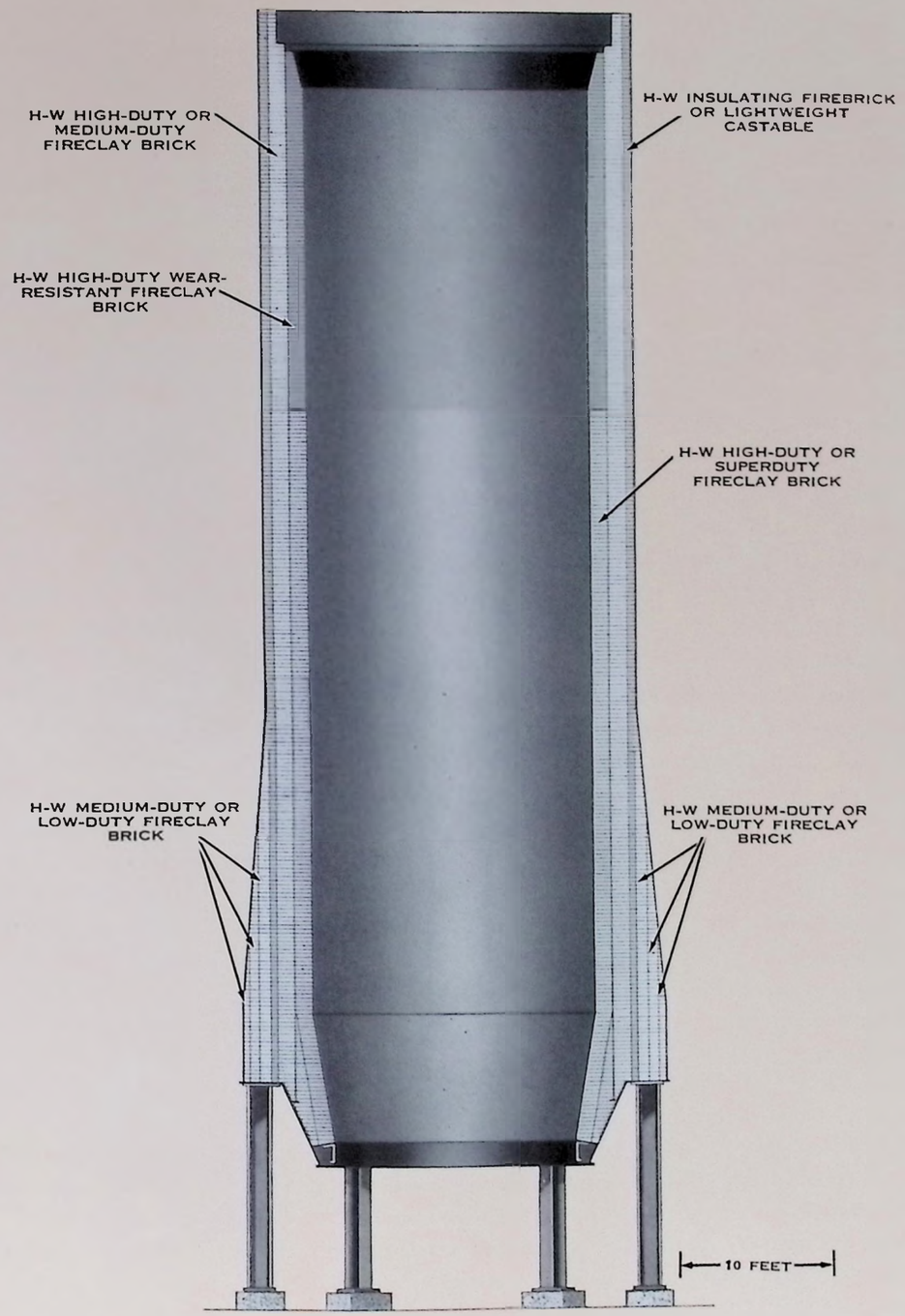
The raw limestone or dolomite is charged at the top of the kilns in the form of lumps several inches in diameter. In descending, it passes successively through preheating, calcining, and cooling zones. The fuel may be coke, gas, oil, or coal. When coke is used, it is charged with the stone; this is the mixed-feed method of charging. Gas is usually center fired by means of a multi-port duct called the center burner, located in the lower zone of the shaft. Coal and fuel oil, which are less commonly used than coke or gas, are generally burned in an external firebox or Dutch oven. The life of the lining is affected by such variables as the size of the stone, its cleanness and hardness, the uniformity of distribution of the charge, the kind of the fuel, the draft, and the operating temperature.

The different types of shaft kilns have different operating characteristics, and specific refractories provide for the several sets of conditions. However, some operating conditions are common to all types of shaft kilns. The top section of the kiln is subjected to the impact and abrasive action of the raw stone as it enters the kiln and descends into the shaft. Fireclay brick which are dense, strong, and highly resistant to abrasion and impact are used for this part of the lining. Among the brands which give outstanding service are Duro, Wylam A, Benezet, Walsh T, and similar Harbison-Walker brands of high-duty fireclay brick.

Brick used in the hotter parts of kilns show greater diversification in types and classes than those in the top zone. Kilns that operate on natural draft have limited production rates, and temperature and corrosive conditions are relatively moderate. The calcining zones of most such kilns are lined predominantly with high-duty fireclay brick like Benezet BF and H-W Mo BF. For some kilns in which the temperature of reaction between lime and silica is not reached, Star Dash silica brick are favored because of their enhanced spalling resistance, their great load-bearing capacity, resistance to abrasion, and dimensional stability. Conditions in the burning zones of some natural draft kilns are of such severity that hard-fired superduty fireclay brick such as Varnon and Kenmore are used more economically.

Careful installation of the refractory brick lining can contribute significantly to successful operation of shaft kilns. Combinations of special keys often provide a convenient means of installing a tightly fitting lining. With an all-key lining each brick is securely locked in, and any possibilities of dislodging brick by the furnace burden is largely avoided. Brick combinations for all-key linings of various thicknesses for a wide range of diameters are given on page 503. The X-1 and X-2 keys illustrated are regularly supplied in several brands of high-duty and superduty fireclay qualities.

Shaft kilns operated with forced draft are high-production units and a large amount of heat commensurate with the tonnage calcined is necessary. The temperature and corrosive conditions in such shaft kilns are more demanding on refractories than in other kilns. Not only is the temperature throughout the calcining



Typical Mixed-Feed Shaft Lime Kiln

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zone much higher than in natural draft kilns, but channeling of the flame through restricted passageways in the body of the charge and between the charge and the lining can cause a blow-torch effect with extremely high localized temperatures. Very high temperatures intensify corrosive conditions upon the refractories. Through many years, ALUSITE, a high-alumina brick of the 70 per cent alumina class, has been widely preferred for use in the hot zones of high-production kilns. The extreme refractoriness and good resistance to mechanical wear at high temperatures adapts ALUSITE for this severe service. The 90 per cent alumina brick KORUNDAL are used advantageously for extreme conditions which brick of lower alumina content cannot withstand. In some kilns which operate at very high production rates or in which high-temperature channeling occurs, it is sometimes necessary to use basic brick. These are extremely refractory and chemically compatible with lime. These properties preserve the lining and prevent contamination of lime for high-purity uses. THERMAG H, FORSTERITE, and other Harbison-Walker basic refractories fulfill this need most satisfactorily.

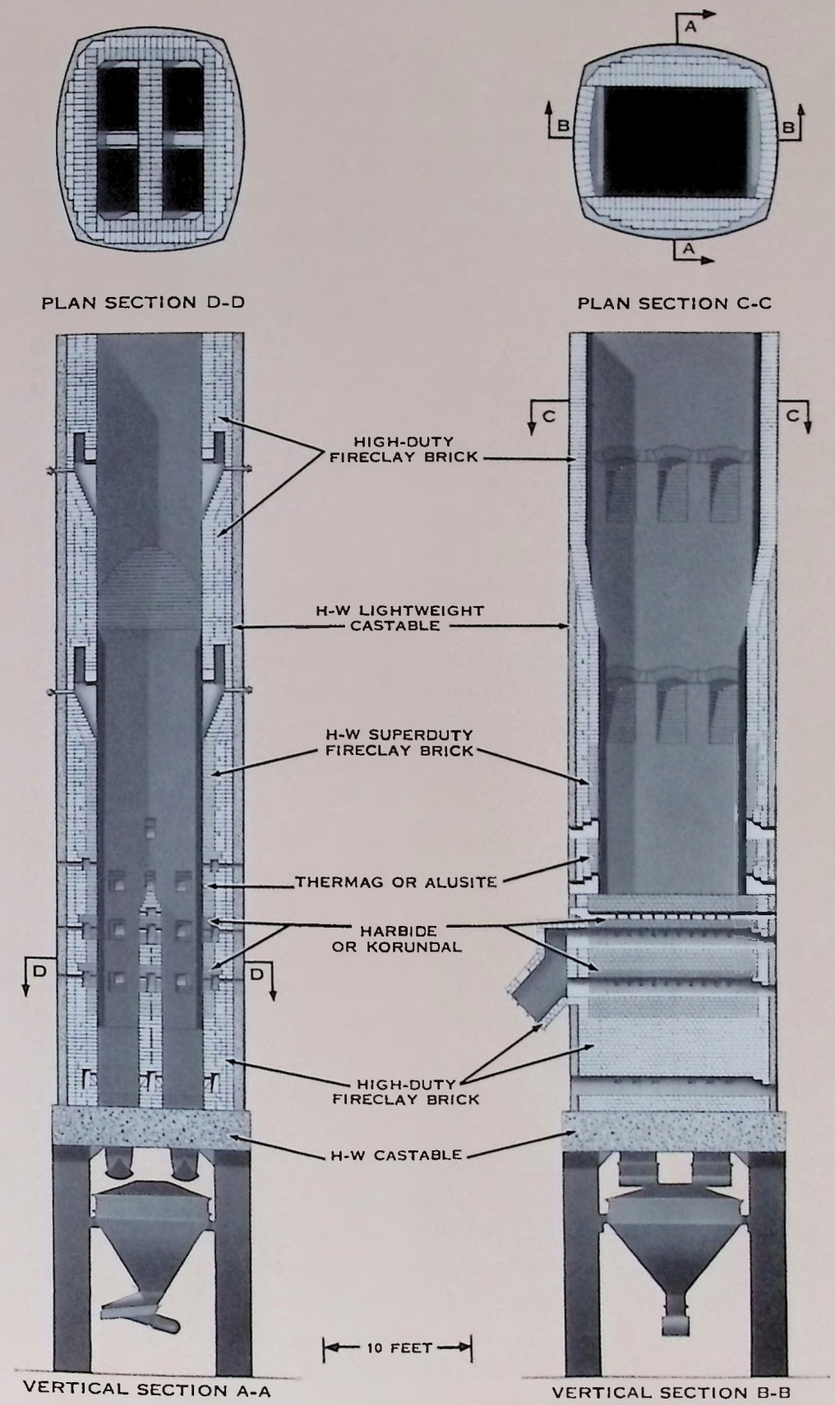
Below the hot zone is the cooling zone. In kilns designed either for mixed feed or for center firing, the combustion air enters at or near the bottom of the kiln, rises through the downcoming charge, and quickly cools the descending lime. The main requirement for the brick lining in the lower part of the cooling zone is that it be resistant to abrasion. DURO and WYLAM A are frequently used for this application. In shaft kilns with external burners, the combustion air enters largely through the burner, and does not cool the descending column of lime appreciably. Hence, the brick for lining the part of the shaft kiln below the calcining zone must be adequately refractory and resistant to abrasion. In addition, they must have good spalling resistance to withstand the temperature fluctuations during the drawing of the lime. Harbison-Walker high-duty fireclay brick are used in this part of the kiln lining.

Center burner walls may be high-duty fireclay brick such as WOODLAND, or if the conditions warrant, superduty fireclay brick such as VARNON. The cap of the burner which takes the full brunt of the descending load of lime may properly be made of KORUNDAL which is capable of withstanding the high temperature and heavy loading at this point. When the span between the walls of the burner duct is considerable, HARBIDE silicon carbide refractory and KORUNDAL XD 90 per cent alumina brick both possessing great physical strength and high spalling resistance are used in the superstructure.

Kilns with external fireboxes have specific refractory requirements. The fireboxes, or "Dutch ovens," may be lined with superduty or high-duty fireclay brick. STAR silica is sometimes used in the construction of the arches over the eyes forming the entrance to the kiln, and its use is frequently extended for short distances up into shaft linings.

Important savings in fuel result from the insulation of shaft lime kilns. This is accomplished by placing suitable insulating material between the refractory lining and the steel shell. Insulating firebrick such as H-W 20 or insulating castable materials including H-W LIGHTWEIGHT CASTABLE—EXTRA STRENGTH are often used for this purpose.

Throughout all types of kilns, HARWACO BOND is used with excellent results for laying fireclay and high-alumina brick. KORUNDAL BONDING MORTAR may be used for laying KORUNDAL brick, FIREBOND for silica brick, and H-W PERIKLASE and H-W FORSTERITE BONDING MORTARS for basic brick.



Azbe Center-Fired Lime Kiln

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MALLEABLE IRON AIR FURNACES

The melting and refining of malleable iron are accomplished in furnaces of the reverberatory type, usually having removable roof sections called "bungs." The furnace is commonly referred to as a "malleable" or "air" furnace. The fuel is generally pulverized coal or oil. In the direct-melting process, the charge consists of cold metal; in the duplex process, it consists of molten iron from a cupola.

Brick used in the bungs must be adequately refractory to withstand the high temperatures of melting. They must have sufficient mechanical strength to sustain the pressure to which they are subjected in the bung frames, and to withstand occasional rough handling without damage. In addition, they must not shrink at high temperatures and they must be of suitable texture and composition to resist the spalling effects of severe thermal shock caused by rapid melting schedules, or by the removal of the bungs for charging the furnace while hot. The widely used superduty fireclay ALAMO, BOONE, and H-W SUPER SAVAGE brick satisfactorily meet these requirements.

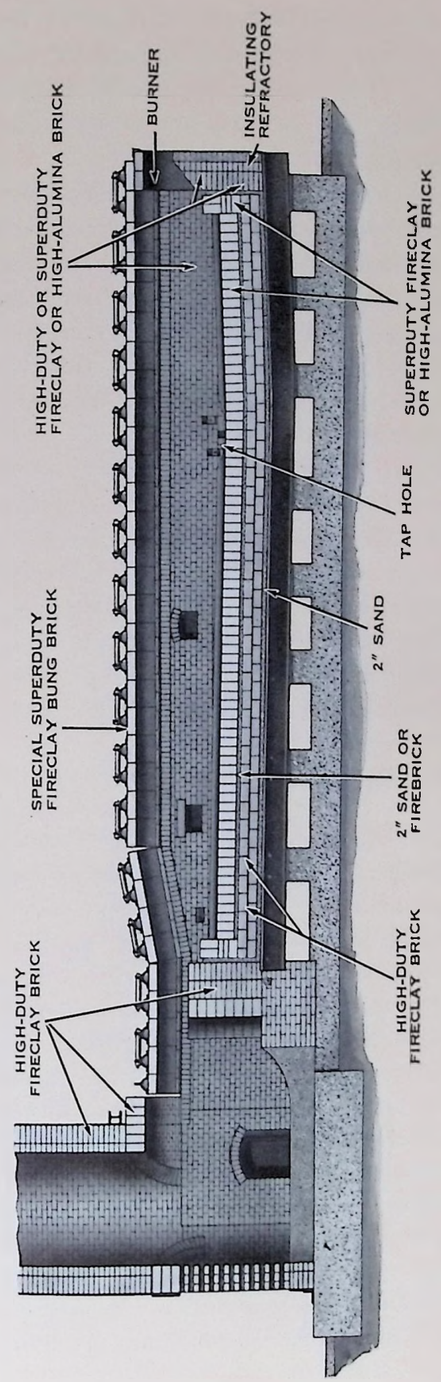
For service in the sidewalls above the slag line, the brick must be highly refractory, and have high resistance to spalling and to corrosion by fuel ash and molten slag. Among the Harbison-Walker brands used for this service are the high-duty fireclay brick WALSH S, H-W HIGH GRADE S, and H-W SAVAGE T. These brick are manufactured by the power-press or extrusion processes, with special attention to uniformity of burn. Where operating conditions are especially severe, the superduty fireclay brick ALAMO S, BOONE, and H-W SUPER SAVAGE are used with excellent results.

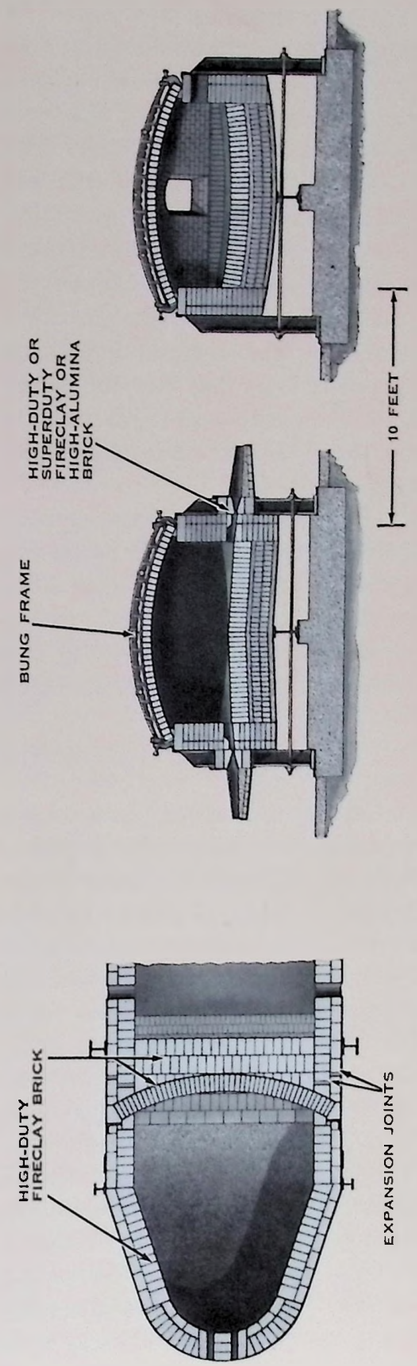
At and below the slag line, the sidewall brick must resist the erosive action of molten metal, and the corrosive effect of slag high in iron oxide and containing some alkaline compounds. In general, the same brands of brick are used as those employed above the slag line. In some cases, the use of ALUSITE high-alumina brick of the 70 per cent alumina class, CORALITE of the 80 per cent alumina class, or H-W MULLITE brick is economical for this vulnerable location.

Sidewalls generally consist of a permanent wall 4½ inches thick, built of high-duty fireclay brick, with a replaceable inner wall 9 inches thick, of header construction. The burner end wall is sometimes backed up with brick such as H-W 16-20 or H-W 20 insulating firebrick. For best results, sidewall brick may be laid with dipped joints using a thin slurry of ANKORITE 65 bonding mortar.

Taphole blocks should be set in such manner that they may be easily replaced. This is accomplished by setting them in a replaceable false wall 9 inches thick outside the sidewall, with a suitable opening through the sidewall. High-duty fireclay brick such as WOODLAND, WALSH, H-W HIGH GRADE XX, and H-W SAVAGE are generally used for taphole blocks. For severe conditions it frequently is economical to use the superduty fireclay brick VARNON or KENMORE, or the high-alumina brands ALCOR, CORALITE XD, or KORUNDAL XD.

In the malleable furnace, sand bottoms have largely given way to brick bottoms, most of which are ventilated. With this ventilated construction, the entire furnace rests upon a steel pan, beneath which air can circulate. The working bottom may be built of ALAMO S, BOONE, VARNON, or KENMORE superduty fireclay brick, or of ANCHOR DASH, ALUSITE, or CORALITE high-alumina brick, depending upon service conditions. In the installation of the working





Typical Malleable Iron Air Furnace

HARBISON-WALKER REFRACTORIES COMPANY

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bottom, the brick are laid in ring courses as tightly as possible, usually in the form of an inverted arch skewed against the sidewalls. In some cases, the bottom is crowned, and occasionally it is skewed beneath the walls. Brick for this service must be uniform in width and free from warpage to attain the thinnest possible joints between rings. The brick may be laid with very thin dipped joints of high-temperature mortar, such as CORALITE BONDING MORTAR, KORUNDAL BONDING MORTAR, or ANKORITE 65 bonding mortar; or they may be laid dry and grouted thoroughly with a thin slurry of the mortar. (For details of bottom construction, see drawing on page 417.)

The breeching and stack are generally built of high-duty fireclay brick and may be laid with the high-temperature mortar HARWACO BOND.

Some malleable iron is produced by melting the metal in cupolas, and superheating it in electric furnaces. For this service, the cupola is lined with dense high-duty or superduty fireclay brick of hard burn. The roof and sidewalls of the electric furnaces are usually built of silica brick. The bottoms are of monolithic construction, for which a mixture of H-W GROUND QUARTZITE and H-W WEATHERED BOND B CLAY is recommended.

Harbison-Walker products have successfully served the malleable iron industry for many years. The wide distribution of the company's manufacturing facilities permits Harbison-Walker to serve malleable plants economically, regardless of their location.

Adequate stocks are maintained of the standard sizes required for the various sections of the malleable furnace, as well as of the commonly used shapes for door tile, taphole blocks, and others. The company also supplies high-duty and superduty fireclay brick, as well as insulating firebrick of various classes, for use in continuous and periodic annealing furnaces.

MISCELLANEOUS USES OF REFRACTORIES

MODERN REFRACTORY PRACTICE necessarily is so broad in scope in relation to its number of pages that some applications of major importance are reviewed but briefly. Many industrial processes of first rank require the most specialized refractories of highest qualities even though not in large quantities. The kinds needed for the widely different furnace constructions and operating conditions comprise virtually the entire range of long-established and many newer specialized refractory products.

Acids: Sulfuric acid, a fundamental need in the manufacture of many chemicals, is the acid which is most extensively employed industrially. Sources of sulfur dioxide used in its manufacture include the burning of elemental sulfur, the roasting and smelting of sulfide ores, and the burning of pyrite and hydrogen sulfide. High-duty and superduty fireclay brick fulfill the requirements of multiple-hearth roasters and rotary kilns used for reducing the sulfur content of ores by roasting. KORUNDAL brand is generally preferred for the linings of hydrogen sulfide and high-temperature sulfur burners.

Acid towers, including those for the chamber and contact sulfuric acid processes, and hydrochloric acid absorbing towers, as well as many other types, are lined with dense impervious and chemical-resistant brick such as DURO and W-ACID. These brick provide highly durable linings and packing tile—including rings, rectangular tile, and grid shapes—of designs especially adapted for the conditions involved in different processes.

For the high-temperature requirements of concentrators, ALAMO and ANCHOR brick render long service.

With the economical availability of hydrogen and chlorine for burning to hydrochloric acid, VARNON extra hard-fired superduty fireclay brick give long life in the furnace linings.

Artificial Abrasives, including fused alumina and the carbides of silicon and boron, are produced from base materials such as refined alumina, borax, coke, silica sand, and others, some of which have been prepared by various high-temperature processes requiring the use of refractories. Conversion of the base materials into the desired crystalline forms is accomplished at exceedingly high temperatures in electric furnaces.

The products of the electric furnaces may be reduced to the form of grains, mixed with suitable bonding agents, and formed under pressure into various shapes suitable for cutting and grinding. Shapes which depend upon a ceramic bond for their strength are fired in periodic or continuous kilns. All the different kinds of refractories particularly suited for building these kilns are available in Harbison-Walker products.

Calcium Carbide, a basic industrial product of major importance, is used for making acetylene gas upon which is based the production of many compounds of organic synthesis. It is produced in high-temperature submerged-arc electric furnaces lined with fireclay brick. As the charge of coke and limestone becomes fused, a monolithic protective coating forms on the surface of the lining. H-W MAGNESITE, H-W PERIKLASE, and KORUNDAL brick shapes are used to best advantage in the walls adjacent to the tapholes. The granular refractory materials H-W MAGNAMIX and H-W C-MIX are used for maintenance.

Carbon Black is produced from natural gas and oil in reaction furnaces of special designs. In natural gas reactors, carbon is precipitated mainly from methane gas, and Harbison-Walker high-duty fireclay and superduty fireclay brick, STAR silica brick, H-W MULLITE and other high-alumina brands most satisfactorily fulfill the refractory needs. In oil furnace reactors, carbon is precipitated at very high temperatures. Brands which are used with good success are H-W CORUNDUM, KORUNDAL XD, and in some positions H-W HIGH-ALUMINA CASTABLE.

Coal Chemical Industry, with its myriad of organic products in its first step of distillation of volatiles, most efficiently employs massive refractory oven constructions of complex designs, as described on page 366.

Enameled Ware is made by coating metal products with pulverized "frit," followed by heating in a furnace to a temperature at which the frit fuses and forms a glaze which adheres permanently to the metal. The furnaces generally are of a semi-muffle type built with silicon carbide floors and muffles, supported by piers of silica brick, extra hard-fired superduty fireclay brick, or high-alumina brick having high strength in soaking heats. STAR silica, VARNON and KORUNDAL 90 per cent alumina brick are used with good results. High-duty and superduty fireclay brick, often insulated, serve well for walls and arches.

Frit Furnaces, used for the production of "frit" for glazes and enamels, are lined with high-duty or superduty dense fireclay brick and in some cases with high-alumina brick. Many frits are highly corrosive to refractories. To resist corrosion the refractories in contact with the frits should have low porosity and low permeability. VARNON S superduty and BENEZET OHC high-duty fireclay brick typically among corresponding H-W brands serve well for this purpose.

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Gas Manufacture: Manufactured gases most widely used comprise water gas, coal gas, producer gas, oil gas, and coke-oven gas from the chemical-recovery coke ovens.

Water Gas: The refractory linings of water gas generators are subjected to the corrosive and abrasive action of ash and slag and to severe mechanical treatment. The refractories in the carburetors and superheaters are required to withstand the action of reducing gases, thermal shock, and corrosion. H-W brands of fireclay and high-alumina brick fulfill all the requirements.

Coal Gas: For coal gas manufacture, retort shapes of STAR silica are supplied which have the properties required.

Producer Gas: In the production of producer gas from bituminous coal, Harbison-Walker high-duty and superduty brands of fireclay brick from various plants serve most satisfactorily for protection of the shell.

Oil Gas: High-duty and superduty fireclay brick brands of specific properties made by Harbison-Walker give excellent service in linings of regenerators and checker chambers used in making oil gas. Superduty brands are commonly preferred for checkers in the top courses with high-duty brick in the lower zones.

Reforming Natural Gas: The refractory linings of various designs of furnaces most successfully used for cracking natural gas consist of H-W high-duty and superduty fireclay brick.

The Phosphorus Industry has progressed from the drying and calcining of phosphate rock, and the manufacture of phosphoric acid by the sulfuric acid method, to the large-scale production of elemental phosphorus in electric furnaces and blast furnaces, and also to the production of superphosphates. Refractories which meet the requirements of the furnaces used include Harbison-Walker superduty fireclay brick, high-alumina brick, acid-proof brick, and brick of other types for special needs. H-W HARCAST having unusually high strength and resistance to carbon monoxide disintegration, among refractory castables is especially suited for the upper sidewalls and arches of electric furnaces producing elemental phosphorus.

Salt Bath Furnaces perform the function of hardening steel in a controlled atmosphere by immersion in molten salts. VARNON BF brand laid with HARWACO BOND gives long service in contact with chloride salts. Carbonates and cyanides, which are highly basic salts, are sometimes melted in furnaces lined with basic brick.

Titania is used extensively as a durable white pigment, and is important for production of titanium metal through the chloride process.

Rotary kilns used for calcining the refined titania are lined with VARNON and DURO brick from which splendid service is secured.

Vacuum Processing of Steel: The quality of steel is significantly improved when the metal is melted, poured, or treated in a vacuum. Vacuum degassing is generally applied to the melting equipment and the pouring systems or both, although it is sometimes used only in subsequent treating furnaces. In the latter case, the equipment is usually a gas-fired muffle-type or an electric-resistance-type furnace.

The hot metal is either poured directly into ingot molds under vacuum or is treated separately in the ladle under vacuum and poured into ingot molds at atmospheric pressure. The refractory accessories attendant to pouring in a vacuum are made of high-alumina, basic, and sometimes fireclay compositions. The vessels in which metal is degassed are lined with high-alumina, basic brick, and various special refractories. Harbison-Walker supplies the specific refractories for each of these applications.

NICKEL

THE great contribution of nickel to industry, primarily for the production of many indispensable alloys, continues to increase in importance to world economy. The furnaces and refractories employed in the usual metallurgy of nickel in many phases correspond closely to those used in copper smelting and refining.

Nickel ore concentrates are charged into multiple-hearth or fluid-bed roasters in which part of the sulfur is removed. Harbison-Walker brands of high-duty fireclay brick and castables, which most satisfactorily fulfill the requirements for lining these roasters, are described on pages 387 and 443.

Hot concentrates from the roasters are introduced directly into the nickel reverberatory furnaces for smelting. In size and design these furnaces are similar to copper-matte-smelting reverberatory furnaces. The walls and suspended roofs are built of basic refractories. Metal-encased magnesite-chrome brick serve the purpose with splendid results.

The molten matte from the reverberatory furnace is introduced into Peirce-Smith-type converters and blown to Bessemer matte. The converters are lined with hard-burned magnesite or chrome-magnesite brick. Construction details and refractory maintenance are closely similar to those of copper converting practice, as described on page 370.

To a lesser degree, raw nickel sulfide concentrates are smelted in blast furnaces. These generally are rectangular water-jacketed furnaces, the crucibles of which are lined with hard-burned magnesite brick and the upper walls with dense, tough high-duty fireclay brick such as WALSH T. Coke is used as the fuel. The matte and slag flow into rectangular settlers which are lined with hard-burned chrome or magnesite brick. After gravity separation, the matte is tapped for charging into the converters.

Reverberatory-type nickel anode furnaces of about 200 tons capacity are usually built with superduty fireclay brick invert-arch bottoms, 80 per cent alumina brick in the lower sidewalls, and 60 per cent alumina brick in the upper walls. Silica brick are used in the roofs.

Electric furnaces used for refining nickel and for the production of alloys usually are lined with hard-burned magnesite brick in the sub-bottoms and lower sidewalls. The monolithic working bottom is made and maintained with H-W MAGNAMIX or H-W C-MIX. High-alumina brick of the 60 per cent and 70 per cent alumina classes are used economically in the upper sidewalls. Superduty fireclay brick generally have been adequate for the roofs.

As optimum circumstances govern, electric nickel-matte smelting is economically practiced. This is accomplished in rectangular arc furnaces which may be built with invert-arch bottoms and lower sidewalls of hard-fired magnesite brick. Alumina-silica refractories are used in the upper sidewalls and roofs. High-duty and superduty fireclay brick are considered adequate for the roof and walls above the slag line.

The extraction of nickel by hydrometallurgical and other nonpyrometallurgical processes requires the use of refractories for drying and sintering equipment and for steam power generation. For the utilization of sulfur dioxide from the smelter gases, sulfuric acid is produced. Acid-proof brick are used for lining vessels and other equipment employed in the manufacture and storage of the sulfuric acid.

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NONFERROUS METALS

THE smelting, refining, and electrolytic reduction processes in nonferrous metallurgy involve widely different furnaces, refractories, and other equipment. Through sustained research and coordinated technical service, Harbison-Walker has supplied the refractories required for the diverse particular needs. Some of these refractories are produced primarily to provide for improvements in long-established processes, and others for entirely new metallurgical developments.

Nonferrous metals which are produced and used in largest tonnages are discussed in relation to furnaces and refractories in other sections of this chapter.

In recent years, many special metals of the nonferrous group which heretofore have had only minor consideration have been growing rapidly in importance. Their established and potential uses differ widely. To cite a few examples, boron and beryllium metals as well as their hydrides are excellent propellent fuels; calcium, sodium, and magnesium serve well for the reduction of other metals from chlorides or carbides. Included among the many metals of great importance for their present and future needs for new alloys and numerous other purposes are chromium, cobalt, columbium, zirconium, and uranium. The refractories used in the metallurgy of these metals are available from the complete range of Harbison-Walker products.

Antimony: Antimony is obtained as a by-product in smelting ores of copper and lead, and also by smelting the ores of antimony. By-product antimony is collected as baghouse dust consisting largely of the oxide.

Antimony ore may be smelted directly in a blast furnace to produce antimony oxide and metallic antimony, but preferred procedure consists in first oxidizing the antimony sulfide of the ore, and then reducing the oxide. The oxidation is carried out in blast furnaces or rotary kilns. The blast furnace is similar to that used for the smelting of lead ore. Generally, it has a few courses of fireclay brick such as WALSH T installed above the water jacket. WALSH T high-duty fireclay brick linings in rotary kilns used for oxidation of antimony ore give long service.

Bismuth: Bismuth occurs in many copper and lead ores and generally is obtained by the reduction of residues from the smelting of these metals. It is recovered from copper ores as a flue dust which generally is treated at lead-smelting plants. It is separated from lead either during the electrolytic reduction or by removal as an alloy with metallic calcium or magnesium. The refractories required are similar to those used in lead smelting. Fireclay brick having the highest degree of immunity to disintegration by carbon deposition from carbon monoxide gas give longest service.

Cadmium: Cadmium is recovered from zinc ores and to some extent from copper and lead ores by roasting at sufficiently high temperatures to drive off most of the metal in the form of a fume. The dusts are processed and enriched and finally given a purification treatment in retorts. The refractories used, mainly high-duty and superduty fireclay brick, correspond closely to those employed in various steps of zinc metallurgy. In the process of refinement of zinc for the maximum degree of purity, cadmium is distilled off, condensed, and collected in a baghouse.

Magnesium: Magnesium metal is commercially produced by electrolysis of fused magnesium chloride or by thermal decomposition of calcined dolomite with silicon metal contained in ferrosilicon. The production of dry magnesium chloride may be accomplished by the chlorination of magnesium oxide in the presence of carbon. DURO brick, used to withstand the chlorination and abrasive action of the charge and to line the electrolytic cells, give long satisfactory service. The magnesium chloride may also be prepared from magnesium hydroxide treated with hydrochloric acid. In this case, however, the resultant magnesium chloride is simply dried by evaporation. Cells lined with dense fireclay brick are used for the electrolytic deposition of magnesium from the molten chloride. The excellent workmanship of DURO and VARNON and their resistance to corrosive chemical conditions which prevail, account for their excellent performance in this application.

In electrolytic cells of some designs, dense high-alumina refractories having low permeability are used in upper walls because they best withstand the severe corrosive action. KORUNDAL and MONOFRAX brands most economically fulfill this requirement. H-W brands of high-duty fireclay brick render long service in the covers.

Metal Chlorides: Various metals are converted to chlorides, generally from the oxides, as an initial step in their reduction. This is accomplished in an atmosphere of chlorine and carbon monoxide at the temperature of reaction of about 1800°F. for several of the chlorides. VARNON BF superduty fireclay brick are highly resistant to disintegration by carbon deposition and to the chemical action of chlorine. They are used with good results for lining furnaces producing titanium tetrachloride. HARWACO BOND air-set mortar is used for laying the VARNON BF brick in many instances.

Titanium tetrachloride as well as some other metal chlorides are reduced to metallic powder or sponge usually with magnesium metal in an atmosphere of helium, enclosed in a heated vessel.

Sodium is reduced from the chloride by electrolysis. DURO and exceedingly dense H-W high-duty fireclay brick brands laid with HARWACO BOND render long lining service in the cells. Unusually good workmanship and size tolerance are paramount because joints are more vulnerable than the brick at the relatively low temperature of operation.

Tin: Tin may be smelted in blast furnaces but regenerative reverberatory furnaces now are largely favored. The blast furnaces may be lined with high-duty and superduty fireclay brick. Metallic tin alone does not exert severe corrosive action on refractories and fireclay brick serve best for the reverberatory furnace construction. VARNON superduty fireclay brick and dense blast-furnace brick of hardest burn give long life in the bottoms. Workmanship of the highest quality is necessary to secure the tightest possible joints. SALAMANDER and similar H-W medium-duty brands are used in the sub-bottoms. The roofs of the reverberatory furnaces often are built of ALAMO or VARNON superduty fireclay brick, which also serve well in sidewalls with H-W high-duty fireclay brick which are sometimes used in the upper part of the walls.

CHROMEX B hard-burned chrome-magnesite brick give excellent service in furnaces used in the retreatment of slag rich enough in tin to warrant its recovery. Furnaces of various types in which tin is recovered from tin-plated steel, in many cases are built with ALAMO superduty fireclay brick laid with HARWACO BOND mortar.

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OPEN-HEARTH FURNACES

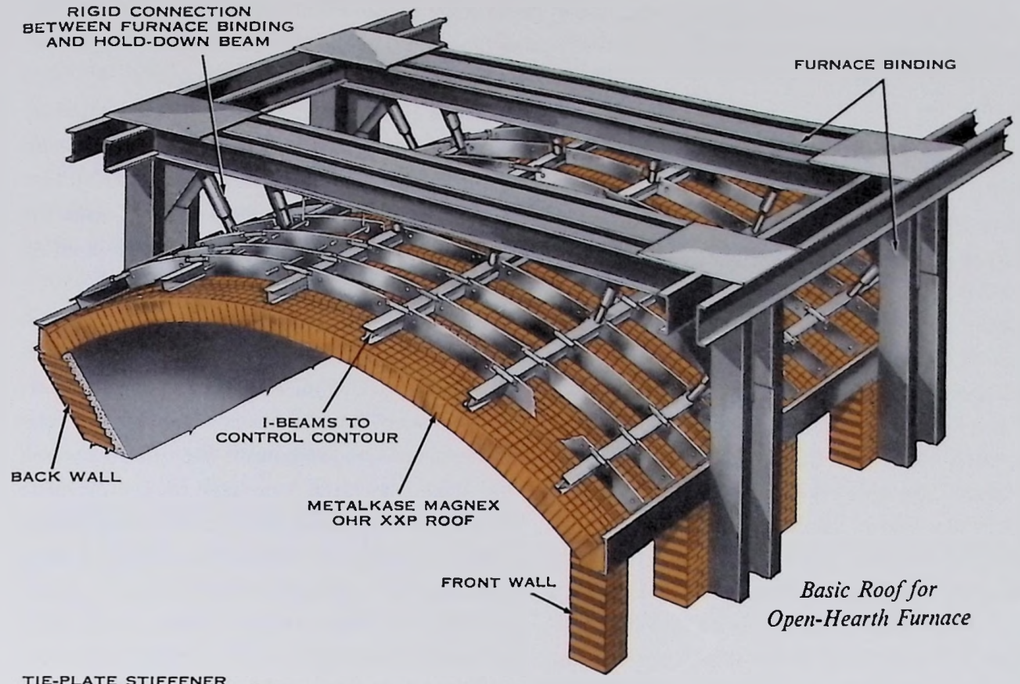
BASIC OPEN HEARTH

In few types of industrial furnaces are the refractories requirements so varied and so specialized as in the different parts of the basic open-hearth furnace. The roof brick must withstand the corrosive action of basic dust and fumes at exceedingly high furnace temperatures and must have sufficient strength to sustain the arch stresses. The injection of oxygen through lances in the furnace roof has increased the severity of operating conditions and has added the additional factors of localized areas of higher temperatures and of slag impingement on the under surface of the roof. The front and back walls are exposed to high temperatures, the cutting action of flame, erosion from solids entrained in the gas currents, corrosion by volatile oxides, the splashing of slag, and the washing of metal. The hearth material must be highly refractory and resistant to the scouring action of the bath, and to corrosion by slag. End walls and bulkheads are subjected to the erosive action of solid particles carried by the rapidly moving gases and to chemical attack by the solids which adhere to the end wall after impingement. The regenerator checkers are required to absorb and give off heat quickly, to serve for extended campaigns without clogging, fluxing, or spalling, and to resist reaction with the carry-over of dust in the outgoing gases so that the flow of gases is not restricted by an accumulation of solids at the top of the checker setting. Although furnaces which are operated with oxygen to accelerate the production of steel have less requirement for checker capacity, the regenerators are still of great importance to the proper operation of the furnaces.

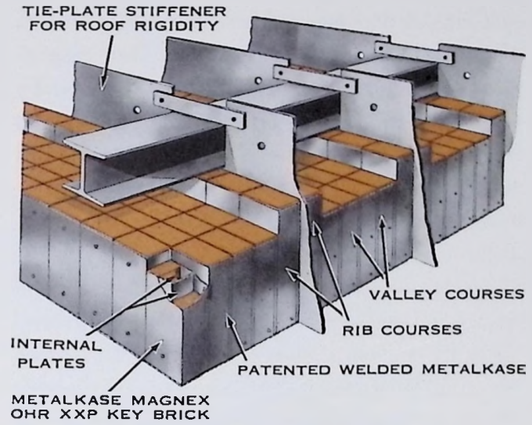
Roofs: Traditionally, open-hearth furnace roofs have consisted of silica brick sprung arches of the ribbed ring type similar to that illustrated on page 248 or of bonded construction such as that shown on page 247. The properties which have always made Harbison-Walker's STAR and VEGA brands of silica refractories so valuable for open-hearth roofs are high refractoriness, low porosity with excellent resistance to the fluxing action of basic dust and fumes, very high mechanical strength and rigidity at temperatures almost up to their melting point, constancy of volume above a red heat, freedom from thermal spalling within the high-temperature range, relative lightness of weight contributing to low arch stresses, and uniform excellence of workmanship. These properties are developed to the maximum commercial degree, and maintained by rigid laboratory control of quality at every stage of manufacture.

For many years, STAR silica brick, of conventional quality, were the standard of excellence for open-hearth roofs. As furnace operating temperatures became higher, there was increasing use of VEGA, the original superduty silica brick, which established many performance records in open-hearth shops throughout the United States. Even with oxygen lancing, VEGA brick continue to give good service in some plants, in roofs of higher rise placed at a somewhat higher level above the bath.

Harbison-Walker has continued to pioneer in the production of highly improved silica open-hearth roof brick. The most recent development receiving recognition is that of the brand modification known as VEGA HP, which has not only high refractoriness but also remarkable resistance to spalling for a silica refractory, at all furnace temperatures.



Basic Roof for Open-Hearth Furnace



Enlarged Detail of Basic Roof Construction Showing Rib and Valley Courses

With the development of the oxygen lance to accelerate the rate of production in the open-hearth furnace, basic refractories have become widely used for the roof. The brick used have been developed specifically for this purpose, and the design features necessary to make the sprung arch stable, when built of the heavier basic brick, have been determined. The combined use of basic refractories in the roof and oxygen injections through lances has led to substantial increases of production capacities in existing furnaces.

The modifications of the basic open-hearth furnace roofs, which accomplish structural stability and durability of the refractories, include the following:

The use of 2¼ to 3 inches of rise per foot of span instead of the conventional 1½-inch rise of silica brick roofs;

The use of steel tie plates such as those which have become standard in basic bulkheads and walls;

Contour control of the arch, of sufficient rigidity to prevent buckling of any portion;

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The use of special brick with properties which prevent continual growth of the hot face of the roof;

Provision for thermal expansion which places the line of thrust in the cold portion of the arch.

Harbison-Walker first produced the refractory best adapted to service in basic roofs of the newer design in the brand now known as METALKASE MAGNEX OHR XXP. This brick proved to be outstanding in all of the early installations of this type. METALKASE MAGNEX OHR XXP consists of chemically-bonded magnesite-chrome refractory for greatest resistance to penetration and reaction by iron oxide, and to possible effects from other conditions of furnace atmosphere. Some roof shapes are internally plated for maximum resistance to spalling, whereas other sizes are sufficiently resistant without internal plates. The high stability of volume of this brick and its resistance to change under open-hearth service conditions made it an immediate success in roof service. Sustained Harbison-Walker research and development provide additional roof refractories for even more severe furnace conditions. These various brands are described on pages 104 to 110.

Harbison-Walker's spinel-bonded magnesite and burned magnesite-chrome refractories also possess superior properties for open-hearth roof service. Brick of these compositions are normally used without internal plates, because of their extremely good resistance to spalling. The spinel-bonded brick of high periclase content are unique in their resistance to penetration by the oxides in the furnace atmosphere and to reaction with these oxides.

Many open-hearth furnaces will continue to operate with silica brick roofs of the highest quality as the most economical refractory practice. In these silica brick roofs, METALKASE magnesite-chrome brick are frequently used to advantage in shoulders adjacent to and including front- and back-wall skewbacks. The shoulders may consist of alternate courses of basic and silica brick, or they may consist entirely of METALKASE. The latter are especially advantageous in tilting furnaces in which these sections of the roof may come in contact with the slag above the bath when the furnace is tilted for pouring.

Front Walls: The front walls of open-hearth furnaces are subjected to extremely severe conditions whether or not oxygen is used. The piers between the doors are exposed to flame impingement and erosion on the inner face and two sides; to rapid changes in temperature when doors are raised; and to mechanical abuse when the charge is thrust through the door openings. The refractory material of highest resistance to this severe service, especially when the charging practice avoids excessive mechanical damage, is METALKASE MAGNEX H. These brick are of chemically-bonded magnesite-chrome composition, and are encased by sheets of mild steel. In service, the metal oxidizes for a short distance back from the hot end, and the oxide is absorbed by the refractory material, with the formation of a strong monolithic surface high in refractoriness and resistance to spalling. Additional reinforcement and structural strength are given to the front-wall piers by the use of steel tie plates up to ⅜-inch thick in horizontal joints, at vertical intervals of one to four courses. These plates are rigidly attached to the furnace buckstays and restrain any tendency of the walls to move. With the increasing severity of the service conditions in front walls exposed to oxygen lancing, Harbison-Walker metal-encased brick of spinel-bonded or forsterite-bonded periclase are fulfilling the more rigorous requirements.

Open-hearth doors, most of which are water-cooled, are commonly lined with air-setting monolithic refractory material on the face exposed to the heat. The lining may consist of PLASTIC THERMOLITH BATCH rammed into place, or H-W CHROMEPAK poured around studs welded to the doors. For some operating conditions, ALUSITE high-alumina brick, or METALKASE MAGNEX brick may be better suited.

Back Walls: In a sloping back wall, the brick in the entire lower part are covered with basic granular hearth material and the only brick exposed to the furnace atmosphere are those in a few courses immediately below the skewbacks. The covered portions of the back walls are often built of H-W PERIKLASE in furnaces which have H-W PERIKLASE subhearths, or they may be built with CHROMEX B or MAGNEX B. These are hard-burned brick and are generally laid without steel tie plates in this service. The exposed portion of the back wall is installed with METALKASE MAGNEX brick with the use of tie plates if the height of the wall is sufficient to require this reinforcement.

In furnaces with vertical back walls the most severe service conditions are imposed upon the refractories, as they are not protected by granular monolithic materials. Under these conditions tie plates should be installed in the wall, and the upper portion of the straight back wall should be built of the same type of metal-encased basic brick as those used in the front wall. For the slag line and the portion of the back wall directly above it, a strong dense burned basic brick is best. H-W PERIKLASE brick are particularly suited for this application. Under certain conditions, CHROMEX BH, hard-burned chrome-magnesite brick of slightly higher magnesia content than CHROMEX B, is used economically.

Hearth: The subhearth of the modern open-hearth furnace is advantageously built of H-W PERIKLASE, a high-purity fired magnesite brick having extremely high resistance to hydration on initial heating. This brick is used in both the stadium type of construction considered standard for many years, and in the more recently used invert-arch construction. The H-W PERIKLASE brick, when installed with a modified heat-setting H-W PERIKLASE BONDING MORTAR, provide complete stability of the refractory subhearth and maximum resistance to penetration by the molten steel in the working bottom. In furnaces subject to extended periods of nonproduction, the use of CHROMEX B subhearths may be preferred.

The use of high-duty fireclay brick for the contour base is still standard practice, although many furnaces are being changed to sloping steel pans which approximate the contour, thus eliminating the need for the brick fill.

A thin layer of refractory concrete is used on most furnace hearths to level the rivet heads and joints of the steel pan before installing the brick subhearth proper. For inverted arch installations, the arch contour is formed with H-W CHROME FILL.

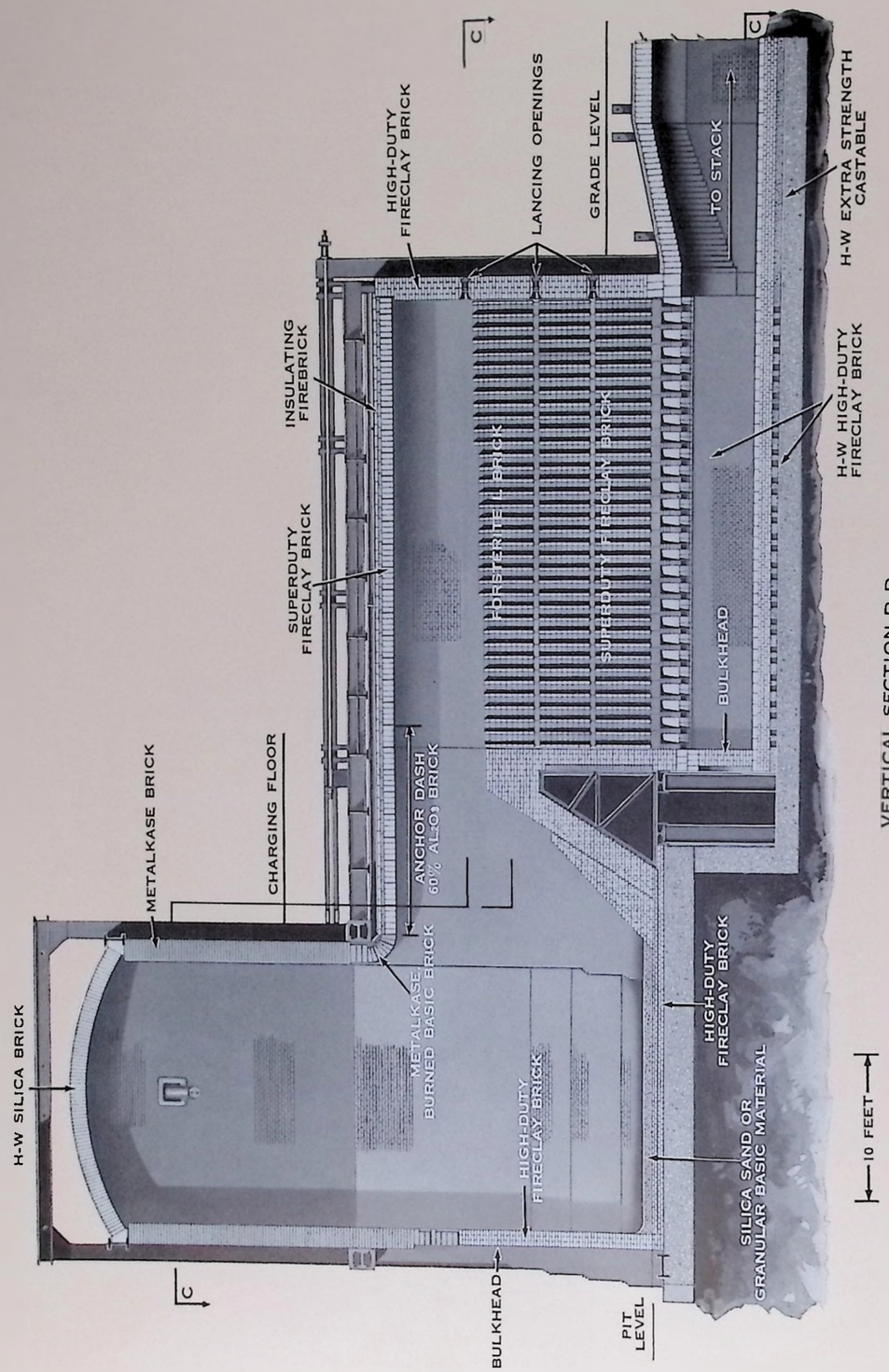
The monolithic hearth which forms the working bottom is air-rammed upon the brick subhearth, to the desired contour. H-W C-MIX is the widely accepted standard for open-hearth furnace bottoms which are required to withstand the most severe conditions. This basic ramming mix has a high content of high-purity periclase. It has unusual properties of physical and chemical stability with negligible shrinkage at extremely high temperatures, a high degree of immunity to hydration, and high strength over the range of steel furnace temperatures. The basic ramming mix H-W MAGNAMIX is also used to advantage in furnace bottoms in which various steels are produced, because it sinters to a hard, dense monolith over a range of

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Typical Basic Open-Hearth Furnace

Typical Basic Open-Hearth Furnace

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VERTICAL SECTION D-D

Typical Basic Open-Hearth Furnace

somewhat lower temperatures.

Both H-W C-Mix and H-W Magnamix are air-setting ramming mixes prepared from high-purity dead-burned magnesites. They require only the addition of water to bring them to the proper ramming consistency and their high magnesia contents are undiluted at the time of installation by any additions such as basic slag. They are rammed into place forming the final contour of the bottom and banks, and develop a strong set during the heating-up of the furnace. The bottoms are placed in service without use of the sintered top dressing which was formerly standard practice for basic open-hearth furnaces.

The hearths are maintained with the patented material QX Magnifrit, or with other basic granular materials such as H-W Washington Dead-Burned Magnesite Grains or H-W Magnaset. H-W Magnamix is used for maintenance where an air-setting basic hearth material is needed. New tapholes are installed with H-W C-Mix, which is also used for repiping the tapholes, together with H-W Magnamix and H-W Magnamix 85.

Because of the extremely high temperatures of the modern open-hearth furnace, dead-burned magnesite is used extensively for fettling, and its use results in more economical bottom practice.

Port Ends: The uptake varies considerably in design. Many furnaces have a single uptake; many others continue to use the center division wall arch with the resultant double uptake. Regardless of this difference, the use of basic brick in the walls of the uptake has extended almost without exception down to at least floor level and in many furnaces basic brick are used all the way down to the slag pocket walls. Metalkase Magnex H is one of the H-W brands of basic brick giving excellent results in the end-wall bulkhead, in the pit and checker-wall portions of the uptake, and in the straight portions of walls which may be suspended.

In many furnaces, with or without the center arch and division wall, the under-cut or chill wall is fully suspended and for this wall Metalkase Chromex B shapes give excellent service. The bridge-wall portion of this under-cut wall is often built of Chromex B because of its high load-bearing ability under conditions of soaking heat. The bridge wall may be faced with Metalkase Magnex brick to provide a monolithic hot face across the metal joints.

Chromex B and Metalkase Chromex B wedge shapes continue to be the leading refractories for basic arches installed under the burner at floor level to provide a divided uptake construction in suspended installations.

Metalkase Chromex B is used in the suspended fantail nose of many uptakes. Some furnaces have not yet used suspended construction in this area and continue to use the silica arch to support the floor sidewall and provide the entrance to the checkers. However, the present severity of operating conditions tends to increase the use of basic brick in this position.

Continuing progress in open-hearth practice prompts the need for refractories having certain enhanced properties for the walls of the uptake. The metal-encased modification of brick of the high-periclase series gives promise of increasing the life of these walls considerably, even under operating conditions of extreme severity.

Regenerators: The walls and arches of the regenerator chamber are ordinarily built of high-duty or superduty fireclay brick. However, the regenerator chambers of furnaces having double-pass checkers, or of furnaces having single-pass checkers accessory to the use of oxygen in the system, in many instances need to be built of more refractory materials. At

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present ALUSITE and other brands of high-alumina brick are being used, together with FORSTERITE L and spinel-bonded magnesite brick of high-periclase content in more extensive portions of the regenerator system.

The checkers have traditionally consisted of high-duty fireclay brick. At present, superduty fireclay brick or high-alumina brick are used for the top courses of practically all furnace regenerators. The use of FORSTERITE L basic brick now is considered most economical for the checker settings at many plants. Harbison-Walker's checker brick of various kinds are thermally efficient, resistant to spalling and fluxing, and afford a liberal margin in refractoriness so that the proper combination of brick can be selected for maximum durability and efficiency. The various brands are supplied in a wide variety of shapes and sizes which can be fitted together in various standard checker arrangements or in any one of the many special arrangements designed to meet particular conditions of heat transfer, dust accumulation, or other specific conditions.

Bonding Mortars: All basic brick not metal encased should be laid with mortar. THERMOLITH and H-W PERIKLASE BONDING MORTAR are air-setting and are recommended for use with all types of basic brick. For metal-encased brick, mortar is used only in leveling up the walls. THERMOLITH, H-W SPECIAL FURNACE CHROME, and H-W WASHINGTON FURNACE MAGNESITE may be used for this purpose.

Fireclay brick in regenerator walls and high-alumina brick or silica brick in other parts of the furnace may be laid with HARWACO BOND. Silica brick in the roof or other parts of the furnace are advantageously laid with STARBOND or VEGA BOND heat-setting mortars, having compatible physical and chemical properties to assure maximum durability of the structure. When a basic mortar is desired THERMOLITH also is well suited for the joints in fireclay brick and silica brick walls.

ACID OPEN HEARTH

In acid open-hearth furnaces, silica refractories are employed almost exclusively above the charging floor level. STAR silica brick, of conventional quality, are used extensively in front walls, back walls, uptakes, and roofs. VEGA superduty silica brick are preferred for the roofs at many plants. The use of VEGA BOND and STARBOND silica bonding mortars for laying the silica brick will contribute to longer service.

The furnace bottoms are made of mixtures of H-W GROUND QUARTZITE and plastic fire clay, or of silica sand. The subbottoms are built mainly of silica brick and between these and the steel pan there may be one or more courses of high-duty fireclay brick and a course of insulating firebrick.

In the port uptake walls and especially in the end wall METALKASE CHROMEX B brick and METALKASE MAGNEX brick in many cases are used to avoid some of the build-up problems in these parts of the furnace and to extend the service life. In the lower portion of the uptakes silica brick are used.

The regenerator chambers are usually built of high-duty or superduty fireclay brick and the checkers may be high-duty fireclay brick, superduty fireclay brick, or silica brick.

OXYGEN-PROCESS STEELMAKING VESSELS

IN oxygen steelmaking processes, oxygen of high purity is directed through a water-cooled lance onto the bath consisting of molten iron and fluxes, with scrap or iron ore as a coolant, to effect the refining of iron into steel. They differ from most other steelmaking methods in that no outside fuel is used. The heat required is liberated by the exothermic reactions of oxidation of carbon, silicon, phosphorus, and some metallics.

While the various systems, known as the L-D process, the Stora-Kaldo process, and the Rotor process, differ from each other in detail, all utilize the same fundamental metallurgy. These processes are used primarily in the production of low-carbon steels but may be applied to steel of many grades.

All of these systems were developed in Europe, the L-D process in Austria, the Stora-Kaldo process in Sweden, and the Rotor process in Germany. In each process, the charge consists predominantly of hot metal from the blast furnace or cupola which is introduced into the furnace following the scrap, iron ore, or sinter portion of the charge. Required fluxes are added just before or just after insertion of the water-cooled lance, through which oxygen is directed against the bath. The production of a heat of steel requires a relatively short period of time, which varies with the size of the vessel, but usually is less than one hour. Alloy additions may be made to the vessel but are more commonly added in the ladle.

Extremely severe service conditions to which the refractories are exposed include drastic temperature changes, impact of heavy scrap, and violent erosion by slag and molten metal, in addition to the usual severe factors of high temperatures, corrosive effects of oxides and other fluxes, and mechanical stresses caused by the tilting of the furnaces.

Harbison-Walker has pioneered in the research and development of refractories specifically designed for the conditions found in these processes. The refractories developed by Harbison-Walker for this service provide the complete linings which have performed very successfully and have made tonnage records.

OXIBAK brand of magnesite brick laid with strong-setting H-W PERIKLASE BONDING MORTAR forms the protective lining against the shell. These hard-fired magnesite brick make a strong, dense lining highly resistant to the furnace operating conditions to which they may be exposed at times near the end of the lining campaign. This permanent lining, as it is commonly termed, extends to the full height of the furnace and also across the hearth in the form of a stadium or invert-dome bottom, mainly depending upon the size of the vessel.

H-W OXIMIX is a basic ramming mix used to form the monolithic hearth of the furnace. It is used as the intermediate monolith between the special hard-fired magnesite brick lining against the shell and the working lining which consists of another type of brick. The H-W OXIMIX forms a solid layer, free from open spaces between the two brick linings and increases the resistance to penetration by slag. In the most vulnerable positions of the working lining it serves best for patching.

For the working lining, the basic OXILINE brick of several modifications continue to hold outstanding service records in the basic oxygen steelmaking vessels throughout the United States. These brick are available in different chemical compositions and physical properties for various specialized requirements. Among

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the modifications, one of major importance is the most resistant to atmospheric hydration. In addition to excellent service, an important additional benefit resulting from its use is the avoidance of deterioration of the lining when the vessel is not in use.

Under some conditions, burned special magnesite brick of high periclase content and of high density may be used for the working lining. This is especially true for the uppermost courses of the cone section, where slag build-up is removed periodically, and in the parts of the working lining which must withstand the mechanical impact of scrap and the scouring action of the hot metal charged.

H-W Oxibond, a basic mortar of high magnesia content, is used for leveling and maintaining the desired contour during the installation of the working lining. This practice helps materially in securing the densest and most impervious lining.

H-W C-Mix, the high-purity ramming mix of maximum periclase content, which develops high strength and superior resistance to erosion and corrosion, is used for making the most durable taphole installations.

Auxiliary equipment, including a water-cooled hood, refractory-lined offtakes and dust-collector system, is lined with standard refractories including Plastic Thermolith Batch at the top of the water-cooled hood, Alamo and other brands of superduty fireclay brick in the offtake, and high-heat-duty fireclay brick in parts of the dust-collector system. Some of the dust-collection equipment also includes hoppers lined with Duro brick, or with H-W Extra Strength Castable, both of which are highly resistant to severe attrition.

PETROLEUM REFINING AND PETROCHEMICALS

Since the earliest days when only simple products were extracted from petroleum, the conversion of crude oil into many different end products has become exceedingly complex. At a rapidly accelerating pace, new knowledge is permitting a continually increasing number of valuable materials to be made from petroleum. The refinery, which originally produced only fuels and lubricants, now makes a host of intermediate products or petrochemicals by numerous processes. As each new product is developed, the processing methods require not only additions, but also modifications, so that the complexity of an originally simple process has become very great. Present-day practice in the refining of crude petroleum is extremely flexible, in order to produce the wide variety of finished products demanded by constantly changing market conditions. Although many of the modern processes are of a chemical rather than a physical nature, practically all of them require heat. This is supplied by a combustion of fuel oil, natural gas, or refinery-fixed gas.

The crude oil received at the refinery is first subjected to atmospheric distillation and subsequent fractionation. The general fractions or cuts, separated through differences in their temperatures of vaporization, then receive further processing for the production of gasoline or other marketable products. This processing may consist of vacuum distillation, thermal cracking, catalytic cracking, reforming, polymerization, isomerization, or other refining processes.

Heaters: Atmospheric distillation is accomplished by means of tubular heaters, which may be of the chamber or box type, the cellular type, or the circular type. Usually, tubes are so

arranged in the combustion chamber that they absorb a large percentage of the radiated heat. An economizer or convection section, composed of a bank of closely nested tubes and located between the combustion chamber and the stack, picks up heat by convection from the gases leaving the radiant heating zone.

Tubular heaters are also used in conjunction with reaction chambers or soaking drums in thermal cracking installations. They are employed for thermally reforming low-grade gasoline, for preheating the charge to catalytic cracking and polymerization plants, and for preheating and reboiling purposes in connection with isomerization and treating units. The settings of these tubular heaters normally have roofs and walls of suspended construction.

The requirements which heaters must meet are so varied that frequently they are individually designed for the specific job. In the newer types, temperatures commonly do not exceed 1800°F., while in some of the older types the temperatures may reach 2000°F. to 2200°F.

The kind of refractory employed in tubular heaters depends on the operating conditions. Lightweight insulating materials such as insulating brick or insulating castables are commonly used in the settings of heaters of the newer types. The use of precast panels of insulating castable provides simplicity of construction, and is proving to be both economical and efficient for furnace closures. In some types of heaters, in which the division walls or checker walls are subjected to soaking heats, fireclay and high-alumina refractories ranging from high-duty fireclay brick to Korundal (90 per cent Al_2O_3) brick are used. Harbison-Walker makes a complete series of insulating brick, insulating castables, and dense refractories comprising the entire range of materials best suited for all the particular conditions.

Boilers: Most petroleum processing plants utilize steam generating equipment. While these furnaces are treated more fully on page 355, some special requirements of the petroleum industries are worthy of mention.

A variety of fuels is used in firing the boilers of petroleum processing plants. Refinery gas is often the standard fuel and may involve no unusual conditions. The fuel may, however, range from acid sludge to tar. These fuels, often waste products, may contain materials such as alkalies, lime, vanadium pentoxide, or sulfur compounds which are damaging to refractories. Harbison-Walker brands of superduty fireclay brick, high-alumina brick of the various classes from 50 per cent to 90 per cent alumina, and corresponding mortars, high-alumina castables, and high-alumina plastic refractories are especially well suited to these severe conditions.

The CO boiler is becoming increasingly used in refineries. For fuel, it utilizes the regenerator flue gases, which contain 6 to 8 per cent CO, and also salvages the sensible heat of the waste gases. Inasmuch as the CO burned in such a unit ignites only with difficulty, auxiliary burners are tangentially fired into these units and relatively high temperatures must prevail for proper combustion. Since the gases entering the CO boiler from the regenerator contain some catalyst carry-over, the gas ducts and boiler linings must be resistant to erosion from the dust-laden gas stream. Another consideration in the selection of refractories used in contact with carbon monoxide gas may be the possibility of disintegration of the lining materials through the deposition of carbon, as described on page 312. Among the lining materials best suited for these conditions are Varnon brand of high-fired superduty fireclay brick, H-W Harcast superduty fireclay castable, and H-W Castolast high-alumina cast-

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able. These materials are all low in iron, dense, and abrasion-resistant, and they withstand exposure to carbon monoxide gas.

Catalytic Cracking Units: A wide variety of catalytic cracking units, generally referred to as "Cat Crackers," is used in the petroleum industry. Formerly, most of the "Cat Crackers" were of the fixed-bed type, while more recent installations have moving beds. In some of these units, the catalyst is in the form of beads or pellets which move downward through the reactor by gravity. In fluid-type reactors, the catalyst is very finely divided and in the presence of vapor, stays in turbulent suspension. The reactor temperature is usually 850° to 950°F. Coupled with the reactor vessel, there is usually a regenerator or kiln for burning deposited carbon from the catalyst to restore its activity. Temperatures in these units range from 1100° to 1600°F. The refractory linings in these vessels and auxiliaries serve to protect the steel shell against erosion and corrosion, graphitization, and excessive temperatures.

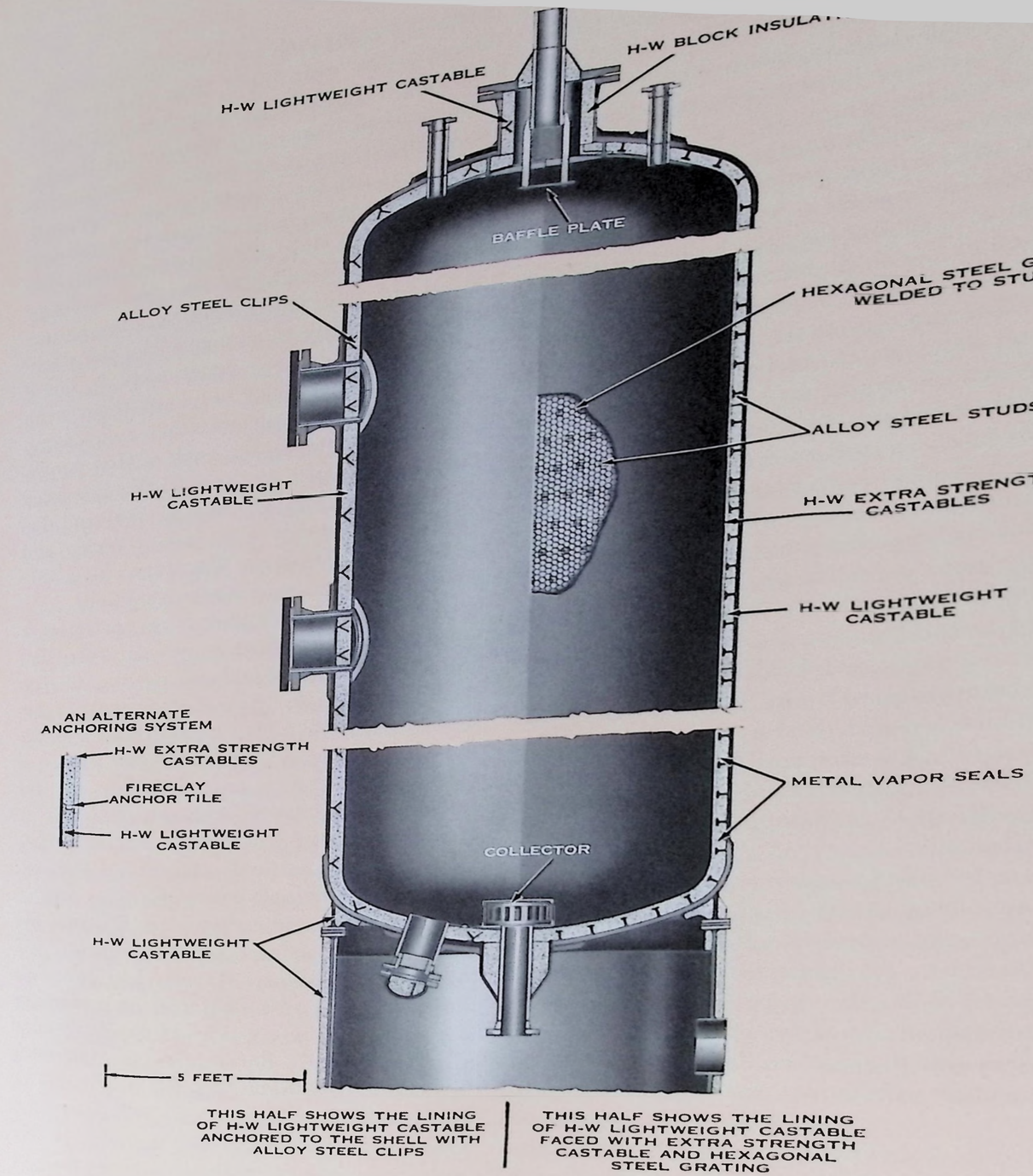
Some regenerator linings are installed with special dense fireclay tile, fastened to the steel shell of the vessel with special alloy steel anchors, and backed with insulating materials. Heavy-duty castables and insulating castables have gained favor for use in lining catalytic vessels and auxiliaries and are either gunned or troweled into place. H-W Extra Strength Castable used for tough, abrasion-resisting surfaces, and H-W Lightweight Castable 22 used for insulating backing, have proved their merits in years of service. H-W Lightweight Castable 22 and H-W CC Lightweight Castable (a special material for catalytic cracking units) offer a means of providing, in one material, linings having not only low thermal conductivity, good strength, and low permeability, but also sufficient abrasion resistance for a large portion of the construction.

Linings for piping-bends, slide valves, feed lines, and cyclones are exposed to severe abrasive action. Materials used for these linings, because of their outstanding strength and abrasion resistance in the range of 600° to 1800°F., include the strong-setting ramming and troweling mix Harcor K and the refractory castables H-W Extra Strength Castable, H-W Harchrome Castable, having a chrome ore base, H-W Harcast, with a superduty fireclay base, and H-W Castolast, having a high-alumina base.

Catalytic Reforming Units: Several types of catalytic reforming units are in widespread use in the refining industry. Some of these vessels are lined with insulating castables with alloy steel shrouds, while others have a dual lining consisting of insulating castable and heavy-duty castable. The operating temperatures range from 800° to 1000°F. and pressures from 50 to 750 psi. The reactions within these reforming units sometimes require linings of low iron content and H-W Low-Iron Lightweight Castable 22, H-W Harcast BF, and H-W Castolast G fulfill the demands.

Coking Units: The fluid coker, which is becoming increasingly important, has considerable similarity to the fluid catalytic cracking units in its demands on refractory and insulating lining materials. Castable linings similar to those in "Cat Crackers" are often used.

Waste Material Furnaces: Many refining plants develop waste products which must be disposed of by burning. Incinerator furnaces for burning waste materials are built in a great variety of designs, depending upon the amounts and kinds of materials to be handled. Some of those which necessarily are burned in refineries and petrochemical plants contain very corrosive fluxes such as alkalies and vanadium oxide.



Typical Lining of Petroleum Reactor Vessel

HARBISON-WALKER REFRACTORIES COMPANY

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Acidic fumes are sometimes evolved in the combustion process. Harbison-Walker brands of superduty and high-alumina brick and mortars and high-alumina plastic refractories fulfill the requirements for these severe conditions to best advantage.

Petrochemical Reactors: Harbison-Walker brick and castable materials are particularly adapted for use in a wide variety of petrochemical reactors. Castable linings are usually applied by the air-placement gun method, using various systems of support. Typical linings of this type are shown on page 437. Suspended brick construction has been widely used with excellent results. It has long been a recognized fact that streams of fluid hydrocarbons may deposit carbon in the pores of some refractories in sufficient concentration to disintegrate them. By contrast, VARNON and KENMORE brands of high-fired superduty fireclay brick are giving many years service under these conditions.

Frequently, petrochemical reactors employ a fixed bed of catalyst which must be contained by supporting and hold-down layers of inert refractory material which is resistant to the destructive factors involved, including carbon deposition. Usually, such beds of material must "breathe" freely to permit the passage of vapors through the catalyst bed. Harbison-Walker furnishes a variety of calcined and fired products for such purposes, including crushed and sized calcined clays of specific properties, partition rings, grid tile, and refractory balls. Perforated tile, containing many closely spaced and tapered holes, are supplied to form the supporting floors for some designs of catalyst beds.

Corrosion Protection: Many of the applications for refractories in refineries and petrochemical plants involve extremely severe conditions in the main other than resistance to high temperatures. In some applications in the petrochemical industry, resistance of the refractories to corrosion is of paramount importance, both for high-temperature applications and for those in which high temperatures do not prevail. Castable refractory materials become firmly bonded to the steel shells of vessels and stacks and develop very low permeabilities especially when applied by the pneumatic gun. They resist penetration by liquid and gaseous materials, and keep them from contact with the steel and other metal parts. Even insulating castables, such as H-W LIGHTWEIGHT CASTABLE 22 and H-W LOW-IRON LIGHTWEIGHT CASTABLE 22, can perform this function exceedingly well. H-W HARCAST and H-W EXTRA STRENGTH CASTABLE effectively retard corrosion under severe conditions.

DURO and W-ACID brands of acid-proof brick are used with excellent results for corrosion protection to gas scrubbers, cooling towers, stacks, acid gas ducts, sour stock tanks, reaction vessels, and water tanks. DURO and W-ACID brick serve advantageously for paving of alkalation units and pump foundations, and for lining vessels, acid trenches, and sumps.

Some miscellaneous applications of refractories in refineries and petrochemical plants, such as for multiple-hearth furnaces, sulfur recovery units, and carbon black furnaces are described in other sections of this chapter.

Anchoring Systems: Monolithic castable linings mentioned in the foregoing paragraphs are supported by a variety of attachments to the steel shell. Illustrations of anchoring systems are shown on page 437.

POURING-PIT REFRACTORIES

THE pouring pit is an important adjunct to steelmaking plants. In the pit are located the facilities for handling the molten steel from the refining or melting furnaces to the ingot molds. The steel tapped from the furnace flows into a refractory-lined ladle from which it is poured either directly or indirectly into the molds, where the metal solidifies. Most steel plants use the bottom-pour method of emptying the ladles, and many plants follow the bottom-pour method of filling the ingot molds. A variety of refractory shapes and monolithic materials are required in the different parts of the equipment used for handling the molten steel, and the total quantity of pouring-pit refractories used annually is large indeed.

Among pouring-pit refractories are included those used in the ladles (ladle brick, stopper-rod sleeves, nozzles, pocket or well blocks, and stoppers), pouring baskets, ingot-mold plugs, bottom-pouring refractories (funnels, fountain brick, king or spider brick, and runner brick), and hot tops. Most of these are made of fireclay material. Each refractory must serve its particular purpose in the operation, and each must be made of material which will meet a minimum requirement as to refractoriness, mechanical strength, and resistance to erosion, corrosion, and thermal shock. Harbison-Walker pouring-pit refractories, which are produced in several manufacturing districts, are made with special attention to quality and workmanship.

Ladle Linings: In the steel plant, the materials used for lining the ladles are standard brick sizes and special shapes. Most large steel ladles are lined with a special kind of fireclay brick, such as H-W LADLE, having high density and relatively low P.C.E. value. These brick have the property of swelling considerably when brought to operating temperatures. The expansion seals the joints and makes tight linings. Current investigations as to the use of more refractory brick in the linings give promise of improvement in service.

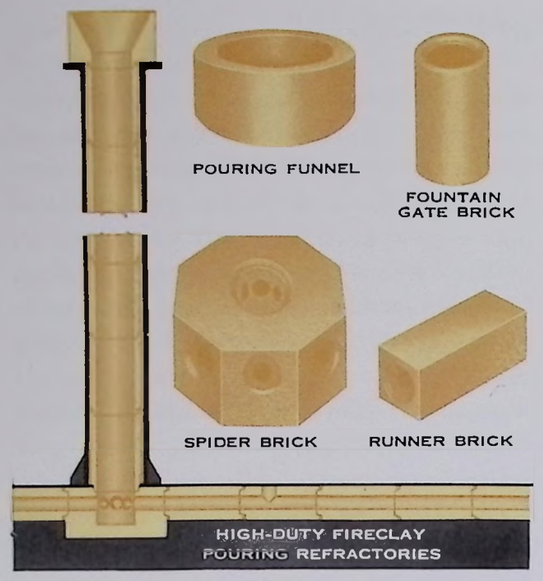
High-duty and superduty fireclay brick which have been hard burned to prevent shrinkage in service are used also, especially for lining smaller ladles.

Sleeves: In bottom-pour ladles, cylindrical brick shapes having high resistance to thermal spalling, to metal erosion, and to corrosion by slag are used for the sleeves which fit over and protect the stopper rods. The sleeves must also have higher refractoriness than the usual ladle brick. For normal service, H-W brand of high-duty fireclay sleeves give satisfactory results. H-W SUPER SAVAGE superduty fireclay sleeves provide an extra margin of refractoriness. THERMAG and various other basic sleeves, as well as H-W MULLITE sleeves, have superior resistance to corrosion by the slag of manganese-bearing steels. These compositions may also be used advantageously when teeming is delayed or continues for a relatively long time.

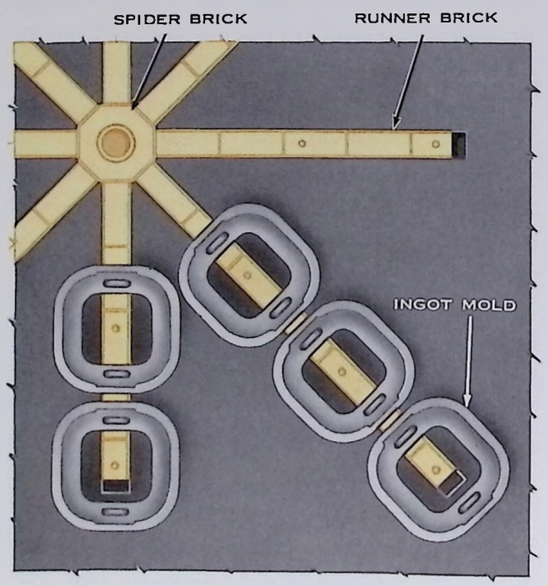
Nozzles: The nozzles used in bottom-pour ladles are generally made of fire clay. At the temperature of molten steel, they become pyroplastic to the optimum degree for tight sealing under the stopper-head pressure. Other properties of major importance are resistance to erosion and spalling conditions. In order to secure close seating of the stopper for avoidance of leakage, the most precise workmanship is essential. Nozzles of H-W brand are supplied in various sizes and designs, best suited for ladles of different capacities and heats.

Hard-fired high-duty and superduty fireclay brick nozzles are also used under special con-

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VERTICAL SECTION THROUGH CENTER RUNNER—(FOUNTAIN)



PARTIAL PLAN VIEW SHOWING TYPICAL ARRANGEMENT OF TILE SPIDER AND RUNNER BRICK

3 FEET

Bottom-Pouring Assembly for Ingot Molds

ditions. With particularly hot and corrosive steels, or when it is important to control the rate of steel flow most accurately, both basic refractory nozzles and basic inserts in clay nozzles are serving to best advantage.

The materials used for seating the nozzle brick in the ladles include H-W Black Patch, other ramming mixes, and well blocks made from refractory fire clay.

Stopper Heads: The important requirements of stopper heads are refractoriness, high-temperature strength, and resistance to thermal shock. They must have adequate compressive strength, to seat themselves closely on the slightly softened nozzle surface, to seal tightly against metal leakage. Stopper heads are made of graphite, bonded with refractory clays possessing the specific properties needed for the purpose. For many years, Harbison-Walker has produced special clays used in making graphite stoppers of the highest quality.

Basket Pouring: Pouring of steel directly from the ladle into the top of the mold requires refractories for the ladles, usually a hot top at the top of each ingot mold, and frequently a refractory plug at the bottom of the mold. In top pouring, an intermediate pouring vessel may be used. Such a vessel is called a tundish, pouring basket, or pouring box. Harbison-Walker makes various refractory products which are especially suited for the construction of these intermediate pouring devices.

Bottom Pouring: In the bottom-pour method of filling the molds, the molten steel from the ladle passes downward through a vertical refractory-lined tube arrangement called a "fountain," then outward through horizontal lateral assemblies of runner brick to the bottom of one or more ingot molds, and under the pressure-head of the metal flows upward in the molds to the desired level.

For steel plants in which bottom-pour practice is employed, Harbison-Walker supplies fountain brick, king or spider brick, and runner brick in various sizes and designs to meet every need. Typical shapes and an assembly for bottom pouring of ingots are illustrated on page 440. The brick are fireclay shapes of essentially the same quality as the stopper-rod sleeves. The best of workmanship is an essential requirement. These refractories must possess not only adequate refractoriness and resistance to thermal shock, but also high resistance to the erosive action of fast-flowing metal. Harbison-Walker brands of refractories for this service meet the requirements most satisfactorily.

Hot Tops: Various kinds of refractories are used for hot tops, including dense fireclay shapes, insulating firebrick and castables. In general the trend is toward the use of insulating refractories to reduce the rate of heat loss from the sink head. H-W 26 insulating firebrick are used with very good results. Harbison-Walker castables, especially adapted for fabrication of hot tops at the steel plant, are widely used.

PULP AND PAPER

Chemical pulp used in the manufacture of practically all types of paper is produced principally by the sulfite, sulfate (kraft), and soda processes. Neutral sulfite semi-chemical and similar related processes are now in commercial production and still others are being developed to effect greater economy and higher production rates. Refractories are required in each process to meet a variety of special conditions.

Large quantities of steam are used in all pulp mills for such requirements as power generators, digesters, and evaporators. Some of this steam is produced in the usual steam power boilers and in bark-burning boilers. Additional steam is provided by the chemical-recovery boilers used in some of the processes.

Sulfite Process: In the sulfite process, refractories are required for boiler settings and for lining furnaces which burn sulfur or pyrites to produce SO_2 gas used to make acid for the cooking liquor. Refractories for sulfur burners must be carefully selected to meet different design and operating conditions. Harbison-Walker high-duty and superduty fireclay brick and high-alumina brick are accepted standards of quality for these applications.

Dense, highly impervious, acid-resisting brick are required for linings of acid towers, accumulators, storage tanks and blow pits, and for the lining and packing of acid-reclaiming towers. For the various combinations of severe conditions involved, Duro and W-Acid brands of acid-proof brick, tile, and tower packing shapes are unexcelled.

Harbison-Walker manufactures special digester brick for the linings of sulfite digesters. Impregnated Duro digester brick now in service hold promise of meeting the increased severity of conditions in the neutral sulfite processes.

In the past, waste liquor from the sulfite process was discarded. Within relatively recent years, new techniques have been developed which make possible the recovery of chemicals from this spent liquor, with the utilization of waste heat, in the same type of equipment as that used in the sulfate and soda processes.

Sulfate and Soda Processes: Sulfate and soda pulp are produced by alkaline processes and the equipment used in modern mills for both is largely similar.

Black liquor washed from the pulp is concentrated, and its combustible constituents are

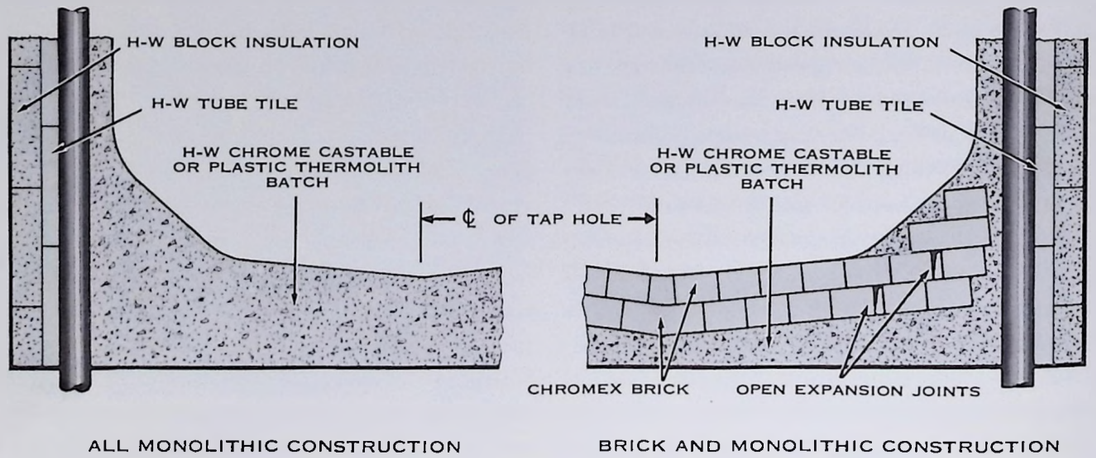
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burned in chemical-recovery boilers in which valuable chemicals are recovered and steam is generated for power and process requirements. Chemicals in the form of molten smelt are tapped continuously from the bottom of the furnace into dissolving tanks. The smelt is composed principally of sodium salts which are very corrosive to the refractories. In the bottoms and lower sidewalls of recovery boilers, H-W CHROME or CHROMEX brick are preferred. H-W CHROME CASTABLE and PLASTIC THERMOLITH BATCH (plastic chrome ore) are giving excellent service in monolithic bottoms and packing around sidewall water tubes. However, the chrome refractories should not be exposed simultaneously to the action of both steam and the sodium compounds. The use of H-W HARCHROME CASTABLE, having highest strength and resistance to erosion, reduces the rate of wear in the spout area, and more closely approaches the life of the entire lining. The balance of the setting of the chemical-recovery boilers, in positions where chrome refractories are not used, is usually built of high-heat-duty fireclay brick or castables.

In some operations the black liquor is fed into a rotary incinerator for the production of black ash. Harbison-Walker high-duty and superduty fireclay brick of dense texture and high resistance to corrosion give exceptionally good results in these units.

DURO and W-ACID chemical brick, laid with H-W ALKAMORTAR, are widely used for lining dissolving tanks, causticizing tanks, reaction tanks, and cold liquor storage tanks as well as for the storage of acid used in bleaching plants. The Universal Circle design as described and illustrated on page 120 is particularly well adapted to these installations.

Rotary kilns are used for calcining limestone and lime sludge for the recovery of lime from the causticizing operations. The refractories used for lining these kilns are described on page 451.



Typical Bottom Construction for Chemical-Recovery Boiler

ROASTERS — MULTIPLE-HEARTH

ROASTERS or roasting furnaces were initially designed primarily for the desulfurizing of ores and ore concentrates. However, multiple-hearth roasters are so flexible and transmit heat so efficiently that they have become widely adapted to other uses. Today, their applications may be for roasting, incinerating, calcining, activating, and drying in the chemical, petroleum, and other process industries. In these furnaces, the charge is treated continuously as it drops to successive hearths and is rabbled across them.

Flash roasters are essentially a type of multiple-hearth roaster with the central hearths removed to form a combustion chamber. The finely ground charge is roasted or burned in the brief interval of time while the particles are falling through the heated air within the combustion chamber—hence the terminology "flash roasting."

Fluidized-solids reactors are frequently employed for roasting sulfide ores. Refractories used in these reactors are discussed in some detail on page 387.

The requirements of the refractory brick used in multiple-hearth and flash roasters are exceedingly exacting. This is especially true of the workmanship of shapes used to form the hearths, which are segments of domes or cones of slight curvature. The hearths of some roasters are built entirely of special shapes while for some others, combinations of standard 9-inch sizes are used except for the drop-hole construction.

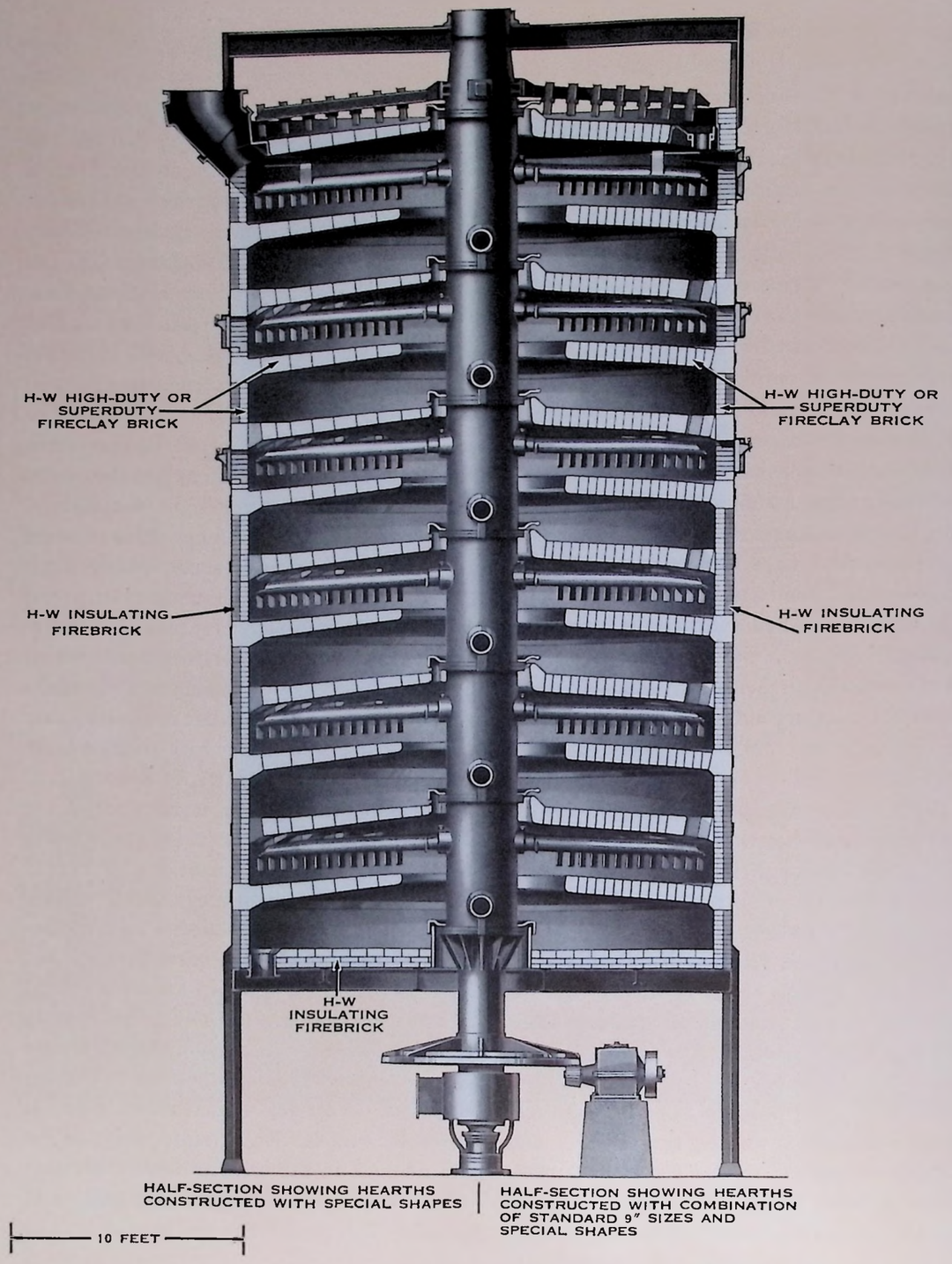
The brick must have low porosity, high mechanical strength at working temperatures, and ability to withstand rapid changes in temperature. Another important property is low thermal expansion. Harbison-Walker roaster brick are manufactured with a thorough understanding of these requirements. By selection of the most suitable clays and by special controls throughout the various stages of manufacture, the company produces brick which are best for this service. Typically among Harbison-Walker brands, WALSH XX, H-W HIGH GRADE XX, and WOODLAND high-duty brick, and ALAMO, KENMORE, and VARNON superduty brick are used.

In some of the multiple-hearth furnaces which are equipped with auxiliary burners between the hearths, it becomes necessary to make a special selection of refractories other than high-duty fireclay brick, having the special characteristics best adapted for the linings, hearths, and shafts. In the operation of some of these furnaces, and in some used for flash roasting, exceedingly high temperatures and severe fluxing conditions may prevail. Depending upon the severity of the treatment to which the refractories in the combustion chambers are subjected, Harbison-Walker furnishes either superduty fireclay brick, or high-alumina brick such as ALCOR, H-W MULLITE, or KORUNDAL.

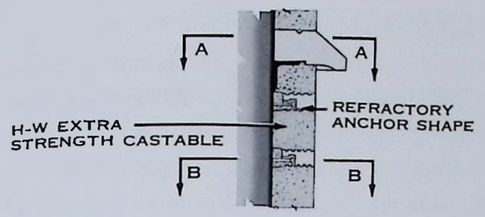
Harbison-Walker produces refractories for roasters in which highly reducing atmospheres are maintained. These refractories are rendered practically immune to disintegration by carbon deposition through close control in manufacture of such factors as chemical composition, firing temperatures, and kiln atmospheres.

In the manufacture of brick to be used in roasting sulfide ores, the high-quality clays used must be properly processed in order to prevent "sulfating" in service. This reaction, which is caused by combination of sulfur trioxide gas with alumina in the brick to form aluminum sulfate, may cause swelling or disintegration of the brick. The presence of the trioxide results from the oxidation of sulfur dioxide in small

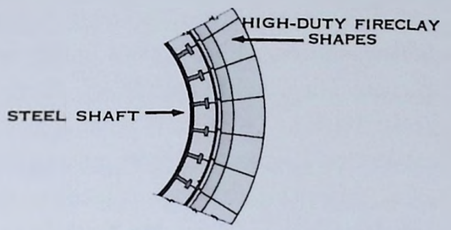
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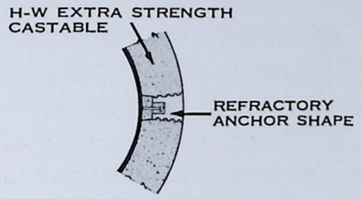
Multiple-Hearth Roasting Furnace



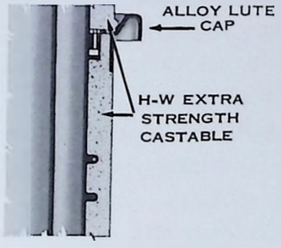
VERTICAL SECTION NO. 1 ILLUSTRATING CASTABLE MATERIAL FOR SHAFT LINING



PLAN VIEW AT SECTION A-A ABOVE



PLAN VIEW OF SECTION B-B ABOVE



VERTICAL SECTION NO. 2 ILLUSTRATING USE OF CASTABLE MATERIAL WITH SPECIAL ALLOY RODS OR MESH REINFORCING

Illustrations of Typical Monolithic Shaft Linings For Multiple-Hearth Roasters

amounts. The use of Harbison-Walker extra hard-fired high-duty and superduty fireclay brick avoids this difficulty.

In the treatment of abrasive and corrosive materials, HARBIDE silicon carbide 9-inch split brick, attached to the rabble blades, contribute greatly to the durability of the blades.

Many roasters are provided with a course of insulating firebrick between the shell and the refractory lining. The brand H-W 26 is used extensively, primarily because of its high compressive strength. For a higher degree of insulation, H-W 23, H-W 20, and H-W 16-20 brands may be used, depending upon the specific conditions. H-W 26 is used also with excellent results in door linings.

H-W BLOCK INSULATION and H-W MINERAL FIBER COATING can be used for exterior insulation when desirable for the avoidance of acid condensation and corrosion of the steel shell. By this practice heat losses due to radiation also are reduced and working conditions are more comfortable.

In many cases, repairs to old hearths can be made and new hearths can be formed economically and with a minimum loss in time by the use of castable refractories. H-W EXTRA STRENGTH CASTABLE and H-W HIGH-ALUMINA CASTABLE are especially suited for this service. They are also used for lining the shaft.

The high-temperature bonding mortars HARWACO BOND and THERMOLITH, used for laying brick and for coating hearths, effectively bond the shapes, and go far toward preventing calcines from working into joints during periods of unavoidable shutdowns. Accurate measurements of hearths built of Harbison-Walker brick and laid with these bonding mortars have shown no cumulative rise during operating periods extending over many years even though interruptions of operation may have occurred.

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ROTARY KILNS

The popularity of rotary kilns is based upon their ability to treat many different materials uniformly and continuously over a wide range of output capacities. Numerically the most important are the kilns used for producing cement clinker, lime, and calcined dolomite. Thousands of these kilns are in operation throughout the world. Rotary kilns are also used in the processing or manufacture of phosphates, alumina, magnesia, titania, zirconia, carbon or coke, manganese dioxide, lightweight aggregates, and ores of iron, chromium, lithium, and uranium; for calcining clay and bauxite, reduction of some metals, the burning of sulfur, and the processing of lithopone.

A modern rotary kiln is characterized by the use of refractories designed to fit each particular need. Increasingly rigorous kiln conditions, imposed by higher operating temperatures or greater chemical activity of materials in contact with the linings, necessitate the use of refractories especially suited for each purpose. For meeting these needs many different kinds of refractories are available. Harbison-Walker products cover the entire range of requirements, and recommendations of specific brands or combinations for any particular kiln service will be made promptly upon request.

Kiln Linings: Commercial kilns range in size from those only a few yards in length and 3 to 6 feet in diameter to giants over 500 feet long and with diameters of 12 feet or more. The linings in a single kiln may be exposed to a temperature range from about 500°F. at the cooler end to over 3200°F. in the high-temperature zone. Chemical and physical changes in the kiln load usually attend the temperature rise, and the lining in different parts of the kiln may have to resist abrasion and impact of the load, destructive action of hot gases and fumes, and corrosive chemical attack by the hot charge.

No single refractory can economically be used to resist all the conditions throughout a rotary kiln. To obtain optimum results it is necessary to use specific refractories for each of the various combinations of service conditions. For resistance to abrasion at the moderate temperatures which prevail in the feed end of many kilns, such brands of hard, dense fireclay brick as DURO or WYLAM A give excellent service. Higher temperatures require additional refractoriness, and selection may be made from high-duty fireclay brick brands like WALSH XX, H-W CROWN, and H-W SPECIAL. The outstanding superduty fireclay brick, VARNON and ALAMO, are used in the most severe service that fireclay refractories can withstand. The high mechanical strength, corrosion resistance, and refractoriness of VARNON and ALAMO and their H-W counterparts produced in widely separated locations make it economical to use these brick for the lining of the high-temperature zones of some kilns, and the intermediate zones of others, depending upon the maximum temperature of operation. They may often be used advantageously at intermediate temperatures, where maximum resistance to abrasion is required.

Chemical and thermal conditions too severe for fireclay refractories require linings of high-alumina or basic refractories. ALUSITE 70 per cent or ANCHOR 60 per cent alumina brick are generally used for service demands just beyond those of superduty fireclay refractories. Supplementing ALUSITE, with increasing severity of service, among high-alumina refractories selection is made from CORALITE, CORALITE XD, and KORUNDAL XD, which belong respectively to the 80 per cent, 85 per cent, and 90 per cent alumina classes of high-alumina refractories. Basic brick such as MAGNEX, FORSTERITE, MAGNECON, H-W PERIKLASE, THERMAG H, or other H-W basic brands are necessarily used for the most economical operation of some kilns. These brick have high resistance to attack by chemically basic materials, and withstand much higher temperatures than other commercially available refractories. In addition, they gain resistance to chemical and thermal conditions by their ability to take and hold a protective coating in various kiln operations.

Nose blocks and lifter arrangements in rotary kilns may be subjected to both abrasion and thermal stresses. VARNON superduty fireclay brick are used extensively. The properties of KORUNDAL XD high-alumina brick and MULCARB semi-silicon carbide brick make them especially suitable for the most severe conditions.

Sizes and Shapes: Brick of many shapes and dimensions have been used in rotary kilns. Selection of the most advantageous sizes and shapes depends on the thickness of the lining, type and class of refractory material, condition of the kiln shell, nature of kiln load, and several special conditions evaluated by experience of the kiln operator. Various special shapes are supplied for feed and discharge ends, lifters, and burner openings.

A full complement of standard radial, arch, and wedge blocks for all diameters provides for every need. The usual lining thickness in domestic practice is either 6 or 9 inches. For a 6-inch lining of fireclay or high-alumina material, 9 x 6 x 4-inch rotary kiln blocks or 9 x 6 x 3½-inch rotary kiln arches are generally used. For 9-inch linings, 9 x 9 x 4-inch rotary kiln blocks or 9 x 6 x 3½-inch rotary kiln wedges are used.

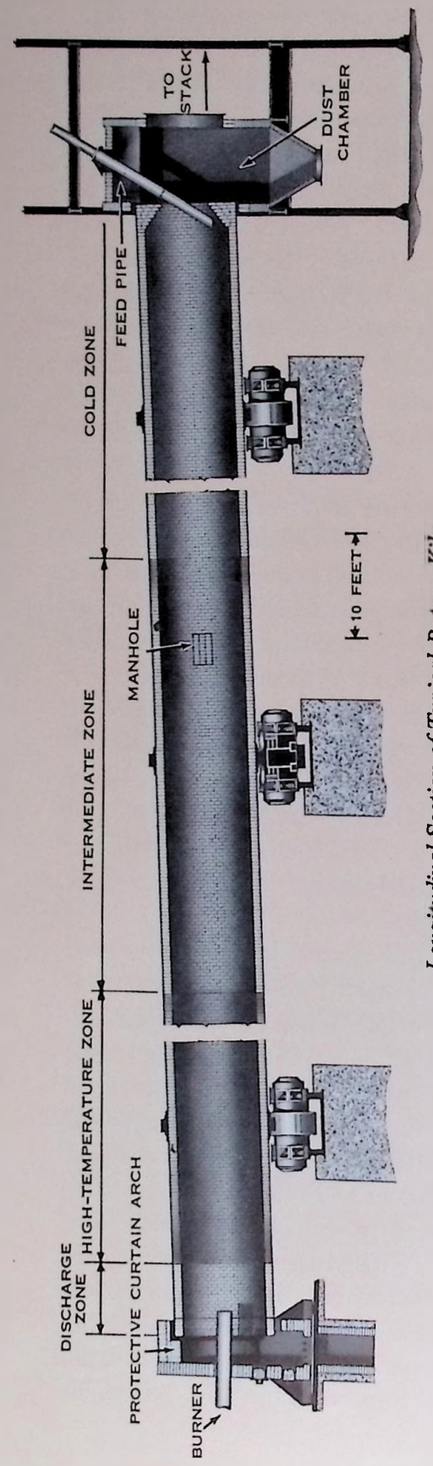
By laying basic brick with steel plates between the joints parallel to the axis of the kiln, a high degree of structural stability is obtained. The steel plates are commonly of 14 or 16 gauge but thicker and thinner plates also are used. The arches and wedges are supplied with the steel plates firmly attached as may be desired. In service, the plates oxidize for a short distance back from the hot face and the iron oxide formed combines in part with the basic refractory material to form a monolithic structure which resists penetration, decreases spalling, and helps to hold the coating. The unaffected portion of the metal reinforces the lining.

In addition to the practice of using brick of a single size for one specific kiln, it is sometimes desirable to use brick of two different sizes in a single kiln. This is particularly advantageous in plants having kilns of different diameters, because it allows kilns of several different sizes to be lined from a stock of only two sizes of kiln brick. For example, a plant with a 9′-0″, a 10′-0″, and an 11′-0″ kiln would need to carry a stock of brick only for the 9′-0″ and 11′-0″ kilns; the 10′-0″ kiln would be lined with approximately equal amounts of brick from both stocks.

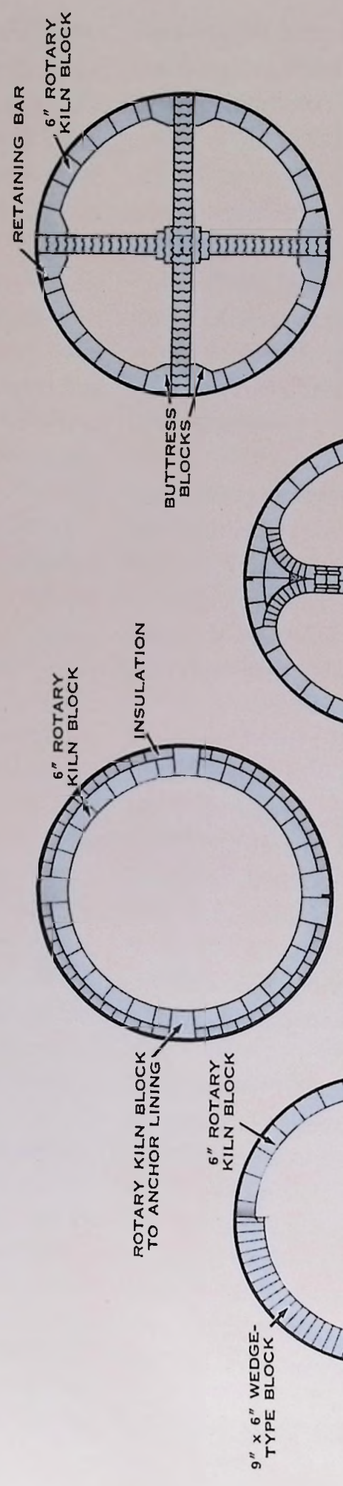
The practice of using a few brick designed for the next size smaller kiln and the next size larger than the kiln being lined is often advantageous to the purpose of installing a tight lining. By following this practice, corrections can be made for variations in kiln diameters, for shell distortions, and for slight variations in brick dimensions and bricklaying.

The steel shells of rotary kilns which have been in use for a long time generally are somewhat warped, particularly in the high-temperature sections. Linings installed in such kilns may be at a considerable disadvantage because of the difficulty in securing tight linings in

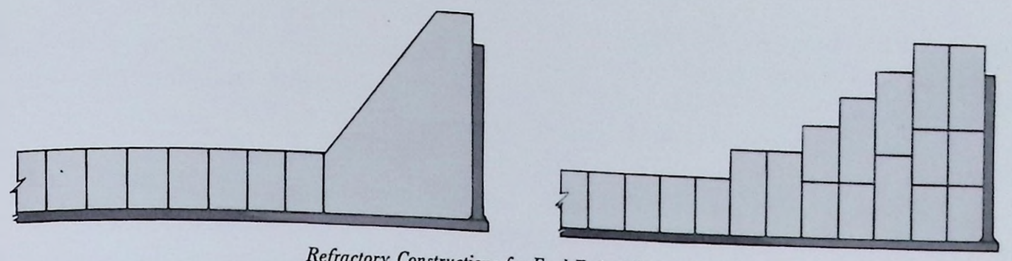
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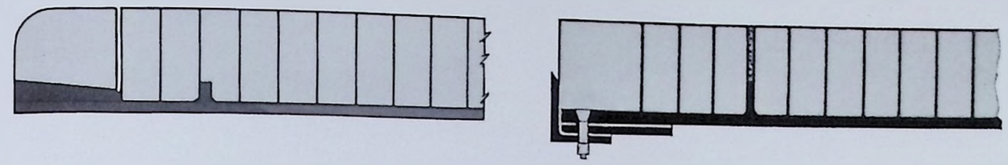
Longitudinal Section of Typical Rotary Kiln



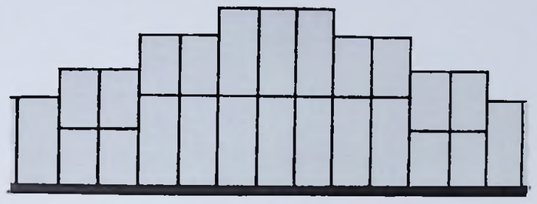
Cross-Sections of Various Designs



Refractory Constructions for Feed End of Rotary Kilns.



Refractory Constructions for Discharge End of Rotary Kilns.



Refractory Dam Construction in Rotary Kilns.

which the brick have uniform bearing with each other around the rings. Arch and wedge types of liners are easier to use than the radial blocks, for the best possible bricklaying workmanship in distorted shells. For even the most substantial shells, the tendency to take a slightly oval shape as rotated, cannot be avoided. The horizontal diameter may be slightly or appreciably greater than the vertical. Particularly in the case of kilns which are operated at very high temperatures, the arch and wedge type of brick can have definite advantages over the usual rotary kiln blocks because of reduced bending moment to which the brick are subjected in kilns which distort circumferentially to a measurable degree.

In order to match kiln size to different volumes of gas and load in different parts of the kiln, single kilns sometimes are made with sections of different diameters. The tapered section between two straight sections of different diameter requires special brick or installation techniques. If the taper is of small slope it is often feasible to use rotary kiln blocks and bed each block in HARWACO MASTIC to eliminate the small space that would otherwise exist between brick and shell. The brick can also be fitted to a tapered section by using a combination of arches and wedges. The tapered section may be lined with special brick with beveled backs to fit the shell. Generally two special brick would be made; one to fit the larger diameter, and the other the smaller diameter. Combinations of the two sizes would take care of all intervening diameters.

Insulation: In the effort to improve efficiency, the insulation of kilns has been practiced with

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varying degrees of success. The insulation has been applied as a separate brick lining between the kiln shell and the working lining of refractory material, as inserts in recesses in strong dense brick shapes, or as an insulating brick lining that in itself is able to withstand the kiln operating conditions. Examples of the first instance are found in the use of a working lining of basic brick with a back-up lining of high-alumina or fireclay brick in some extremely high temperature kilns, particularly when it is not practicable to maintain a coating.

For intermediate- and cold-zone application, ROTOTHERM insulating brick are successfully used as backup for high-duty fireclay brick. ROTOTHERM brick have good strength, they are not friable, and when subjected to pressure and abrasive action, their surface in contact with the harder fireclay refractory tends to compress slightly rather than abrade away.

LOTHERM strong insulating brick are used for intermediate-zone linings of cement kilns directly exposed to operating conditions.

Mortars and Monolithic Materials: Kiln linings are usually laid dry. To lessen the opportunity for penetration of the charge into the joints they are frequently filled with a grout such as HARWACO BOND which has good workability and can flow into all openings. HARWACO BOND is an air-setting high-temperature bonding mortar which gives added strength to all structures in which it is used.

Monolith-forming refractory materials such as H-W EXTRA STRENGTH CASTABLE are used for selected service in many kilns. These materials are used instead of brick in places which are hard to fit such as the linings of chain sections in wet kilns and around discharge ports.

Refractory Heat Exchangers, Lifters, and Dams: Under certain conditions, much can be done to improve the thermal efficiency of rotary kilns by proper placement of refractory heat exchangers, lifters, and dams, all of which function by providing more intimate contact between the kiln load and the hot gases. To meet the service requirements, these structures must be adequate in refractoriness, and also have high mechanical strength and good resistance to spalling. This combination of necessary properties is completely met by several brands of Harbison-Walker refractories.

Various operating factors govern the optimum locations of the heat exchangers, commonly called quadrant and trefoil constructions, because of their designs.

Kiln Accessories: Among other accessories of rotary kilns are firing hoods, dust chambers, and coolers. For these constructions Harbison-Walker has a complete selection of appropriate lining materials.

The firing hood is subjected to spalling, abrasion, and high-temperature conditions. ALAMO brick have the physical and chemical characteristics necessary to withstand these conditions. Sometimes it is advantageous to use monolithic construction, with such refractories as H-W SUPER PLASTIC CS or H-W MULLITE PLASTIC REFRACTORY.

Dust chambers are exposed to a range of conditions varying from moderate temperatures with moist atmosphere and low dust content, to high temperatures with dry atmospheres and abrasive dust. A wide range of medium- and high-duty fireclay brick such as SALAMANDER and WALSH XX have been used successfully in dust chambers. As in the case of firing hoods, it is sometimes advantageous to use monolithic construction. H-W EXTRA STRENGTH CASTABLE is excellent for the purpose.

The operating conditions in a cooler may be severe and refractories requirements are correspondingly important. In the heavily taxed parts of coolers a strong, dense, abrasion-resistant brick of the class of DURO fireclay brick may be required. For extremely hot and abrasive service the toughness and refractoriness of KORUNDAL XD (90 per cent alumina) may be utilized to great advantage.

ROTARY KILNS FOR CEMENT

Stringent specifications for refractories to be used in cement kilns have evolved in response to the service conditions. In the drive for better portland cement, manufacturers have resorted to progressively higher operating temperatures and, step by step, materials of higher refractoriness have been made available to them.

Cement kiln technology involves both wet and dry processes. The feed ends of wet kilns are equipped with suspended chains to help dry the slurry and move it forward in the kiln. To resist abrasion in this section DURO or WYLAM A fireclay brick give unexcelled service. With some designs of chain holders, H-W EXTRA STRENGTH CASTABLE serves with excellent results. In the feed ends of dry-feed kilns, various Harbison-Walker brands of high-duty fireclay brick are used for the linings.

Chemical attack, particularly by lime and alkalies in the mix, becomes a factor in brick wear at the hotter end of the intermediate zone. From this point through the increasingly hotter zones of the kiln, the brick must not only be strong enough to resist the severe mechanical and thermal stresses, but also they must withstand chemical attack. High-alumina brick of the 70 per cent alumina class such as ALUSITE are generally used in the intermediate zone when the burning zone has a basic lining. ALUSITE also gives noteworthy service in the burning zones of many cement kilns. For rigorous demands beyond the ability of even ALUSITE to satisfy, CORALITE, in the 80 per cent alumina class may be used. The characteristics of CORALITE which commend it are high refractoriness, toughness, and resistance to chemical action.

For maximum resistance to chemical attack in burning zones, basic refractories of classes exemplified by MAGNEX, MAGNECON, THERMAG H, or particular modifications of H-W MAGNESITE are used. Under most adverse conditions these brands provide the ultimate in economical service for the high-temperature zone. They are laid with steel plates, or in one of the several modifications of METALKASE brick.

ROTARY KILNS FOR LIME

The most common feed to a rotary lime kiln consists of limestone or dolomite rock, crushed to a maximum particle size of less than 2 to 3 inches. In plants close to a source of supply of marine shells, these are sometimes used. A special type of kiln feed commonly referred to as sludge is obtained as a by-product in paper mills, sugar refineries, and various chemical works. The material is usually a slurry or paste of calcium hydroxide or carbonate.

When limestone is calcined, abrasive action of the stone may be severe, especially at the feed end. In the calcining zone, the lime tends to flux the refractories, as does ash from oil or

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powdered coal fuel. Most linings are subject to the formation of rings, which are removed periodically. Cooling of a kiln, for removal of a ring, may cause the lining to spall.

When lime sludge is calcined, the lining at the feed end must be able to withstand the thermal shock of alternate exposure to hot kiln gases and cold, wet sludge. In addition, many lime sludge kilns are equipped with chain systems. These units call for refractories which withstand mechanical shock and wear. The intermediate zone of lime sludge kilns is not subjected to much abrasion. In the calcining zone the lining is exposed at high temperature to corrosion by lime, alkalies, and fuel ash.

Throughout the kiln each service condition is matched by appropriate brands to give the greatest over-all economy. A typical lining for a stone kiln consists of DURO fireclay brick to resist abrasion at the feed end, VARNON superduty fireclay brick to resist both abrasion and higher temperatures of the intermediate zone, and ALUSITE 70 per cent alumina brick to withstand calcining zone conditions. A typical lining for a sludge kiln consists of DURO or WALSH T to resist abrasion by chains and spalling at the feed end, ALAMO or VARNON to resist the higher temperatures and incipient chemical action of the intermediate zone, and ALUSITE to withstand the calcining zone conditions. For relatively gradual changes from the intermediate zone to calcining zone conditions it may be desirable to interpose a section of ANCHOR, a 60 per cent alumina brick with excellent resistance to corrosion and abrasion at relatively high temperatures.

Under conditions of higher calcining temperatures needed for certain less reactive types of lime or of greater fluxing action resulting from alkalies present in many sludge feeds, it may be economical to use CORALITE 80 per cent alumina brick or the basic refractories FORSTERITE and THERMAG H. In burning lime of highest purity, H-W PERIKLASE is used.

MISCELLANEOUS ROTARY KILN PRACTICE

With few exceptions the cooler zones of rotary kilns are subjected primarily to abrasion which may be supplemented by impact of solid feed. The brick for such service need to have adequate toughness and strength as well as suitable refractoriness. DURO and WYLAM A and other strong high-duty fireclay brick are used.

The zone of highest temperature of some kilns is often subjected to severe abrasion in addition to relatively high temperatures. Such is the case in iron ore sintering kilns which require a superduty fireclay brick. ALAMO S DOT, having great resistance to mechanical damage, is especially suited for this service. Superduty fireclay brick including VARNON, ALAMO, BOONE, and H-W SUPER SAVAGE give excellent service in the hot zones of kilns used for treating phosphate rock, for making lightweight aggregate, for reduction of barytes to barium sulfide, for processing gypsum, for chloridizing uranium ores, for distilling mercury from cinnabar, and for sintering manganese dioxide. Under some specific conditions, the high-duty fireclay brick H-W CROWN, WALSH XX, H-W SPECIAL, WESTERN, and other H-W brands are used in high-temperature zones.

The high-temperature zones of kilns used to produce activated carbon and to calcine alumina and petroleum coke are lined with VARNON high-fired superduty fireclay brick. These brick have great stability of mineral constitution and increased resistance to abrasion, corrosion, and carbon disintegration.

The high-temperature zones of kilns used for producing dead-burned magnesite and dolomite operate at temperatures beyond the service range of fireclay brick. Hence, basic refractories such as FORSTERITE, MAGNECON, or THERMAG H, or the high-alumina refractories ALUSITE or CORALITE should be used.

Some kilns process materials that form melts of corrosive nature at relatively low temperatures. Typical are lithium-bearing ores for which the kiln lining must be high-alumina or basic material to resist the chemical attack even though the temperature is moderate.

SOAKING PITS

SOAKING PITS are furnaces in which steel ingots are heated to the proper temperature before primary rolling into blooms or slabs. The pits are refractory-lined, open at the top, and equipped with movable covers to facilitate handling of the large, heavy ingots.

Mixed blast-furnace and coke-oven gas is by far the most widely used fuel for firing soaking pits in integrated steel plants but natural gas and fuel oil are also in common use. Pits may be rectangular, square, or circular. They are fired from either the end, side, or bottom. Nearly all new pits as built today include recuperators for preheating combustion air. However, a great many regenerative pits are still in operation and a few pits have no provision for preheating the air.

While operating temperatures are relatively moderate, usually ranging from 2200° to 2600° F., service conditions to which the refractories are exposed are frequently severe, particularly over the high-temperature range. Opening of the pit for withdrawing ingots or for charging may cause a sudden drop in temperature of hundreds of degrees. When the pit is closed, heating is correspondingly rapid.

The bottoms of soaking pits are built of supported steel pans. Refractory construction generally consists of a course of insulating firebrick such as H-W 20 placed directly upon the steel pan, with 13½ to 18 inches of high-duty fireclay brick superimposed. In conventional practice, it is usual to place a bed of coke breeze, 10 to 15 inches thick, on top of the refractory bottom in order to absorb scale, serve as a bed for seating the ingots, and conserve heat. In dry-bottom practice, where coke breeze is not used, severe service calls for the use of hard-burned superduty fireclay brick, 70 per cent alumina brick, or basic brick in the bottom. VARNON BF superduty fireclay brick, ALUSITE high-alumina brick, and CHROMEX B basic brick serve well in this application, as does also PLASTIC THERMOLITH BATCH.

In the lower walls, the brick are subjected to corrosive action of molten iron oxide scale. While a wide variety of basic brick have been used in this application, in many cases METALKASE MAGNEX brick have given the best all-round performance under a variety of operating conditions. These brick are resistant to attack by scale and by coke ash at high temperatures and also to the spalling conditions which arise if the bed of coke breeze is frequently renewed. Of the burned type of basic brick, CHROMEX B has generally been considered most satisfactory. ALUSITE high-alumina brick give excellent results in lower walls and in many cases have

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proved to be most economical of all, especially where the extreme upper range of temperatures is not reached. H-W Special Furnace Chrome and Thermolith are the best mortars for laying the brick in the lower wall sections.

The upper walls frequently are built with Kaosil semi-silica fireclay brick, which in service tend to acquire a glaze which contributes to longer life. Kaosil brick withstand the rapid temperature changes and possess the desirable properties of volume stability and rigidity at the working temperature.

For brick in the upper walls, resistance to deformation under load at operating temperature as well as to abrasion, impact, and rapid temperature change is most important. Varnon and Kenmore hard-fired superduty fireclay brick give excellent results in upper walls of pits, particularly those of circular design.

The top of the walls of a pit is capped with curb tile, which usually consist of high-duty or superduty fireclay material, and which must have adequate strength to withstand impact and abrasion resulting from handling of the ingots.

In the selection of pit cover refractories, volume stability and resistance to thermal spalling are important considerations. While in some instances domed pit covers are built of rectangular brick sizes, the use of suspended arch shapes has been widely adopted. High mechanical strength is desirable in these special shapes. Highest standards of workmanship are of paramount importance to secure the close fit necessary for best results. Harbison-Walker special arch shapes fulfill the most rigid requirements. They are generally laid with heat-setting mortars such as Kaosil Fire Clay or H-W Superduty Mortar. When an air-setting mortar is desired, Harwaco Bond may be used.

Kaosil semi-silica fireclay brick perform exceedingly well in soaking-pit covers because of their volume stability and resistance to thermal shock within the normal range of pit operating temperatures. Other widely used brands include the high-duty fireclay brick Woodland X, Walsh XX, H-W Crown, H-W Savage, and Coleman XX. Superduty fireclay brick, including Alamo and Varnon, give best service where conditions are especially severe. The corresponding H-W brands of fireclay brick made in California, Western high-duty and Zenith superduty, afford the advantages of closer proximity to the western steel plants. Where lightness of weight is a requisite, H-W 28 insulating firebrick may be preferred.

In recent years, excellent service has been obtained from monolithic refractories for upper pit walls, copings, and covers. H-W Super Plastic CS, supported by an improved system of anchoring, is giving superior results. It is entirely volume-stable at normal pit operating temperatures and has exceptional resistance to thermal shock. Among its characteristic properties are excellent workability and very high density when rammed into place.

In regenerative-fired pits, dense high-duty fireclay brick are preferred for the checker chambers and checkers. Flue connections may be built of medium-duty fireclay brick such as Webster, Salamander, Wylam, or Coleman.

The Harbison-Walker high standard of quality and workmanship, for the various designs of intricate shapes required in recuperator construction, is widely recognized. These shapes are available in high-duty and superduty fireclay, and high-alumina brands. Leakage of gases in the recuperators is kept to a minimum by laying the brick with Harwaco Bond.

H-W 20, H-W 23, and H-W Block Insulation, either singly or in combination, are extensively used for insulating soaking-pit walls, regenerator chambers, and covers.

SODIUM SILICATE FURNACES

Sodium silicates are made by fusing together silica sand and a sodium compound, generally sodium carbonate (commercially termed soda ash), to form simple glasses having widely diversified ratios of soda to silica. These products are commonly referred to as soluble silicates, and in their comprehensive range of compositions are especially suited for numerous industrial applications, such as adhesives, clay deflocculants, cleansers, ore flotation, and pharmaceuticals, and the bonding of ceramics.

The melting is done in furnaces of both side- and end-port designs, closely similar to the furnaces used in making glass. The economical operation of the furnaces used in the production of sodium silicates (and potassium silicate in lesser amounts) in a large measure depends upon the refractories of which the furnaces are built. In many plants, including those in which all the commercial grades of these alkaline silicates are manufactured, Harbison-Walker refractories are established standards.

The high alkalinity of the batch and the temperatures necessary for fusion impose severe conditions on the refractories in the tank. The regenerators, including the checker settings, are subjected to a very corrosive action by batch dust carry-over and volatile alkalies.

For the bottoms and walls of the usual sodium silicate furnaces, Varnon D, a highly impervious superduty fireclay brick of extra hard burn, is singularly adapted. This brand or its slight modification, Varnon S, may be used to advantage in the breast walls and roofs. The high-alumina brands, H-W Mullite (70 per cent Al_2O_3) and Dialite Dot of the 45 per cent alumina class, when used in upper walls and roofs, provide an extra margin of durability for extremely severe conditions.

Korundal XD, a mullite-bonded corundum refractory of 90 per cent alumina content, is used in various vulnerable positions, primarily for balancing service life of the entire furnace. It serves to advantage in places where the operating conditions are too severe for refractories of the types used in the major portions of the furnaces, as in ports, around the tapping holes and for tuckstones.

Forsterite L, a magnesium-silicate refractory, has become much used in regenerator walls and crowns and for checkers. This brand surpasses the many different kinds of alumina-silica refractories in the service secured from various parts of regenerators. Included in the category of Harbison-Walker basic brick for use in regenerators are several periclase compositions having bonds of forsterite, magnesium-aluminate spinel and other spinels.

Kaosil, a unique semi-silica fireclay brick, sometimes is used with considerable benefit for insulating basic brick regenerator walls. Various H-W insulating firebrick provide higher degrees of insulation.

Among the complete range of refractories widely used in this industry are Harbison-Walker brands of high-duty and superduty fireclay brick furnished from many locations, which facilitates delivery time and lowest transportation costs. Various superduty fireclay brick are used most economically beneath the basic brick checkers and in the settings at the cooler ports. These brands include Varnon S, Alamo S, Dean S, Kenmore, and others.

The use of the proper bonding mortars in the classes corresponding to the brick in various parts of the furnace contributes to maximum refractories service. These mortars are described in detail on pages 138 to 146.

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ZINC

The several types of furnaces which are most widely used in the reduction of zinc ore to metallic zinc include the horizontal retort furnace, commonly referred to as the Belgian retort furnace, the continuous vertical retort furnace, and the electrothermic furnace of vertical shaft construction. Fundamentally, in furnaces of all three types zinc is liberated by the reduction-distillation process.

The ore, consisting principally of sulfides, is roasted and/or sintered prior to treatment in any of the extraction processes. Information on roaster brick is given on page 443 for multiple-hearth and flash roasters, and page 387 for fluidized-solids roasters.

Unlike most metals, zinc is reduced from its oxide at a temperature which is higher than its boiling point. Thus, the zinc is liberated in vapor form and must be condensed. Special consideration must be given to the design of zinc distillation furnaces, to avoid appreciable losses of zinc vapors. Careful selection of the refractories is important for most efficient and dependable furnace operation. Properties of prime importance are high density and low permeability to minimize penetration and possible subsequent condensation of zinc vapors within the refractories. The iron oxide content of the refractories should be low, for least reaction with the zinc. The many different products of Harbison-Walker include refractories best adapted for use in the various types of zinc furnaces.

Horizontal or Belgian Retort Furnace: A furnace of this type consists of two long longitudinal compartments, and contains several hundred cylindrical retorts. These are approximately 8 inches in inside diameter, by 54 to 60 inches long. The closed or butt ends of opposite retorts are supported on a common division wall, and the open ends rest in apertures in the outside furnace walls. The retorts are charged with roasted zinc ore concentrates, or with sintered pellets or nodules, mixed with crushed coal or other suitable carbonaceous material. As the charge is heated by the conduction of heat from the furnace chamber through the retort wall, the zinc oxide is reduced to zinc. The retorts are fitted with conical condensers, usually of fireclay composition, in which the zinc vapors are cooled and collected as liquid.

The division walls of zinc distillation furnaces are subjected to very severe conditions imposed by the combination of soaking heat and heavy load. The Harbison-Walker brands of fireclay brick WALSH T, ALAMO, and VARNON, and STAR silica brick, which serve this purpose, have rigidity and strength at high temperatures and the refractoriness necessary to endure the long-continued soaking heat. The high quality of workmanship of the special shapes and standard sizes contributes its part to the excellent service secured. STAR silica brick are well adapted to service in center walls and shelves in zinc distillation furnaces, especially with natural gas firing.

With raw producer gas as fuel, the fluxing action of slag particularly on silica brickwork in the combustion chamber may be severe. ALAMO and VARNON superduty fireclay brick are highly resistant to this action. For the production of zinc retorts and condensers, Harbison-Walker special plastic bonding and calcined clays serve as raw materials.

Vertical Retort Furnace: A battery of vertical retorts includes several furnaces, each of which contains one retort. An individual retort consists of a rectangular compartment having two parallel sidewalls and two massive end walls, with a superimposed refractory extension into which the charge is fed. Outside and parallel to the sidewalls of the retorts are heating chambers, in which a uniform temperature is maintained. From these chambers, heat is conducted through the retort sidewalls and into the retorts. Each retort has effective internal dimensions of about 1 foot by 6 to 8 feet, and is between 30 and 40 feet high. Silicon carbide brick, usually 4½ inches thick, are used for the construction of the parallel sidewalls of the retorts. The ends of these sidewalls are fitted into vertical slots in a silicon carbide portion of the end walls to permit some movement of the walls due to thermal expansion. Granular silicon carbide and graphite used as a fill in the slots make slip joints which prevent leakage of zinc vapor.

The reduction of zinc in a vertical retort furnace is a continuous process. Roasted zinc ore concentrate, together with reducing carbon, is charged periodically into the top of the retort in the form of coked briquettes. As the slowly descending column of briquettes is heated to reduction temperature, the zinc vapor and carbon monoxide evolved pass through an offtake duct to a condenser where the zinc is collected in liquid form.

STAR silica brick have established excellent records for service in the ends of the furnace back of the silicon carbide, and also in the exterior sidewalls. KAOSIL semi-silica fireclay brick, which also have good strength at high temperatures, may be used instead of STAR. VARNON superduty fireclay brick are used in the upper structure, and H-W silicon carbide refractories are recommended for the walls of the retorts. For the recuperator, VARNON and KENMORE superduty brick are used, and extra hard-burned DIALITE, 50 per cent alumina brick, are well adapted to service in the recuperator base.

Electrothermic Furnace: This is a refractory-lined vertical cylindrical furnace about 40 feet high, with a rotary feed distributor at the top and a circular discharge table at the bottom from which the spent residue is withdrawn. Graphite electrodes are projected into the charge through the furnace walls in the upper and lower parts of the furnace, and the charge in between serves as the resistor or heating element. At the mid-section, the furnace is surrounded by a large vapor-collection ring, through which the zinc vapors and other furnace gases are withdrawn.

The sintered charge along with coke is preheated in a horizontal rotary furnace prior to entering the furnace. The feed mixture is distributed around the periphery of the furnace by the distributor at the top, and the larger coke particles tend to roll toward the center of the furnace. The preponderance of coke in this zone forms a resistance core with an electrical conductivity somewhat higher than that of the material nearer the periphery, causing the current to flow down the center of the furnace. This is necessary for promoting a controlled heating of the charge and to prevent damage to the refractory walls through localized overheating. The zinc oxide in the sinter is reduced, and the zinc vapor is withdrawn through the vapor ring and collected in a condenser.

The refractory linings for the most part consist of dense high-duty fireclay brick such as WALSH S. VARNON BF high-fired superduty fireclay brick are used in the upper portions of the furnace to resist the destructive action of high concentrations of carbon monoxide gas. The discharge table is lined with various H-W brands of high-duty fireclay brick, possessing the particular properties required for the purpose. HARBIDE, H-W silicon carbide brick, are

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recommended for use in positions where abrasion is especially severe. These positions include the distributor top, the outer wall of the vapor ring, and the linings of the condensers and rotary preheaters.

Zinc Oxide Furnace: Over many years, STAR silica brick have given superior service in the walls and roofs of zinc oxide furnaces. High-duty fireclay brick made by deaired extrusion and by the vacuum power-press processes also give excellent service in many such furnaces. Commonly used brands are WALSH XX, WALSH T, and WOODLAND.

Rotary Recovery Furnaces: Rotary kilns are used for the recovery of secondary zinc from scrap and from the residue of zinc retorts. The linings must be resistant to the action of the slag and to the destructive influences of carbon monoxide gas. WALSH T and other H-W hard-burned high-duty fireclay brick, VARNON and KENMORE high-fired superduty fireclay brick, and in some cases STAR silica brick give excellent service.

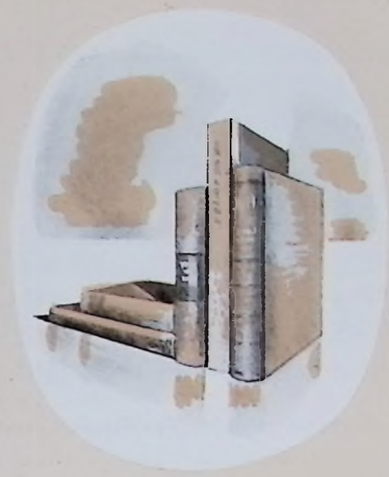
Zinc-Melting Furnaces: The choice of refractories for these furnaces involves several distinct types and classes, in order to secure the best well-balanced service, and to avoid maintenance expense in any part of the furnace in advance of the usual general repairs. High-duty dense fireclay brick, such as WALSH T, and ALUSITE high-alumina brick are used with excellent results for the construction of bottoms and lower sidewalls, with WALSH XX in the upper walls and usually in the roof. ALAMO superduty fireclay brick give outstanding service in combustion chambers and for severe conditions in the roofs as well. HARWACO BOND mortar is used for laying all the brick in the entire furnace structure.

Zinc Refining: The low boiling point of zinc makes practicable refinement by heat, to an exceedingly high degree of purity. A series of furnace constructions is employed for the fractional distillation to remove lead and cadmium. The zinc is boiled in a reverberatory type of furnace for which Harbison-Walker high-duty and superduty fireclay brick of the hard-fired type are used with resultant long service. An adjoining fractionating column is provided with refractory trays made of silicon carbide or superduty fire clay, over which the molten metal cascades. The zinc and cadmium are separated from the lead by distillation. In a much higher column of trays, the cadmium is distilled off just below the boiling point of the zinc. Harbison-Walker superduty fireclay brick with HARWACO BOND mortar are used successfully for these constructions. These same refractories give long service in the liquating accessory.

Other Zinc-Furnace Refractories: Some of the different kinds of furnaces used in zinc metallurgy but not referred to above are fuel fired while others are electrically heated. The operating conditions differ widely. The refractories which serve most economically comprise a wide range which embraces basic brick, plastic and castable monolith-forming refractories, and insulating materials, including insulating firebrick, block insulation, and various lightweight castables.

Mortars: THERMOLITH, FIREBOND, and HARWACO BOND bonding mortars are contributing much to the long service obtained from Harbison-Walker refractories in zinc furnaces.

Auxiliaries: In some plants, the sulfur dioxide gas which is liberated during the roasting of the sulfide ore is utilized in the production of sulfuric acid. DURO and W-ACID acid-proof brick are widely used for linings and packing of sulfuric acid towers, and are suitable for linings and insulators of electrolytic zinc cells.



GENERAL INFORMATION OF INTEREST IN CONNECTION WITH REFRACTORIES

HARBISON-WALKER REFRACTORIES COMPANY

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ESTIMATING QUANTITIES OF REFRACTORIES

Number of Brick Per Cubic Foot: A cubic foot of brickwork requires 17.1 standard 9″ Straights (9″ x 4½″ x 2½″) or 14.2 standard 9 x 4½ x 3 Straights.

Number of Cubic Feet Per 1000 Brick: The volume of 1000 standard 9″ Straights (9″ x 4½″ x 2½″), closely stacked, is approximately 60 cubic feet; that of 1000 standard 9 x 4½ x 3 Straights is approximately 71 cubic feet.

Number of Brick Per Square Foot of Wall

Thickness of Wall	9″ Straights (9″ x 4½″ x 2½″)	9 x 4½ x 3 Straights
2½″	3.56	....
3″	....	3.56
4½″	6.4	5.3
9″	12.8	10.7
13½″	19.2	16.0
18″	25.6	21.3
22½″	32.0	26.7
27″	38.4	32.0

Number of Brick for Rings and for Arches: The combinations of brick required for complete rings of various diameters and various thicknesses will be found in the tables on pages 537 to 558. For arches of various spans and rises the combinations of brick required are given in the tables on pages 561 to 576.

The numbers of brick required for rings or arches not covered by the tables can be determined by calculation from formulas. For rings, the formulas are given on pages 521 and 525; use of the formulas is explained on pages 522 to 524, and 526 and 527. For arches, the formulas and a table of arch constants appear on page 529. Use of the arch formulas and constants is explained and illustrated on pages 530 to 534.

Extra Straights and Sizes: In placing orders for 9-inch (9″ x 4½″ x 2½″) and 9 x 4½ x 3-inch Straights, it is customary and good practice to add small percentages to net counts to take care of breakage and cutting. An adequate number of complementary sizes should be included to facilitate laying. For 9-inch (9″ x 4½″ x 2½″) Straights, joints may be broken with Large 9″ Straights (9″ x 6¾″ x 2½″) and 13½ x 4½ x 2½-inch Straights, and 9″ Splits and 9″-2″ Splits may be used for leveling courses. For 9 x 4½ x 3-inch Straights, joints may be broken with 9 x 6¾ x 3-inch Straights and 13½ x 4½ x 3-inch Straights, and 9 x 4½ x 1½-inch Splits may be used for leveling courses.

Table XXX.

Suggested Extra Quantities — Standard Sizes

A. Extra brick for breaking joints and leveling courses.

Net Amounts of	Add to Net Amounts in Ordering					
9″ Straights (9″x4½″x2½″) 9x4½x3-inch Straights	Large 9″ Straights (9″x6¾″x2½″) 9x6¾x3 Straights	13½x4½x2½ Straights 13½x4½x3 Straights	9″ Splits (9″x4½″x1¼″) 9x4½x1½ Splits	9″-2″ Splits (9″x4½″x2″) 9″-2″ Splits (9″x4½″x2″)	Small 9″ Straights (9″x3½″x2½″) 9x3½x3 Straights	9″ Soaps (9″x2½″x2¼″) 9x3x2¼ Soaps
Less than 250	5%	2½%	2½%	2½%	∽1%	∽1%
250 to 5,000	4%	2%	2%	2%	∽1%	∽1%
Over 5,000	2%	1%	1%	1%	∽1%	∽1%

∽ = Approximate.

Table XXX, Continued

B. Extra pieces to allow for cutting and breakage.

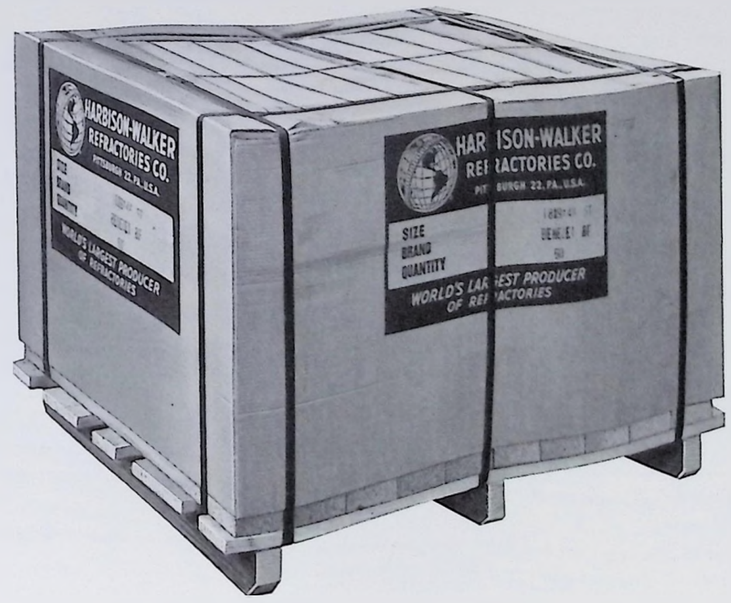
Net Amounts of Standard Sizes	Add to Net Amounts in Ordering
Less than 250	10%
250 to 1,500	5%
1,501 to 5,000	3%
Over 5,000	2%

In addition, the use of some Small 9″ Straights (9″ x 3½″ x 2½″) and 9″ Soaps (9″ x 2½″ x 2¼″) with 9-inch Straights (9″ x 4½″ x 2½″), and 9 x 3½ x 3-inch Straights and 9 x 3 x 2¼-inch Soaps with 9 x 4½ x 3-inch Straights is usually advantageous. The extra amounts shown in Table XXX will usually be sufficient. However, the actual number of extra pieces required for any particular job will depend upon local conditions.



Left: *Typical Containers for Shipment of Monolithic Refractories and Some Mortars.*

Illustration includes standard Harbison-Walker drum, sack, and carton.



Below: *Typical Pallet Unit, Showing Corrugated Paper Covering and Metal Straps for Protection of the Brick During Transit.*

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Overshipments: In filling orders for *special shapes*, it is necessary to make a slightly larger number of shapes than specified, in order to take care of possible breakage during the firing. Some or even all of the extra pieces may come from the kilns in perfect condition. Therefore, the company will ship a limited prescribed quantity of extra pieces, if available, on any given order. This procedure also helps to assure avoidance of shortages resulting from breakage in transit and handling at destination.

Overages in accordance with the following table are allowable on all shipments of sizes and shapes that are not carried in stock.

Quantity Specified	Allowable Overage
1 – 100	10%*
101 – 1,000	7%
1,001 – 5,000	3%
5,001 – 10,000	2%
Over – 10,000	1%

* Not less than one shape. If in sets, one complete set.

Table XXXI.
APPROXIMATE WEIGHTS OF REFRACTORY BRICK

Kind of Brick	Pounds Per Cubic Foot	Pounds Per 9-Inch Straight (9″ x 4½″ x 2½″)
Acid-Proof	135 – 150	7.9 – 8.8
Basic*		
Chrome and Chrome-Magnesite	185 – 205	10.8 – 12.0
Magnesite and Magnesite-Chrome	170 – 197	10.0 – 11.5
Forsterite	155 – 168	9.1 – 9.8
Fireclay		
Superduty	135 – 154	7.9 – 9.0
High-, Medium-, and Low-Duty	120 – 145	7.0 – 8.5
Semi-Silica	115 – 125	6.7 – 7.3
High-Alumina		
50 to 70% Alumina Classes	140 – 160	8.2 – 9.4
80% Alumina Class	155 – 180	9.1 – 10.5
90% Alumina Class	165 – 190	9.7 – 11.1
Mullite	145 – 165	7.0 – 9.7
Corundum (99+% Alumina)	170 – 200	10.0 – 11.7
Insulating Firebrick	30 – 85	1.8 – 5.0
Ladle Brick	130 – 145	7.6 – 8.5
Silica	105 – 118	6.2 – 6.9
Silicon Carbide	145 – 165	8.5 – 9.7
Zircon	210 – 235	12.3 – 13.6

* Metal-encased basic brick weigh about 0.9 pounds more per 9-inch straight, or 15 pounds more per cubic foot, than brick without the casings.

NOTE: The weights of refractory brick depend upon the densities of the raw materials from which they are made, and upon the process of manufacture and the firing conditions.

Table XXXII.
WEIGHTS OF MONOLITH-FORMING REFRACTORIES*
Plastic Refractories, Ramming Mixes, Gun Mixes, and Castables

Type and Class	Approximate Weight Per Cubic Foot In Place, After Drying at 230°F
Basic	
Dead-Burned Magnesite	165 – 175
Chrome	170 – 185
Fireclay	
Superduty	120 – 140
High-Duty	115 – 135
High-Alumina	
50 and 60% Alumina	130 – 140
70 and 80% Alumina	150 – 175
90 and 99% Alumina	155 – 185
Insulating	25 – 90
Silica	130 – 135
Zircon	200 – 210

* For information concerning the amount of material required per cubic foot of construction of specific brands, refer to pages 152 and 153.

Table XXXIII.
WEIGHTS OF SOME OTHER REFRACTORY MATERIALS

Kind of Material	Approximate Weight Per Cubic Foot As Shipped
Basic	
Magnesite and Periclase Grains, dead-burned	110 – 120
Chrome Ore, lump form	150 – 155
Dolomite, dead-burned grains	112 – 124
Fireclay	
Calcined, 1-inch lumps, including fines	95 – 100
Calcined, fine ground	90
Dried Dobies, unground	120
Dried Dobies, ground	80
Raw Plastic Bond Clays, unground	85 – 90
Raw Plastic Bond Clays, ground	75 – 80
Insulating	
Block Insulation	21
Mineral Fiber Coating	23
Silica	
Silica Fire Clay, ground	100
Ground Quartzite	120

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Table XXXIV.

APPROXIMATE AMOUNTS OF MORTAR MATERIAL REQUIRED FOR LAYING BRICK

Mortar Material	Form as Shipped	Pounds of Mortar Per 1000 Standard 9-Inch Brick (9″ x 4½″ x 2½″)* Brick Laid Dry and Grouted	Brick Laid with Dipped or Thinly Troweled Joints
Heat-Setting Mortars			
H-W High-Duty Fire Clay	Dry	200 – 250	300 – 400
H-W Special Mortar	Dry	200 – 250	300 – 400
H-W Superduty Mortar	Dry	200 – 250	300 – 400
H-W Weathered Bond B Clay	Dry	200 – 250	300 – 400
Kaosil Fire Clay	Dry	200 – 250	300 – 400
Ankorite 65	Dry	250 – 300	350 – 450
H-W Star Silica Fire Clay	Dry	200 – 250	300 – 400
H-W Coke Oven Silica Fire Clay	Dry	Not used	400 – 600
Starbond	Dry	200 – 250	300 – 400
Vega Bond	Dry	200 – 250	300 – 400
H-W Washington Furnace Magnesite	Dry	Not used**	500 – 600**
H-W Special Furnace Chrome	Dry	400 – 500	600 – 750
H-W Insulating Brick Mortar	Dry	Not used	250 – 350
Harbide Bonding Mortar	Dry	275 – 325	375 – 475
Air-Setting Mortars			
Penseal	Wet	250 – 300	350 – 450
Harwaco Bond	Wet	250 – 300	350 – 450
Harwaco Bond (Dry)	Dry	200 – 250	300 – 400
H-W Super Harbond	Wet	250 – 300	350 – 450
Coralite Bonding Mortar	Wet	275 – 325	375 – 475
Coralbond	Wet	Not used	400 – 600
Korundal Bonding Mortar	Dry	275 – 325	375 – 475
H-W Corundum Bonding Mortar	Dry	300 – 400	450 – 600
Firebond	Dry	200 – 250	300 – 400
Forsterite Bonding Mortar	Dry	300 – 400	500 – 600
H-W Periklase Bonding Mortar	Dry	300 – 400	500 – 600
Thermolith	Dry	400 – 500	600 – 750
H-W Alkamortar	Dry	Not used	400 – 600
H-W Zircon Bonding Mortar	Dry	450 – 550	650 – 800

* This is for 9-inch straights. Normally, for larger sizes the quantities required are reduced in proportion to the decrease in surface area covered by the mortar per 1000 9-inch equivalent.
NOTE: Minimum figures are used ordinarily for estimating.

** Water not recommended for mixing (see pages 142 and 143).

WEIGHTS OF VARIOUS MATERIALS

Material	Average Weight Per Cubic Foot
Brick	
Building	100 – 135
Cement	
Portland, loose	90
Portland, set	180
Concrete	140 – 160
Coal and Coke	
Anthracite, loose lumps	50 – 55
Bituminous, loose lumps	45 – 50
Coke, loose lumps	25 – 29
Earth	
Loam, dry, loose	76
Loam, dry, packed	95
Loam, soft, loose mud	108
Loam, dense mud	115
Glass	156
Gravel	
Dry, packed	100 – 120
Wet, packed	120
Lime	
Mortar	100
Quick, loose lumps	53
Quick, fine	75
Stone, solid	166
Stone, crushed	90 – 100
Masonry	
Dry	110 – 130
Mortar rubble	130 – 155
Ashlar	140 – 165
Metals	
Aluminum	166
Brass, cast	534
Copper, cast	537
Copper, rolled or wire	555
Iron, gray cast	445
Iron, white cast	475
Iron, wrought	490
Lead	710
Nickel	537
Steel, cast or rolled	490
Tin, cast	455
Uranium	1192
Zinc, cast	443

Material	Average Weight Per Cubic Foot
Oils	
Crude	54
Fuel Oil	
No. 1	51
No. 2	53
No. 3	54
Bunker C	62
Gasoline	45
Kerosene	50
Lubricating Oil	55
Rocks in solid	
Chalk	147
Dolomite	178
Granite	175
Gypsum	145
Limestone and Marble	166
Magnesite	190
Pumice	50
Quartz	165
Sandstone	162
Shale	170
Slate, American	175
Soapstone, talc	170
Sand	
Dry, loose	100
Dry, packed	110
Wet, packed	120
Water	
As ice	58.7
At 39.2°F.	62.425
At 60°F.	62.37
At 212°F.	59.76
Wood, Dry	
Hemlock	25 – 29
Hickory	45 – 50
Mahogany	45 – 50
Maple, hard	43 – 48
Oak, live	55 – 59
Oak, red, black	40 – 41
Oak, white	46 – 50
Pine, white	25 – 26
Pine, yellow short leaf	34 – 38
Pine, yellow long leaf	44 – 45
Spruce	25 – 27

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TEMPERATURE CONVERSION TABLE

By Albert Sauveur

0 to 100					100 to 1000				1000 to 2000					
C.		F.	C.		F.	C.		F.	C.		F.	C.		F.
—17.8	0	32.0	10.0	50	122.0	37.8	100	212	260	500	932	538	1000	1832	816	1500	2732
—17.2	1	33.8	10.6	51	123.8	38	101	214	266	510	950	543	1010	1850	821	1510	2750
—16.7	2	35.6	11.1	52	125.6	39	102	216	271	520	968	549	1020	1868	827	1520	2768
—16.1	3	37.4	11.7	53	127.4	39	103	217	277	530	986	554	1030	1886	832	1530	2786
—15.6	4	39.2	12.2	54	129.2	40	104	219	282	540	1004	560	1040	1904	838	1540	2804
—15.0	5	41.0	12.8	55	131.0	41	105	221	288	550	1022	566	1050	1922	843	1550	2822
—14.4	6	42.8	13.3	56	132.8	41	106	223	293	560	1040	571	1060	1940	849	1560	2840
—13.9	7	44.6	13.9	57	134.6	42	107	225	299	570	1058	577	1070	1958	854	1570	2858
—13.3	8	46.4	14.4	58	136.4	42	108	226	304	580	1076	582	1080	1976	860	1580	2876
—12.8	9	48.2	15.0	59	138.2	43	109	228	310	590	1094	588	1090	1994	866	1590	2894
—12.2	10	50.0	15.6	60	140.0	43	110	230	316	600	1112	593	1100	2012	871	1600	2912
—11.7	11	51.8	16.1	61	141.8	49	120	248	321	610	1130	599	1110	2030	877	1610	2930
—11.1	12	53.6	16.7	62	143.6	54	130	266	327	620	1148	604	1120	2048	882	1620	2948
—10.6	13	55.4	17.2	63	145.4	60	140	284	332	630	1166	610	1130	2066	888	1630	2966
—10.0	14	57.2	17.8	64	147.2	66	150	302	338	640	1184	616	1140	2084	893	1640	2984
— 9.44	15	59.0	18.3	65	149.0	71	160	320	343	650	1202	621	1150	2102	899	1650	3002
— 8.89	16	60.8	18.9	66	150.8	77	170	338	349	660	1220	627	1160	2120	904	1660	3020
— 8.33	17	62.6	19.4	67	152.6	82	180	356	354	670	1238	632	1170	2138	910	1670	3038
— 7.78	18	64.4	20.0	68	154.4	88	190	374	360	680	1256	638	1180	2156	916	1680	3056
— 7.22	19	66.2	20.6	69	156.2	93	200	392	366	690	1274	643	1190	2174	921	1690	3074
— 6.67	20	68.0	21.1	70	158.0	99	210	410	371	700	1292	649	1200	2192	927	1700	3092
— 6.11	21	69.8	21.7	71	159.8	100	212	413.6	377	710	1310	654	1210	2210	932	1710	3110
— 5.56	22	71.6	22.2	72	161.6	104	220	428	382	720	1328	660	1220	2228	938	1720	3128
— 5.00	23	73.4	22.8	73	163.4	110	230	446	388	730	1346	666	1230	2246	943	1730	3146
— 4.44	24	75.2	23.3	74	165.2	116	240	464	393	740	1364	671	1240	2264	949	1740	3164
— 3.89	25	77.0	23.9	75	167.0	121	250	482	399	750	1382	677	1250	2282	954	1750	3182
— 3.33	26	78.8	24.4	76	168.8	127	260	500	404	760	1400	682	1260	2300	960	1760	3200
— 2.78	27	80.6	25.0	77	170.6	132	270	518	410	770	1418	688	1270	2318	966	1770	3218
— 2.22	28	82.4	25.6	78	172.4	138	280	536	416	780	1436	693	1280	2336	971	1780	3236
— 1.67	29	84.2	26.1	79	174.2	143	290	554	421	790	1454	699	1290	2354	977	1790	3254
— 1.11	30	86.0	26.7	80	176.0	149	300	572	427	800	1472	704	1300	2372	982	1800	3272
— 0.56	31	87.8	27.2	81	177.8	154	310	590	432	810	1490	710	1310	2390	988	1810	3290
0	32	89.6	27.8	82	179.6	160	320	608	438	820	1508	716	1320	2408	993	1820	3308
0.56	33	91.4	28.3	83	181.4	166	330	626	443	830	1526	721	1330	2426	999	1830	3326
1.11	34	93.2	28.9	84	183.2	171	340	644	449	840	1544	727	1340	2444	1004	1840	3344
1.67	35	95.0	29.4	85	185.0	177	350	662	454	850	1562	732	1350	2462	1010	1850	3362
2.22	36	96.8	30.0	86	186.8	182	360	680	460	860	1580	738	1360	2480	1016	1860	3380
2.78	37	98.6	30.6	87	188.6	188	370	698	466	870	1598	743	1370	2498	1021	1870	3398
3.33	38	100.4	31.1	88	190.4	193	380	716	471	880	1616	749	1380	2516	1027	1880	3416
3.89	39	102.2	31.7	89	192.2	199	390	734	477	890	1634	754	1390	2534	1032	1890	3434
4.44	40	104.0	32.2	90	194.0	204	400	752	482	900	1652	760	1400	2552	1038	1900	3452
5.00	41	105.8	32.8	91	195.8	210	410	770	488	910	1670	766	1410	2570	1043	1910	3470
5.56	42	107.6	33.3	92	197.6	216	420	788	493	920	1688	771	1420	2588	1049	1920	3488
6.11	43	109.4	33.9	93	199.4	221	430	806	499	930	1706	777	1430	2606	1054	1930	3506
6.67	44	111.2	34.4	94	201.2	227	440	824	504	940	1724	782	1440	2624	1060	1940	3524
7.22	45	113.0	35.0	95	203.0	232	450	842	510	950	1742	788	1450	2642	1066	1950	3542
7.78	46	114.8	35.6	96	204.8	238	460	860	516	960	1760	793	1460	2660	1071	1960	3560
8.33	47	116.6	36.1	97	206.6	243	470	878	521	970	1778	799	1470	2678	1077	1970	3578
8.89	48	118.4	36.7	98	208.4	249	480	896	527	980	1796	804	1480	2696	1082	1980	3596
9.44	49	120.2	37.2	99	210.2	254	490	914	532	990	1814	810	1490	2714	1088	1990	3614

NOTE: The numbers in bold face type refer to the temperature in degrees, either Fahrenheit or Centigrade, which it is desired to convert into the other scale.

EXAMPLE

To convert 410°F., read to left—Equivalent is 210°C.
To convert 410° C., read to right—Equivalent is 770° F.

INTERPOLATION FACTORS

C.	Degrees	F.	C.	Degrees	F.
0.56	1	1.8	3.33	6	10.8
1.11	2	3.6	3.89	7	12.6
1.67	3	5.4	4.44	8	14.4
2.22	4	7.2	5.00	9	16.2
2.78	5	9.0	5.56	10	18.0

TEMPERATURE CONVERSION TABLE

By Albert Sauveur

2000 to 2250			2250 to 2500			2500 to 2750			2750 to 3000		
C.		F.	C.		F.	C.		F.	C.		F.
1093	2000	3632	1232	2250	4082	1371	2500	4532	1510	2750	4982
1099	2010	3650	1238	2260	4100	1377	2510	4550	1516	2760	5000
1104	2020	3668	1243	2270	4118	1382	2520	4568	1521	2770	5018
1110	2030	3686	1249	2280	4136	1388	2530	4586	1527	2780	5036
1116	2040	3704	1254	2290	4154	1393	2540	4604	1532	2790	5054
1121	2050	3722	1260	2300	4172	1399	2550	4622	1538	2800	5072
1127	2060	3740	1266	2310	4190	1404	2560	4640	1543	2810	5090
1132	2070	3758	1271	2320	4208	1410	2570	4658	1549	2820	5108
1138	2080	3776	1277	2330	4226	1416	2580	4676	1554	2830	5126
1143	2090	3794	1282	2340	4244	1421	2590	4694	1560	2840	5144
1149	2100	3812	1288	2350	4262	1427	2600	4712	1566	2850	5162
1154	2110	3830	1293	2360	4280	1432	2610	4730	1571	2860	5180
1160	2120	3848	1299	2370	4298	1438	2620	4748	1577	2870	5198
1166	2130	3866	1304	2380	4316	1443	2630	4766	1582	2880	5216
1171	2140	3884	1310	2390	4334	1449	2640	4784	1588	2890	5234
1177	2150	3902	1316	2400	4352	1454	2650	4802	1593	2900	5252
1182	2160	3920	1321	2410	4370	1460	2660	4820	1599	2910	5270
1188	2170	3938	1327	2420	4388	1466	2670	4838	1604	2920	5288
1193	2180	3956	1332	2430	4406	1471	2680	4856	1610	2930	5306
1199	2190	3974	1338	2440	4424	1477	2690	4874	1616	2940	5324
1204	2200	3992	1343	2450	4442	1482	2700	4892	1621	2950	5342
1210	2210	4010	1349	2460	4460	1488	2710	4910	1627	2960	5360
1216	2220	4028	1354	2470	4478	1493	2720	4928	1632	2970	5378
1221	2230	4046	1360	2480	4496	1499	2730	4946	1638	2980	5396
1227	2240	4064	1366	2490	4514	1504	2740	4964	1643	2990	5414

TEMPERATURE CONVERSION TABLE

FAHRENHEIT TO CENTIGRADE SCALE

F.	C.	F.	C.	F.	C.	F.	C.	F.	C.	F.	C.
3000	1649	3200	1760	3400	1871	3600	1982	3800	2093	4000	2204
3010	1654	3210	1766	3410	1877	3610	1988	3810	2099	4050	2232
3020	1660	3220	1771	3420	1882	3620	1993	3820	2104	4100	2260
3030	1666	3230	1777	3430	1888	3630	1999	3830	2110	4150	2288
3040	1671	3240	1782	3440	1893	3640	2004	3840	2116	4200	2316
3050	1677	3250	1788	3450	1899	3650	2010	3850	2121	4250	2343
3060	1682	3260	1793	3460	1904	3660	2016	3860	2127	4300	2371
3070	1688	3270	1799	3470	1910	3670	2021	3870	2132	4350	2399
3080	1693	3280	1804	3480	1916	3680	2027	3880	2138	4400	2427
3090	1699	3290	1810	3490	1921	3690	2032	3890	2143	4450	2454
3100	1704	3300	1816	3500	1927	3700	2038	3900	2149	4500	2482
3110	1710	3310	1821	3510	1932	3710	2043	3910	2154	4550	2510
3120	1716	3320	1827	3520	1938	3720	2049	3920	2160	4600	2538
3130	1721	3330	1832	3530	1943	3730	2054	3930	2166	4650	2566
3140	1727	3340	1838	3540	1949	3740	2060	3940	2171	4700	2593
3150	1732	3350	1843	3550	1954	3750	2066	3950	2177	4750	2621
3160	1738	3360	1849	3560	1960	3760	2071	3960	2182	4800	2649
3170	1743	3370	1854	3570	1966	3770	2077	3970	2188	4850	2677
3180	1749	3380	1860	3580	1971	3780	2082	3980	2193	4900	2704
3190	1754	3390	1866	3590	1977	3790	2088	3990	2199	4950	2732

Degrees Fahrenheit $= 9/5\ C + 32$ *Degrees Centigrade* $= 5/9\ (F - 32)$

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PYROMETRIC CONE EQUIVALENT (P.C.E.)

Pyrometric Cone Equivalent is defined as "the number of that standard cone whose tip would touch the supporting plaque simultaneously with that of a cone of the material being investigated, when tested in accordance with the Standard Method of Test for Pyrometric Cone Equivalent (P.C.E.) of refractory materials (A.S.T.M. Designation C 24) of the American Society for Testing Materials."

Revisions in the A.S.T.M. Method C 24 for P.C.E. testing were adopted in June, 1955. Important changes are the following:

1. New temperature end points were adopted for the Orton Standard P.C.E. cones, in accordance with the determinations made by the National Bureau of Standards, for cones up to and including No. 37.

2. The low-temperature end of the P.C.E. cone series was extended down to cone No. 12.

3. A new standard cone, No. 31½, was inserted between cone Nos. 31 and 32.

4. Standard cones No. 28 and 30 were withdrawn from the P.C.E. test series.

The temperatures given in the table apply only to the small (1⅛-inch) P.C.E. cones when heated in an oxidizing atmosphere at the prescribed rate of 270°F. per hour.

The P.C.E. test is not to be regarded as an accurate measurement of temperatures, but rather as "a comparison of thermal behavior in terms of standard cones." While the test does not provide an index of the behavior of a refractory in service, it is useful in evaluating the relative refractoriness of fireclay and some classes of high-alumina refractory materials. It is not applicable to basic and some other refractories.

PYROMETRIC CONE EQUIVALENT (P.C.E.)

Cone Temperatures (to the nearest 5°)

Cone No.	End Points °F.	End Points °C.	Cone No.	End Points °F.	End Points °C.
12	2440	1335	29	3020	1660
12-13	2450	1345	29-31	3040	1670
13	2460	1350	31	3060	1685
13-14	2505	1375	31-31½	3075	1690
14	2550	1400	31½	3090	1700
14-15	2580	1415	31½-32	3105	1710
15	2605	1430	32	3125	1715
15-16	2660	1460	32-32½	3130	1720
16	2715	1490	32½	3135	1725
16-17	2735	1500	32½-33	3150	1735
17	2755	1510	33	3170	1745
17-18	2765	1515	33-34	3185	1755
18	2770	1520	34	3205	1765
18-19	2790	1530	34-35	3225	1775
19	2805	1540	35	3245	1785
19-20	2825	1555	35-36	3260	1795
20	2845	1565	36	3280	1805
20-23	2885	1585	36-37	3295	1810
23	2920	1605	37	3310	1820
23-26	2935	1615	38	3360	1850*
26	2950	1620	39	3390	1865*
26-27	2965	1630	40	3425	1885*
27	2985	1640	41	3580	1970*
27-29	3000	1650	42	3660	2015*

* Based on the work of Fairchild and Peters, "Characteristics of Pyrometric Cones," Jour. Amer. Cer. Soc., Vol. 9, Page 700 (1926). Cones Numbers 39-42, inclusive, were heated at a rate of 600°C. per hour.

MELTING POINTS OF SELECTED METALS AND ALLOYS*

	Degrees Fahrenheit	Degrees Centigrade
Aluminum	1220.	660.
Antimony	1166.9	630.5
Beryllium	2341.	1283.
Cadmium	609.6	320.9
Chromium	∽3445.	∽1895.
Cobalt	2718.	1492.
Columbium	4380.	2415.
Copper (reducing atmosphere)	1981.	1083.
Gold	1945.4	1063.0
Iridium	4430.	2443.
Iron, pure	2795.	1535.
Cast iron, white	∽2100.	∽1150.
Cast iron, gray	∽2245.	∽1230.
Steel, plain carbon (1% carbon and less)	∽2680.	∽1470.
Lead	621.1	327.3
Magnesium	1202.	650.
Molybdenum	∽4750.	∽2620.
Nickel	2647.	1453.
Palladium	2826.	1552.
Platinum	3216.	1769.
Rhodium	3560.	1960.
Silver	1761.4	960.8
Tantalum	5425.	2996.
Tin	449.4	231.9
Titanium	∽3034.	∽1668.
Tungsten	6115.	3380.
Uranium	2071.	1133.
Vanadium	∽3450.	∽1900.
Zinc	787.1	419.5
Zirconium	∽3360.	∽1850.

MELTING POINTS OF SELECTED MINERAL OXIDES AND COMPOUNDS*

		Degrees Fahrenheit	Degrees Centigrade
Chromic Oxide	(Cr_2O_3)	∽4080.	∽2250.
Corundum	(Al_2O_3)	∽3720.	∽2050.
Cristobalite	(SiO_2)	3133.	1723.
Lime	(CaO)	∽4660.	∽2570.
Magnetite	(Fe_3O_4)	2901.	1594.
Periclase	(MgO)	∽5070.	∽2800.
Rutile	(TiO_2)	3326.	1830.
Zirconia	(ZrO_2)	4890.	2700.
Albite	($Na_2O \cdot Al_2O_3 \cdot 6SiO_2$)	2019.	1104.
Anorthite	($CaO \cdot Al_2O_3 \cdot 2SiO_2$)	2827.	1553.
Dicalcium Ferrite	($2CaO \cdot Fe_2O_3$)	2640.	1449.
Dicalcium Silicate	($2CaO \cdot SiO_2$)	∽3865.	∽2130.
Diopside	($CaO \cdot MgO \cdot 2SiO_2$)	2536.9	1391.5
Fayalite	($2FeO \cdot SiO_2$)	2201.	1205.
Forsterite	($2MgO \cdot SiO_2$)	∽3450.	∽1900.
Hercynite	($FeO \cdot Al_2O_3$)	∽3236.	∽1780.
Leucite	($K_2O \cdot Al_2O_3 \cdot 4SiO_2$)	3079.	1693.
Mullite	($3Al_2O_3 \cdot 2SiO_2$)**	∽3362.	∽1850.
Pseudowollastonite	($CaO \cdot SiO_2$)	2811.	1544.
Spinel	($MgO \cdot Al_2O_3$)	∽3875.	∽2135.

* In converting temperatures from Centigrade to Fahrenheit, temperatures above 3300°F. are given to the nearest five degrees. Additional melting points are given in the Glossary.

** At the melting point, the mullite contains about 73.0 per cent alumina.

∽ = Approximate.

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APPROXIMATE FURNACE TEMPERATURES

KIND OF FURNACE	Degrees Fahrenheit	Degrees Centigrade
Aluminum-Industry Furnaces	1800 – 2250	980 – 1230
Carbon-Baking Furnaces	2000	1095
Reduction Pots	1600 – 1700	870 – 925
Siphon Ladles		
Melting and Refining Furnace	1300 – 1600	705 – 870
Metal Temperature	2000 – 2400	1095 – 1315
Furnace Upper Structure		
Boiler Settings	2200 – 2800	1205 – 1540
Combustion Chambers	400 – 600	205 – 315
Exit Gases into Stack		
By-Product Coke Oven	900 – 2300	480 – 1260
Checkers	1800 – 2200	980 – 1205
Coking Chamber	2350 – 2750	1290 – 1510
Combustion Flues		
Ceramic Kilns—Periodic and Tunnel	1900 – 2300	1040 – 1260
Building Brick and Sewer Pipe, firing temperature	2200 – 3200	1205 – 1760
Refractory Brick, firing temperature		
Copper Furnaces	2200 – 2450	1205 – 1345
Converter	1990 – 2300	1090 – 1260
Ladles		
Reverberatory Smelting Furnace	2500 – 3000	1370 – 1650
Smelting End	2300	1260
Skimming End	2160 – 2400	1180 – 1315
Refining Furnace	1200 – 1800	650 – 980
Roasters	2000 – 2500	1095 – 1370
Electrical Porcelain Kilns		
Glass-Tank Furnaces	2800 – 2900	1540 – 1595
Borosilicate Glasses		
Bottle Glass	1000 – 1150	540 – 620
Annealing Lehrs	2000 – 2400	1095 – 1315
Feeders	2650 – 2850	1455 – 1565
Melting End	2200 – 2450	1205 – 1345
Refining End		
Plate and Window Glass	1120 – 1200	605 – 650
Annealing Lehrs	2000 – 2100	1095 – 1150
Drawing End	2750 – 2860	1510 – 1570
Melting End	2150 – 2250	1175 – 1230
Refining End		
Lead Furnaces	2200 – 2400	1205 – 1315
Drossing Furnace	1450 – 2000	790 – 1095
Blast Furnace (in Crucible)		
Lime Kilns	1000 – 1400	540 – 760
Rotary		
Cold Zone		

NOTE: In converting temperatures from Fahrenheit to Centigrade, the figures are given to nearest five degrees.

APPROXIMATE FURNACE TEMPERATURES—Continued

KIND OF FURNACE	Degrees Fahrenheit	Degrees Centigrade
Preheat Zone	1800 – 2200	980 – 1205
Calcining Zone	2200 – 2600	1205 – 1425
Shaft		
Calcining Zone	2000 – 2400	1095 – 1315
Iron and Steel Furnaces		
Blast Furnace		
Bosh	2800 – 3200	1540 – 1760
Inwall	1000 – 2800	540 – 1540
Hearth	2700 – 2800	1480 – 1540
Top	400 – 1000	205 – 540
Blast-Furnace Stove		
Combustion Well and Top Checkers	1400 – 2600	760 – 1425
Bottom Checkers	250 – 650	120 – 345
Bessemer Converter		
Iron into Vessel	2350 – 2500	1290 – 1370
Steel into Ladles	2900	1595
Steel into Molds	2850	1565
Electric Steelmelting Furnaces	2750 – 3200	1510 – 1760
Malleable Iron Furnaces		
Air Furnace	2950 – 3050	1620 – 1675
Annealing Furnace	1400 – 1800	760 – 980
Metal Mixers	2050 – 2500	1120 – 1370
Open-Hearth Furnace		
Walls and Roof	2910 – 3200	1600 – 1760
Regenerator, Top of Checkers	2000 – 2700	1095 – 1480
Steel into Ladles	2875 – 2950	1580 – 1620
Steel into Molds	2775 – 2875	1525 – 1580
Oxygen-Process Steelmaking Vessel	2900 – 3200	1595 – 1760
Reheating Furnaces for Slabs and Billets		
Heating Zone	2300 – 2650	1260 – 1455
Soaking End	2200 – 2400	1205 – 1315
Slabs or Billets as discharged	2100 – 2350	1150 – 1290
Soaking Pits		
Ingot in Pits	2250 – 2350	1230 – 1290
Linings	2250 – 2600	1230 – 1425
Oil-Refinery Furnaces		
Catalytic Cracking Units	850 – 950	455 – 510
Catalytic Reforming Units	800 – 1000	425 – 540
Heaters	1800 – 2200	980 – 1205
Portland Cement Kilns, Rotary		
Clinkering Zone	2400 – 3000	1315 – 1650
Cold Zone	1000 – 1600	540 – 870
Pottery Kilns	1800 – 2500	980 – 1370
Zinc Distillation Furnaces	2300 – 2500	1260 – 1370

NOTE: In converting temperatures from Fahrenheit to Centigrade, the figures are given to nearest five degrees.

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DECIMALS OF AN INCH FOR EACH 1/64TH

		1/4	.25	1/2	.5	3/4	.75
1/64	.015625	17/64	.265625	33/64	.515625	49/64	.765625
1/32	.03125	9/32	.28125	17/32	.53125	25/32	.78125
3/64	.046875	19/64	.296875	35/64	.546875	51/64	.796875
1/16	.0625	5/16	.3125	9/16	.5625	13/16	.8125
5/64	.078125	21/64	.328125	37/64	.578125	53/64	.828125
3/32	.09375	11/32	.34375	19/32	.59375	27/32	.84375
7/64	.109375	23/64	.359375	39/64	.609375	55/64	.859375
1/8	.125	3/8	.375	5/8	.625	7/8	.875
9/64	.140625	25/64	.390625	41/64	.640625	57/64	.890625
5/32	.15625	13/32	.40625	21/32	.65625	29/32	.90625
11/64	.171875	27/64	.421875	43/64	.671875	59/64	.921875
3/16	.1875	7/16	.4375	11/16	.6875	15/16	.9375
13/64	.203125	29/64	.453125	45/64	.703125	61/64	.953125
7/32	.21875	15/32	.46875	23/32	.71875	31/32	.96875
15/64	.234375	31/64	.484375	47/64	.734375	63/64	.984375

SCREEN SCALE SERIES

U. S. STANDARD				TYLER STANDARD			
Sieve Number	Sieve Opening Inches	Sieve Opening Millimeters	Diameter Wire Decimals of an Inch	Mesh	Opening in Inches	Opening in Millimeters	Diameter Wire Decimals of an Inch
...	.....	.....	.....	...	1.050	26.67	0.148
...	.....	.....	.....	...	0.742	18.85	0.135
...	.....	.....	.....	...	0.525	13.33	0.105
...	.....	.....	.....	...	0.371	9.423	0.092
2½	0.315	8.00	0.073	...	.....	.....	.....
3	0.265	6.73	0.065	3	0.263	6.680	0.070
3½	0.223	5.66	0.057	...	.....	.....	.....
4	0.187	4.76	0.050	4	0.185	4.699	0.065
5	0.157	4.00	0.044	...	.....	.....	.....
6	0.132	3.36	0.040	6	0.131	3.327	0.036
7	0.111	2.83	0.036	...	.....	.....	.....
8	0.0937	2.38	0.0331	8	0.093	2.362	0.032
10	0.0787	2.00	0.0299	...	.....	.....	.....
12	0.0661	1.68	0.0272	10	0.065	1.651	0.035
14	0.0555	1.41	0.0240	...	.....	.....	.....
16	0.0469	1.19	0.0213	14	0.046	1.168	0.025
18	0.0394	1.00	0.0189	...	.....	.....	.....
20	0.0331	0.84	0.0165	20	0.0328	0.833	0.0172
25	0.0280	0.71	0.0146	...	.....	.....	.....
30	0.0232	0.59	0.0130	28	0.0232	0.589	0.0125
35	0.0197	0.50	0.0114	...	.....	.....	.....
40	0.0165	0.42	0.0098	35	0.0164	0.417	0.0122
45	0.0138	0.35	0.0087	...	.....	.....	.....
50	0.0117	0.297	0.0074	48	0.0116	0.295	0.0092
60	0.0098	0.250	0.0064	...	.....	.....	.....
70	0.0083	0.210	0.0055	65	0.0082	0.208	0.0072
80	0.0070	0.177	0.0047	...	.....	.....	.....
100	0.0059	0.149	0.0040	100	0.0058	0.147	0.0042
120	0.0049	0.125	0.0034	...	.....	.....	.....
140	0.0041	0.105	0.0029	150	0.0041	0.104	0.0026
170	0.0035	0.088	0.0025	...	.....	.....	.....
200	0.0029	0.074	0.0021	200	0.0029	0.074	0.0021
230	0.0024	0.062	0.0018	250	0.0024	0.061	0.0016
270	0.0021	0.053	0.0016	270	0.0021	0.053	0.0016
325	0.0017	0.044	0.0014	325	0.0017	0.043	0.0014

CONVERSION TABLES

LENGTH

Multiply		By	To Obtain
Microns	(μ)	0.*0001*	Centimeters
Millimeters	(mm.)	0.*001*	Meters
Millimeters	(mm.)	0.*039370*	Inches
Centimeters	(cm.)	0.*01*	Meters
Centimeters	(cm.)	0.*39370*	Inches
Meters	(m.)	39.*370*	Inches
Meters	(m.)	3.*2808*	Feet
Inches	(in.)	25.*400*	Millimeters
Inches	(in.)	2.*5400*	Centimeters
Feet	(ft.)	30.*480*	Centimeters
Feet	(ft.)	0.*30480*	Meters

AREA

Multiply		By	To Obtain
Square Millimeters	($mm.^2$ or sq. mm.)	0.*0015500*	Square Inches
Square Centimeters	($cm.^2$ or sq. cm.)	0.*15500*	Square Inches
Square Meters	($m.^2$ or sq. m.)	10,000.	Square Centimeters
Square Meters	($m.^2$ or sq. m.)	10.*764*	Square Feet
Square Inch	($in.^2$ or sq. in.)	645.*16*	Square Millimeters
Square Inch	($in.^2$ or sq. in.)	6.*4516*	Square Centimeters
Square Feet	($ft.^2$ or sq. ft.)	144.	Square Inches
Square Feet	($ft.^2$ or sq. ft.)	929.*03*	Square Centimeters
Square Feet	($ft.^2$ or sq. ft.)	0.*092903*	Square Meters

VOLUME

Multiply		By	To Obtain
Cubic Centimeters	($cm.^3$ or cu. cm.)	0.*061023*	Cubic Inches
Cubic Centimeters	(c.c.)	.*001000*	Liters
Cubic Meters	($m.^3$ or cu. m.)	35.*315*	Cubic Feet
Cubic Inches	($in.^3$ or cu. in.)	16.*387*	Cubic Centimeters
Cubic Feet	($ft.^3$ or cu. ft.)	1,728.	Cubic Inches
Cubic Feet	($ft.^3$ or cu. ft.)	28,317.	Cubic Centimeters
Cubic Feet	($ft.^3$ or cu. ft.)	28.*32*	Liters
Cubic Feet	($ft.^3$ or cu. ft.)	7.*4805*	Gallons, U. S. Liquid
Cubic Yards	($yd.^3$ or cu. yd.)	27.	Cubic Feet
Cubic Yards	($yd.^3$ or cu. yd.)	0.*76456*	Cubic Meters
Liters		1,000.*027*	Cubic Centimeters
Liters		61.*02*	Cubic Inches
Liters		0.*03531*	Cubic Feet
Liters		1.*0567*	Quarts, U. S. Liquid
Gallons, Imperial	(gal.)	1.*20094*	Gallons, U. S. Liquid
Gallons, U. S. Liquid	(gal.)	3.*785*	Liters
Gallons, U. S. Liquid	(gal.)	3,785.	Cubic Centimeters
Gallons, U. S. Liquid	(gal.)	231.	Cubic Inches
Gallons, U. S. Liquid	(gal.)	0.*13368*	Cubic Feet
Gallons, U. S. Liquid	(gal.)	0.*8327*	Imperial Gallons

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CONVERSION TABLES—Continued

MASS AND WEIGHT

Multiply		By	To Obtain
Grams	(g.)	0.035274	Ounces Avoirdupois
Grams per Cubic Centimeter		62.43	Pounds per Cubic Foot
Kilograms	(kg.)	2.2046	Pounds Avoirdupois
Ounces Avoirdupois	(oz. av.)	28.350	Grams
Pounds Avoirdupois	(lb. av.)	453.59	Grams
Pounds Avoirdupois	(lb. av.)	0.45359	Kilograms
Pounds per Cubic Foot		0.01602	Grams per Cubic Centimeter
Metric Tons	(t.)	1,000.	Kilograms
Metric Tons	(t.)	2,204.6	Pounds Avoirdupois
Gross Tons	(G.T.)	2,240.	Pounds Avoirdupois
Net Tons	(N.T.)	2,000.	Pounds Avoirdupois
Net Tons	(N.T.)	907.18	Kilograms
Cubic Feet of Water at 39.2°F.		62.43	Pounds Avoirdupois
Pounds of Water at 39.2°F.		0.016019	Cubic Feet
Pounds of Water at 39.2°F.		0.4536	Liters
U. S. Gallons of Water at 39.2°F.		8.345	Pounds Avoirdupois
U. S. Gallons of Water at 62°F.		8.336	Pounds Avoirdupois

HEAT, ENERGY, WORK

Multiply		By	To Obtain
Gram-Calories	(g.-cal.)	0.003968	British Thermal Units
Gram-Calories	(g.-cal.)	3.087	Foot-Pounds
Kilogram-Calories	(kg.-cal.)	3.968	British Thermal Units
Kilogram-Calories	(kg.-cal.)	3,087.	Foot-Pounds
Kilowatts	(kw.)	1.341	Horse Power
Kilowatts	(kw.)	56.88	Btu per Minute
Kilowatts	(kw.)	44,253.	Foot-Pounds per Minute
Kilowatt-Hours	(kw.-hr.)	1.341	Horse Power-Hours
Kilowatt-Hours	(kw.-hr.)	3,413.	British Thermal Units
Kilowatt-Hours	(kw.-hr.)	2,655,000.	Foot-Pounds
British Thermal Units	(Btu)	778.0	Foot-Pounds
British Thermal Units	(Btu)	252.0	Gram-Calories
British Thermal Units	(Btu)	0.0002930	Kilowatt-Hours
British Thermal Units per Minute	(Btu/min.)	0.01758	Kilowatts
Foot-Pounds	(ft.-lb.)	0.3239	Gram-Calories
Foot-Pounds	(ft.-lb.)	0.001285	British Thermal Units
Foot-Pounds	(ft.-lb.)	0.0000003766	Kilowatt-Hours
Horse Power	(h.p.)	0.7457	Kilowatts
Horse Power	(h.p.)	42.42	Btu per Minute
Horse Power	(h.p.)	33,000.	Foot-Pounds per Minute

THERMAL CONDUCTIVITY

1 Gram-Calorie per Square Centimeter	3.687	Btu per Sq. Ft.
1 Gram-Calorie per Sq. Cm. for 1 Cm. Thickness	1.451	Btu per Sq. Ft. for 1 Inch Thickness
1 Gram-Calorie per Second per Sq. Cm. for 1 Cm. Thickness for 1°C. Temperature-Difference	2,903.	Btu per Hr. per Sq. Ft. for 1 Inch Thickness for 1°F. Temperature-Difference
1 British Thermal Unit per Square Foot	0.2712	Gram-Calories per Sq. Cm.
1 British Thermal Unit per Square Foot for 1 Inch Thickness	0.6889	Gram-Calories per Sq. Cm. for 1 Centimeter Thickness
1 British Thermal Unit per Hour per Square Foot for 1 Inch Thickness for 1° Fahrenheit Temperature-Difference	0.0003445	Gram-Calories per Second per Sq. Cm. for 1 Cm. Thickness for 1°C. Temperature-Difference



SIZES AND SHAPES

HARBISON-WALKER REFRACTORIES COMPANY

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GUARANTEES—*In the sale of refractories, no performance guarantees are made, since the manufacturer has no control over the conditions to which his products are subjected in service.*

Harbison-Walker makes every effort to supply only products which meet high standards of quality, and which in its judgment are best suited for the purposes for which they are intended.

The user will find it advantageous to exercise care and discretion in the selection, handling, installation, and use of refractory materials. It is practicable to choose the proper refractory for a particular application only with a full appraisal of operating factors and experiences. Consultation with Harbison-Walker engineers is offered for assistance they can give.

ALLOWABLE VARIATIONS FROM SPECIFIED DIMENSIONS—*Allowable variations of standard 9-inch brick from the intended or specified dimensions are plus 2 per cent to minus 2 per cent, when measured as described in A.S.T.M. Designation C 134. Length and width are measured on single brick; thickness on a stack of brick 10 high. The allowable variations of rectangular tile and special shapes from the intended or specified dimensions are plus 2 per cent to minus 2 per cent on dimensions of 4 inches or over, and plus 3 per cent to minus 3 per cent on dimensions less than 4 inches.*

ALLOWABLE WARPAGE—*Ninety-five per cent of the tile or shapes shall not show a warpage greater than 1 per cent of the diagonal used in making the measurement, when tested in accordance with A.S.T.M. Designation C 154.*

OVERSHIPMENTS—*Overages in accordance with the following table shall be allowable on all shipments of shapes that are not carried in stock.*

QUANTITY SPECIFIED	OVERAGES	QUANTITY SPECIFIED	OVERAGES
1 – 100	10%*	5,001 – 10,000	2%
101 – 1,000	7%	Over 10,000	1%
1,001 – 5,000	3%		

* Not less than one shape. If in sets, one complete set.

REFRACTORY BRICK CLASSIFICATION

REFRACTORY brick are classified on the basis of their form as Standard Sizes, Rectangular Tile, and Special Shapes.

1. Standard Sizes are brick of certain definite sizes and of relatively simple design which are marketed in sufficient amounts to permit quantity production. Wherever furnace construction and operating conditions permit, standard sizes are to be preferred. They cost less than larger and more intricate shapes, and frequently are more serviceable. The sizes in most common use are generally carried in stock by the manufacturer.

2. Rectangular Tile are solid brick shapes which have six plane rectangular faces, with all opposite faces parallel and with all adjacent faces at right angles to each other.

3. Special Shapes are refractory brick of special design, which may be of either simple or intricate form. Some may be considered as modifications of rectangular tile having the same over-all dimensions.

Nonstandard rectangular tile and special shapes are not included in the list of standard sizes. However, special shapes and rectangular tile for which there is a continuing demand of substantial quantity are carried in stock; those used infrequently or in relatively small quantities are manufactured only on order. Drawings showing complete details of the individual shapes as well as their assembly in the furnace should be included with initial orders for special shapes. On subsequent orders, the drawing and shape numbers should be given.

TABLES AND ILLUSTRATIONS

Standard Sizes: The standard sizes of refractory brick are designed to meet the requirements of furnace construction as fully as possible. They include rectangular sizes (such as straights, soaps, and splits); tapered sizes having only plane surfaces (arch, wedge, and key brick); neck, skew, featheredge, and jamb brick; and tapered sizes having two curved surfaces (circle brick, cupola blocks, and rotary kiln blocks).

The most widely used groups of standard sizes are known as the "9 x 4½ x 2½-inch sizes" (commonly referred to as "9-inch sizes") and "9 x 4½ x 3-inch sizes." These sizes are standard in all types of refractory brick as well as in acid-proof brick.

Many standard sizes larger than those of the 9-inch and 9 x 4½ x 3-inch series are provided in most refractory materials. Wider sizes, 9 x 6¾ x 2½-inch (large 9-inch) and 9 x 6¾ x 3-inch straights and wedges, are used mainly for breaking joints. Longer sizes are available in 12-inch, 13½-inch, and up to 18 inches for some kinds of refractories.

Sizes and Shapes other than Standard: A number of sizes and shapes which are not classified as standard, but which are widely used, are listed. Typical shapes for a few specific applications are illustrated on pages 502 to 507, and 510.

Skewbacks: Proper design of skewback brick is important in the construction of all the numerous types of furnaces having sprung arches. Special attention is therefore called to the illustrations of skewbacks shown on pages 508 and 509.

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STANDARD *9-INCH* (9″ x 4½″ x 2½″) SIZES



9″ Straight
9″ x 4½″ x 2½″



Small 9″ Straight
9″ x 3½″ x 2½″



9″ Soap
9″ x 2½″ x 2¼″



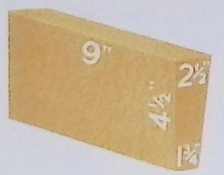
9″ Split
9″ x 4½″ x 1¼″



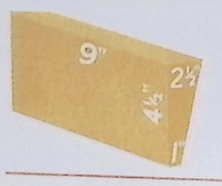
9″—2″ Split
9″ x 4½″ x 2″



9″ No. 1 Arch
9″ x 4½″ x (2½″—2⅜″)



9″ No. 2 Arch
9″ x 4½″ x (2½″—1¾″)



9″ No. 3 Arch
9″ x 4½″ x (2½″—1″)



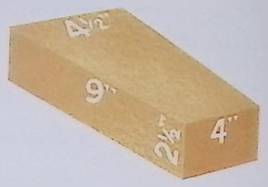
9″ No. 1-X Wedge
9″ x 4½″ x (2½″—2¼″)



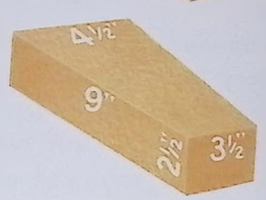
9″ No. 1 Wedge
9″ x 4½″ x (2½″—1⅛″)



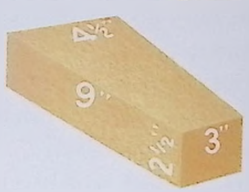
9″ No. 2 Wedge
9″ x 4½″ x (2½″—1½″)



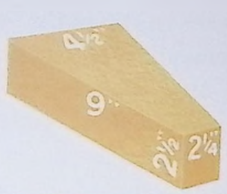
9″ No. 1 Key
9″ x (4½″—4″) x 2½″



9″ No. 2 Key
9″ x (4½″—3½″) x 2½″



9″ No. 3 Key
9″ x (4½″—3″) x 2½″



9″ No. 4 Key
9″ x (4½″—2¼″) x 2½″

"Brick Combinations for Rings" are given on pages 536 to 538.

STANDARD *9-INCH* (9″ x 4½″ x 2½″) SIZES



9″—48° End Skew
(9″—6¾″) x 4½″ x 2½″



9″—60° End Skew
(9″—7⁹⁄₁₆″) x 4½″ x 2½″



9″—48° Side Skew
9″ x (4½″—2¼″) x 2½″



9″—60° Side Skew
9″ x (4½″—3¹⁵⁄₁₆″) x 2½″



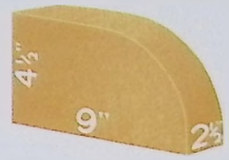
9″ Edge Skew
9″ x (4½″—1½″) x 2½″



9″ Featheredge
9″ x 4½″ x (2½″—⅛″)



9″ Neck
9″ x 4½″ x (2½″—⅝″)



9″ Jamb
9″ x 4½″ x 2½″

STANDARD *9 x 4½ x 3-INCH* SIZES

Name	Dimensions
9″ x 4½″ x 3″ Straight	9″ x 4½″ x 3″
9″ x 3½″ x 3″ Straight	9″ x 3½″ x 3″
9″ x 3″ x 2¼″ Soap	9″ x 3″ x 2¼″
9″ x 4½″ x 1½″ Split	9″ x 4½″ x 1½″
9″ x 4½″ x 3″ No. 1 Arch	9″ x 4½″ x (3″–2¾″)
9″ x 4½″ x 3″ No. 2 Arch	9″ x 4½″ x (3″–2½″)
9″ x 4½″ x 3″ No. 3 Arch	9″ x 4½″ x (3″–2″)
9″ x 4½″ x 3″ No. 4 Arch	9″ x 4½″ x (3″–1″)
9″ x 4½″ x 3″ No. 1 Wedge	9″ x 4½″ x (3″–2¾″)
9″ x 4½″ x 3″ No. 2 Wedge	9″ x 4½″ x (3″–2½″)
9″ x 4½″ x 3″ No. 3 Wedge	9″ x 4½″ x (3″–2″)

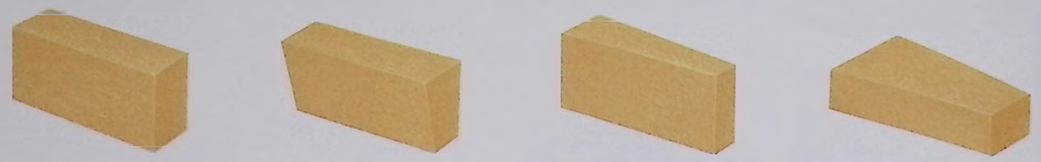
Name	Dimensions
9″ x 4½″ x 3″ No. 1 Key	9″ x (4½″–4″) x 3″
9″ x 4½″ x 3″ No. 2 Key	9″ x (4½″–3½″) x 3″
9″ x 4½″ x 3″ No. 3 Key	9″ x (4½″–3″) x 3″
9″ x 4½″ x 3″ No. 4 Key	9″ x (4½″–2¼″) x 3″
9″ x 4½″ x 3″ 48° End Skew	(9″–6⁵⁄₁₆″) x 4½″ x 3″
9″ x 4½″ x 3″ 60° End Skew	(9″–7¼″) x 4½″ x 3″
9″ x 4½″ x 3″ 48° Side Skew	9″ x (4½″–1¹³⁄₁₆″) x 3″
9″ x 4½″ x 3″ 60° Side Skew	9″ x (4½″–2¾″) x 3″
9″ x 4½″ x 3″ Edge Skew	9″ x (4½″–1½″) x 3″
9″ x 4½″ x 3″ Featheredge	9″ x 4½″ x (3″–⅛″)
9″ x 4½″ x 3″ Neck	9″ x 4½″ x (3″–⅝″)
9″ x 4½″ x 3″ Jamb	9″ x 4½″ x 3″

"Brick Combinations for Rings" are given on pages 536 to 538.

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STANDARD SIZES IN *FIRECLAY and HIGH-ALUMINA* REFRACTORIES

TYPICAL STRAIGHT, ARCH, WEDGE, AND KEY BRICK



Straight *Arch* *Wedge* *Key*

All STANDARD 9-INCH (9″ x 4½″ x 2½″) and 9″ x 4½″ x 3″ SIZES are listed on pages 478 and 479.
All OTHER STANDARD SIZES are listed on pages 480 to 485.

Some NONSTANDARD SIZES and RECTANGULAR TILE are listed on page 486.

Name	Dimensions	Number Per Ring	Diameter of Ring	
			Inside	Outside
STANDARD 9″ x 6″ x 2½″ SIZES				
9″ x 6″ x 2½″ Straight	9″ x 6″ x 2½″	...	.....	.....
9″ x 6″ x 2½″ No. 1 Key	9″ x (6″–5⅜″) x 2½″	91	13′- 0″	14′- 6″
9″ x 6″ x 2½″ No. 2 Key	9″ x (6″–4 13/16″) x 2½″	48	6′- 0″	7′- 6″
9″ x 6″ x 2½″ No. 3 Key	9″ x (6″–3″) x 2½″	19	1′- 6″	3′- 0″
STANDARD 9″ x 6″ FLAT-BACK SIZES				
Flat-Back Straight	9″ x 6″ x 2½″	...	.....	.....
Flat-Back Split	9″ x 6″ x 1¼″	...	.....	.....
No. 1 Flat-Back Arch	9″ x 6″ x (3½″–2½″)	38	2′- 6″	3′- 6″
No. 2 Flat-Back Arch	9″ x 6″ x (3½″–2″)	26	1′- 4″	2′- 4″
STANDARD 9″ x 6″ x 3″ SIZES				
9″ x 6″ x 3″ Straight	9″ x 6″ x 3″	...	.....	.....
9″ x 6″ x 3″ No. 1 Wedge	9″ x 6″ x (3″–2¾″)	227	16′- 6″	18′- 0″
9″ x 6″ x 3″ No. 2 Wedge	9″ x 6″ x (3″–2½″)	113	7′- 6″	9′- 0″
9″ x 6″ x 3″ No. 3 Wedge	9″ x 6″ x (3″–2″)	57	3′- 0″	4′- 6″
9″ x 6″ x 3″ No. 1 Key	9″ x (6″–5⅜″) x 3″	91	13′- 0″	14′- 6″
9″ x 6″ x 3″ No. 2 Key	9″ x (6″–4 13/16″) x 3″	48	6′- 0″	7′- 6″
9″ x 6″ x 3″ No. 3 Key	9″ x (6″–3″) x 3″	19	1′- 6″	3′- 0″

"Brick Combinations for Rings" are given on pages 536 to 558.

STANDARD SIZES IN *FIRECLAY and HIGH-ALUMINA* REFRACTORIES

Name	Dimensions	Number Per Ring	Diameter of Ring	
			Inside	Outside
STANDARD LARGE 9-INCH (9″ x 6¾″ x 2½″) SIZES				
Large 9″ Straight	9″ x 6¾″ x 2½″	...	.....	.....
Large 9″ No. 1-X Wedge	9″ x 6¾″ x (2½″–2¼″)	227	13′- 6″	15′- 0″
Large 9″ No. 1 Wedge	9″ x 6¾″ x (2½″–1⅞″)	91	4′- 6″	6′- 0″
Large 9″ No. 2 Wedge	9″ x 6¾″ x (2½″–1½″)	57	2′- 3″	3′- 9″
STANDARD 9″ x 6¾″ x 3″ SIZES				
9″ x 6¾″ x 3″ Straight	9″ x 6¾″ x 3″	...	.....	.....
9″ x 6¾″ x 3″ No. 1 Wedge	9″ x 6¾″ x (3″–2¾″)	227	16′- 6″	18′- 0″
9″ x 6¾″ x 3″ No. 2 Wedge	9″ x 6¾″ x (3″–2½″)	113	7′- 6″	9′- 0″
9″ x 6¾″ x 3″ No. 3 Wedge	9″ x 6¾″ x (3″–2″)	57	3′- 0″	4′- 6″
STANDARD 12″ x 6″ x 3″ SIZES				
12″ x 6″ x 3″ Straight	12″ x 6″ x 3″	...	.....	.....
12″ x 6″ x 3″ No. 1-X Wedge	12″ x 6″ x (3″–2⅞″)	604	46′- 0″	48′- 0″
12″ x 6″ x 3″ No. 1 Wedge	12″ x 6″ x (3″–2¾″)	302	22′- 0″	24′- 0″
12″ x 6″ x 3″ No. 2 Wedge	12″ x 6″ x (3″–2½″)	151	10′- 0″	12′- 0″
12″ x 6″ x 3″ No. 3 Wedge	12″ x 6″ x (3″–2″)	76	4′- 0″	6′- 0″
STANDARD 13½″ x 4½″ x 2½″ SIZES				
13½″ x 4½″ x 2½″ Straight	13½″ x 4½″ x 2½″	...	.....	.....
13½″ x 4½″ x 2½″ No. 1 Arch	13½″ x 4½″ x (2½″–2⅛″)	76	4′- 3″	5′- 0″
13½″ x 4½″ x 2½″ No. 2 Arch	13½″ x 4½″ x (2½″–1¾″)	38	1′- 9″	2′- 6″
13½″ x 4½″ x 2½″ No. 3 Arch	13½″ x 4½″ x (2½″–1″)	19	0′- 6″	1′- 3″
STANDARD 13½″ x 4½″ x 3″ SIZES				
13½″ x 4½″ x 3″ Straight	13½″ x 4½″ x 3″	...	.....	.....
13½″ x 4½″ x 3″ No. 1 Arch	13½″ x 4½″ x (3″–2¾″)	113	8′- 3″	9′- 0″
13½″ x 4½″ x 3″ No. 2 Arch	13½″ x 4½″ x (3″–2½″)	57	3′- 9″	4′- 6″
13½″ x 4½″ x 3″ No. 3 Arch	13½″ x 4½″ x (3″–2″)	29	1′- 6″	2′- 3″
13½″ x 4½″ x 3″ No. 4 Arch	13½″ x 4½″ x (3″–1″)	15	0′- 4½″	1′- 1½″
STANDARD 13½″ x 6″ x 2½″ SIZES				
13½″ x 6″ x 2½″ Straight	13½″ x 6″ x 2½″	...	.....	.....
13½″ x 6″ x 2½″ No. 1 Key	13½″ x (6″–5″) x 2½″	85	11′- 3″	13′- 6″
13½″ x 6″ x 2½″ No. 2 Key	13½″ x (6″–4⅜″) x 2½″	52	6′- 0″	8′- 3″
13½″ x 6″ x 2½″ No. 3 Key	13½″ x (6″–3″) x 2½″	29	2′- 3″	4′- 6″

"Brick Combinations for Rings" are given on pages 536 to 558.

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STANDARD SIZES IN *FIRECLAY and HIGH-ALUMINA* REFRACTORIES

Name	Dimensions	Number Per Ring	Diameter of Ring	
			Inside	Outside
STANDARD 13½″ x 6″ x 3″ SIZES				
13½″ x 6″ x 3″ Straight	13½″ x 6″ x 3″	..	.....	.....
13½″ x 6″ x 3″ No. 1-X Wedge	13½″ x 6″ x (3″–2⅞″)	679	51′- 9″	54′- 0″
13½″ x 6″ x 3″ No. 1 Wedge	13½″ x 6″ x (3″–2¾″)	340	24′- 9″	27′- 0″
13½″ x 6″ x 3″ No. 2 Wedge	13½″ x 6″ x (3″–2½″)	170	11′- 3″	13′- 6″
13½″ x 6″ x 3″ No. 3 Wedge	13½″ x 6″ x (3″–2″)	85	4′- 6″	6′- 9″
13½″ x 6″ x 3″ No. 1 Key	13½″ x (6″–5″) x 3″	85	11′- 3″	13′- 6″
13½″ x 6″ x 3″ No. 2 Key	13½″ x (6″–4⅜″) x 3″	52	6′- 0″	8′- 3″
13½″ x 6″ x 3″ No. 3 Key	13½″ x (6″–3″) x 3″	29	2′- 3″	4′- 6″

STANDARD MISCELLANEOUS STRAIGHTS

9″ x 6″ x 2″ Straight	10½″ x 4½″ x 2½″ Straight	12″ x 4½″ x 3″ Straight	18″ x 6″ x 2½″ Straight
9″ x 7″ x 2″ Straight	10½″ x 4½″ x 3″ Straight	13½″ x 4½″ x 4½″ Straight	18″ x 6″ x 3″ Straight
9″ x 7½″ x 2″ Straight	10½″ x 4½″ x 4½″ Straight	13½″ x 6″ x 3″ Straight	18″ x 9″ x 4½″ Straight

STANDARD MALLEABLE FURNACE BUNG BRICK



101—9″ Straight Bung
9″ x 4½″ x 3″



101—13½″ Straight Bung
13½″ x 4½″ x 3″



105—9″ Arch Bung
9″ x 4½″ x (3″–2⅞″)
227 Brick Per Ring
17′-3″ Inside Diameter
18′-0″ Outside Diameter



105—13½″ Arch Bung
13½″ x 4½″ x (3″–2⅞″)
227 Brick Per Ring
17′-3″ Inside Diameter
18′-0″ Outside Diameter



9″ Arch Bung
9″ x 4½″ x (2½″–2⅜″)
227 Brick Per Ring
14′-3″ Inside Diameter
15′-0″ Outside Diameter



103—13½″ Arch Bung
13½″ x 4½″ x (3″–2⅜″)
76 Brick Per Ring
5′-3″ Inside Diameter
6′-0″ Outside Diameter

"Brick Combinations for Rings" are given on pages 536 to 558.

STANDARD SIZES IN *FIRECLAY and HIGH-ALUMINA* REFRACTORIES

Name	Inside Chord	Number Per Ring	Diameter of Ring	
			Inside	Outside
STANDARD 9″ x 4½″ x 2½″ CIRCLE BRICK				
24–33 Circle	6 17/32″	12	24″	33″
36–45 Circle	7 3/16″	16	36″	45″
48–57 Circle	7 19/32″	20	48″	57″
60–69 Circle	7 13/16″	24	60″	69″
72–81 Circle	8″	29	72″	81″
84–93 Circle	8⅛″	33	84″	93″
96–105 Circle	8 7/32″	37	96″	105″
108–117 Circle	8 5/16″	41	108″	117″
120–129 Circle	8⅜″	45	120″	129″



Outside Chord . . . . . 9 inches
Radial Dimension . . . . . 4½ inches
Thickness . . . . . 2½ inches

STANDARD 9″ x 4½″ x 3″ CIRCLE BRICK				
24–33–3 Circle	6 17/32″	12	24″	33″
36–45–3 Circle	7 3/16″	16	36″	45″
48–57–3 Circle	7 19/32″	20	48″	57″
60–69–3 Circle	7 13/16″	24	60″	69″
72–81–3 Circle	8″	29	72″	81″
84–93–3 Circle	8⅛″	33	84″	93″
96–105–3 Circle	8 7/32″	37	96″	105″
108–117–3 Circle	8 5/16″	41	108″	117″
120–129–3 Circle	8⅜″	45	120″	129″



Outside Chord . . . . . 9 inches
Radial Dimension . . . . . 4½ inches
Thickness . . . . . 3 inches

STANDARD UNIVERSAL CUPOLA BLOCK NO. 602-4 FOR LININGS 6 INCHES THICK

Diameter Inside Brickwork	No. Per Ring	Diameter Inside Brickwork	No. Per Ring	Diameter Inside Brickwork	No. Per Ring
..	..	4′-0″	18	6′-0″	26
..	..	4′-3″	19	6′-3″	27
2′-6″	12	4′-6″	20	6′-6″	28
2′-9″	13	4′-9″	21	6′-9″	29
3′-0″	14	5′-0″	22	7′-0″	30
3′-3″	15	5′-3″	23	7′-3″	31
3′-6″	16	5′-6″	24	7′-6″	32
3′-9″	17	5′-9″	25	8′-0″	34

Universal Cupola Blocks for linings 4½ inches thick and 9 inches thick are regularly manufactured in High-Duty and Superduty Fireclay material. See page 484 for standard cupola blocks.



Universal Cupola Block

"Brick Combinations for Rings" are given on pages 536 to 558.

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STANDARD SIZES IN *FIRECLAY and HIGH-ALUMINA* REFRACTORIES

Name	Inside Chord	Number Per Ring	Diameter of Ring	
			Inside	Outside
STANDARD 6″ CUPOLA AND ROTARY KILN BLOCKS 9″ x 6″ x 4″				
30- 42 Cupola or RKB	6 7/16″	15	30″	42″
36- 48 Cupola or RKB	6¾″	17	36″	48″
42- 54 Cupola or RKB	7″	19	42″	54″
48- 60 Cupola or RKB	7 3/16″	21	48″	60″
54- 66 Cupola or RKB	7⅜″	23	54″	66″
60- 72 Cupola or RKB	7½″	26	60″	72″
66- 78 Cupola or RKB	7⅝″	28	66″	78″
72- 84 Cupola or RKB	7 23/32″	30	72″	84″
78- 90 Cupola or RKB	7 13/16″	32	78″	90″
84- 96 Cupola or RKB	7⅞″	34	84″	96″
90-102 Cupola or RKB	7 15/16″	36	90″	102″
96-108 Cupola or RKB	8″	38	96″	108″
102-114 Cupola or RKB	8 1/16″	40	102″	114″
108-120 Cupola or RKB	8 3/32″	42	108″	120″
114-126 Cupola or RKB	8 5/32″	44	114″	126″
120-132 Cupola or RKB	8 3/16″	46	120″	132″
123-135 Cupola or RKB	8 3/16″	48	123″	135″
126-138 Cupola or RKB	8 7/32″	49	126″	138″
132-144 Cupola or RKB	8¼″	51	132″	144″
138-150 Cupola or RKB	8 9/32″	53	138″	150″



Outside Chord . . . . . 9 inches
Radial Dimension . . . . . 6 inches
Thickness . . . . . 4 inches

STANDARD 9″ ROTARY KILN BLOCKS 9″ x 9″ x 4″

48- 66 RKB	6 17/32″	23	48″	66″
54- 72 RKB	6¾″	26	54″	72″
60- 78 RKB	6 15/16″	28	60″	78″
66- 84 RKB	7 1/16″	30	66″	84″
72- 90 RKB	7 3/16″	32	72″	90″
78- 96 RKB	7 5/16″	34	78″	96″
84-102 RKB	7 13/32″	36	84″	102″
90-108 RKB	7½″	38	90″	108″
96-114 RKB	7 19/32″	40	96″	114″
102-120 RKB	7 21/32″	42	102″	120″
108-126 RKB	7 23/32″	44	108″	126″
114-132 RKB	7 25/32″	46	114″	132″
117-135 RKB	7 13/16″	48	117″	135″
120-138 RKB	7 13/16″	49	120″	138″
123-141 RKB	7 27/32″	50	123″	141″
126-144 RKB	7⅞″	51	126″	144″
132-150 RKB	7 29/32″	53	132″	150″
138-156 RKB	7 31/32″	55	138″	156″
144-162 RKB	8″	57	144″	162″
150-168 RKB	8 1/32″	59	150″	168″
156-174 RKB	8 1/16″	61	156″	174″
162-180 RKB	8 3/32″	63	162″	180″

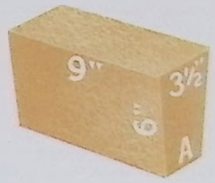


Outside Chord . . . . . 9 inches
Radial Dimension . . . . . 9 inches
Thickness . . . . . 4 inches

"Brick Combinations for Rings" are given on pages 536 to 558.

STANDARD SIZES IN *FIRECLAY and HIGH-ALUMINA* REFRACTORIES

Name	Inside Chord "A"	Number Per Ring	Diameter of Ring	
			Inside	Outside
STANDARD 9″ x 6″ x 3½″ ARCH-TYPE ROTARY KILN BLOCKS				
30-A- 42	2½″	37	30″	42″
36-A- 48	2⅝″	43	36″	48″
42-A- 54	2 23/32″	48	42″	54″
48-A- 60	2 13/16″	53	48″	60″
54-A- 66	2⅞″	59	54″	66″
60-A- 72	2 29/32″	64	60″	72″
66-A- 78	2 31/32″	70	66″	78″
72-A- 84	3″	75	72″	84″
78-A- 90	3 1/32″	80	78″	90″
84-A- 96	3 1/16″	86	84″	96″
90-A-102	3 3/32″	91	90″	102″
96-A-108	3⅛″	96	96″	108″
102-A-114	3⅛″	102	102″	114″
108-A-120	3 5/32″	107	108″	120″
114-A-126	3 5/32″	113	114″	126″
120-A-132	3 3/16″	118	120″	132″
123-A-135	3 3/16″	121	123″	135″
126-A-138	3 3/16″	123	126″	138″
132-A-144	3 7/32″	129	132″	144″
138-A-150	3 7/32″	134	138″	150″
144-A-156	3 7/32″	140	144″	156″
150-A-162	3¼″	145	150″	162″
156-A-168	3¼″	150	156″	168″



Length . . . . . 9 inches
Width . . . . . 6 inches
Outside Chord . . . . . 3½ inches

STANDARD 9″ x 6″ x 3½″ WEDGE-TYPE ROTARY KILN BLOCKS

36-W- 54	2 11/32″	48	36″	54″
42-W- 60	2 7/16″	53	42″	60″
48-W- 66	2 17/32″	59	48″	66″
54-W- 72	2⅝″	64	54″	72″
60-W- 78	2 11/16″	70	60″	78″
66-W- 84	2¾″	75	66″	84″
72-W- 90	2 13/16″	80	72″	90″
78-W- 96	2 27/32″	86	78″	96″
84-W-102	2⅞″	91	84″	102″
90-W-108	2 29/32″	96	90″	108″
96-W-114	2 15/16″	102	96″	114″
102-W-120	2 31/32″	107	102″	120″
108-W-126	3″	113	108″	126″
114-W-132	3 1/32″	118	114″	132″
117-W-135	3 1/32″	121	117″	135″
120-W-138	3 1/32″	123	120″	138″
126-W-144	3 1/16″	129	126″	144″
132-W-150	3 3/32″	134	132″	150″
144-W-162	3⅛″	145	144″	162″



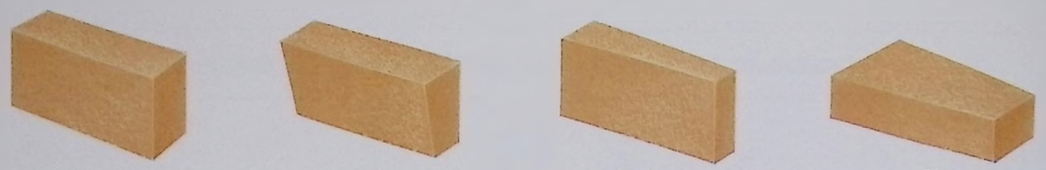
Length . . . . . 9 inches
Width . . . . . 6 inches
Outside Chord . . . . . 3½ inches

NOTE: To facilitate the keying of Arch-Type or Wedge-Type Rotary Kiln Blocks, Split Blocks are manufactured of both two-third (⅔) and three-quarter (¾) thickness. Two (2) each of these should be included for each ring of full size blocks. They are correctly specified by the Block Number followed by a dash and the fraction to indicate the thickness desired, thus, 84-A-96-⅔ and 84-A-96-¾ or 78-W-96-⅔ and 78-W-96-¾.

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SIZES OTHER THAN STANDARD IN *FIRECLAY and HIGH-ALUMINA* REFRACTORIES

TYPICAL STRAIGHT, ARCH, WEDGE, AND KEY BRICK



Straight *Arch* *Wedge* *Key*

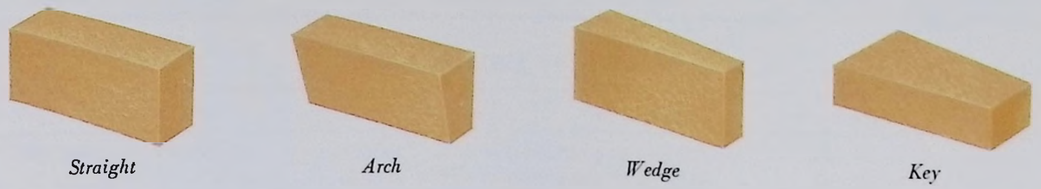
Name	Dimensions	Number Per Ring	Diameter of Ring	
			Inside	Outside
9″ x 9″ x 2½″ Straight	9″ x 9″ x 2½″	...	.....	.....
9″ x 9″ x 2½″ No. 1-X Wedge	9″ x 9″ x (2½″–2¼″)	227	13′- 6″	15′- 0″
9″ x 9″ x 2½″ No. 1 Wedge	9″ x 9″ x (2½″–1⅞″)	91	4′- 6″	6′- 0″
9″ x 9″ x 2½″ No. 2 Wedge	9″ x 9″ x (2½″–1½″)	57	2′- 3″	3′- 9″
9″ x 9″ x 3″ Straight	9″ x 9″ x 3″	...	.....	.....
9″ x 9″ x 3″ No. 1 Wedge	9″ x 9″ x (3″–2¾″)	227	16′- 6″	18′- 0″
9″ x 9″ x 3″ No. 2 Wedge	9″ x 9″ x (3″–2½″)	113	7′- 6″	9′- 0″
9″ x 9″ x 3″ No. 3 Wedge	9″ x 9″ x (3″–2″)	57	3′- 0″	4′- 6″
9″ x 9″ Gas Flue Straight	9″ x 9″ x 3½″	...	.....	.....
9″ x 9″ No. 3 Gas Flue Arch	9″ x 9″ x (3½″–2¼″)	46	2′- 9″	4′- 3″
9″ x 9″ No. 4 Gas Flue Arch	9″ x 9″ x (3½″–2 11/32″)	60	4′- 0″	5′- 6″
9″ x 9″ No. 5 Gas Flue Arch	9″ x 9″ x (3½″–2 11/16″)	70	5′- 0″	6′- 6″
12″ x 9″ x 3″ Straight	12″ x 9″ x 3″	...	.....	.....
12″ x 9″ x 3″ No. 1 Wedge	12″ x 9″ x (3″–2¾″)	302	22′- 0″	24′- 0″
12″ x 9″ x 3″ No. 2 Wedge	12″ x 9″ x (3″–2½″)	151	10′ -0″	12′- 0″
12″ x 9″ x 3″ No. 3 Wedge	12″ x 9″ x (3″–2″)	76	4′- 0″	6′- 0″
13½″ x 9″ x 3″ Straight	13½″ x 9″ x 3″	...	.....	.....
13½″ x 9″ x 3″ No. 1 Arch	13½″ x 9″ x (3″–2¾″)	227	16′- 6″	18′- 0″
13½″ x 9″ x 3″ No. 2 Arch	13½″ x 9″ x (3″–2½″)	113	7′- 6″	9′- 0″
13½″ x 9″ x 3″ No. 3 Arch	13½″ x 9″ x (3″–2″)	57	3′- 0″	4′- 6″
13½″ x 9″ x 3″ No. 1 Wedge	13½″ x 9″ x (3″–2¾″)	340	24′- 9″	27′- 0″
13½″ x 9″ x 3″ No. 2 Wedge	13½″ x 9″ x (3″–2½″)	170	11′- 3″	13′- 6″
13½″ x 9″ x 3″ No. 3 Wedge	13½″ x 9″ x (3″–2″)	85	4′- 6″	6′- 9″
13½″ x 9″ Gas Flue Straight	13½″ x 9″ x 3½″	...	.....	.....
13½″ x 9″ No. 3 Gas Flue Arch	13½″ x 9″ x (3½″–2¼″)	46	2′- 9″	4′- 3″
13½″ x 9″ No. 4 Gas Flue Arch	13½″ x 9″ x (3½″–2 11/32″)	60	4′- 0″	5′- 6″
13½″ x 9″ No. 5 Gas Flue Arch	13½″ x 9″ x (3½″–2 11/16″)	70	5′- 0″	6′- 6″

TYPICAL RECTANGULAR TILE

12″ x 12″ x 3″ Straight	18″ x 12″ x 3″ Straight	24″ x 6″ x 3″ Straight	27″ x 6″ x 3″ Straight
15″ x 12″ x 3″ Straight	21″ x 6″ x 3″ Straight	24″ x 9″ x 3″ Straight	30″ x 12″ x 3″ Straight
18″ x 9″ x 3″ Straight	22″ x 6″ x 3″ Straight	24″ x 12″ x 3″ Straight	36″ x 12″ x 3″ Straight

STANDARD SIZES IN *SILICA* REFRACTORIES

TYPICAL STRAIGHT, ARCH, WEDGE, AND KEY BRICK



Straight *Arch* *Wedge* *Key*

All STANDARD 9-INCH (9″ x 4½″ x 2½″) and 9″ x 4½″ x 3″ SIZES are listed on pages 478 and 479.
All OTHER STANDARD SIZES are listed on pages 487 to 489.

Some NONSTANDARD SIZES are listed on page 490.

Name	Dimensions	Number Per Ring	Diameter of Ring	
			Inside	Outside
STANDARD LARGE 9-INCH (9″ x 6¾″ x 2½″) SIZES				
Large 9″ Straight	9″ x 6¾″ x 2½″	...	.....	.....
Large 9″ No. 1-X Wedge	9″ x 6¾″ x (2½″–2¼″)	227	13′- 6″	15′- 0″
Large 9″ No. 1 Wedge	9″ x 6¾″ x (2½″–1⅞″)	91	4′- 6″	6′- 0″
Large 9″ No. 2 Wedge	9″ x 6¾″ x (2½″–1½″)	57	2′- 3″	3′- 9″
STANDARD 9″ x 6¾″ x 3″ SIZES				
9″ x 6¾″ x 3″ Straight	9″ x 6¾″ x 3″	...	.....	.....
9″ x 6¾″ x 3″ No. 1 Wedge	9″ x 6¾″ x (3″–2¾″)	227	16′- 6″	18′- 0″
9″ x 6¾″ x 3″ No. 2 Wedge	9″ x 6¾″ x (3″–2½″)	113	7′- 6″	9′- 0″
9″ x 6¾″ x 3″ No. 3 Wedge	9″ x 6¾″ x (3″–2″)	57	3′- 0″	4′- 6″
STANDARD 12″ x 4½″ x 3″ SIZES				
12″ x 4½″ x 3″ Straight	12″ x 4½″ x 3″	...	.....	.....
12″ x 4½″ x 3″ No. 1-X Wedge	12″ x 4½″ x (3″–2⅞″)	604	46′- 0″	48′- 0″
12″ x 4½″ x 3″ No. 1 Wedge	12″ x 4½″ x (3″–2¾″)	302	22′- 0″	24′- 0″
12″ x 4½″ x 3″ No. 2 Wedge	12″ x 4½″ x (3″–2½″)	151	10′- 0″	12′- 0″
12″ x 4½″ x 3″ No. 3 Wedge	12″ x 4½″ x (3″–2″)	76	4′- 0″	6′- 0″

"Brick Combinations for Rings" are given on pages 536 to 558.

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STANDARD SIZES IN *SILICA* REFRACTORIES

Name	Dimensions	Number Per Ring	Diameter of Ring	
			Inside	Outside
STANDARD 12″ x 6″ x 3″ SIZES				
12″ x 6″ x 3″ Straight	12″ x 6″ x 3″	...	.....	.....
12″ x 6″ x 3″ No. 1 Arch	12″ x 6″ x (3″–2¾″)	151	11′- 0″	12′- 0″
12″ x 6″ x 3″ No. 2 Arch	12″ x 6″ x (3″–2½″)	76	5′- 0″	6′- 0″
12″ x 6″ x 3″ No. 3 Arch	12″ x 6″ x (3″–2″)	38	2′- 0″	3′- 0″
12″ x 6″ x 3″ No. 1-X Wedge	12″ x 6″ x (3″–2⅞″)	604	46′- 0″	48′- 0″
12″ x 6″ x 3″ No. 1 Wedge	12″ x 6″ x (3″–2¾″)	302	22′- 0″	24′- 0″
12″ x 6″ x 3″ No. 2 Wedge	12″ x 6″ x (3″–2½″)	151	10′- 0″	12′- 0″
12″ x 6″ x 3″ No. 3 Wedge	12″ x 6″ x (3″–2″)	76	4′- 0″	6′- 0″
12″ x 6″ x 3″ No. 1 Key	12″ x (6″–5½″) x 3″	151	22′- 0″	24′- 0″
12″ x 6″ x 3″ No. 2 Key	12″ x (6″–5″) x 3″	76	10′- 0″	12′- 0″
STANDARD 12″ x 9″ x 3″ SIZES				
12″ x 9″ x 3″ Straight	12″ x 9″ x 3″	...	.....	.....
12″ x 9″ x 3″ No. 1-X Wedge	12″ x 9″ x (3″–2⅞″)	604	46′- 0″	48′- 0″
12″ x 9″ x 3″ No. 1 Wedge	12″ x 9″ x (3″–2¾″)	302	22′- 0″	24′- 0″
12″ x 9″ x 3″ No. 2 Wedge	12″ x 9″ x (3″–2½″)	151	10′- 0″	12′- 0″
12″ x 9″ x 3″ No. 3 Wedge	12″ x 9″ x (3″–2″)	76	4′- 0″	6′- 0″
STANDARD 13½″ x 4½″ x 3″ SIZES				
13½″ x 4½″ x 3″ Straight	13½″ x 4½″ x 3″	...	.....	.....
13½″ x 4½″ x 3″ No. 1 Arch	13½″ x 4½″ x (3″–2¾″)	113	8′- 3″	9′- 0″
13½″ x 4½″ x 3″ No. 2 Arch	13½″ x 4½″ x (3″–2½″)	57	3′- 9″	4′- 6″
13½″ x 4½″ x 3″ No. 3 Arch	13½″ x 4½″ x (3″–2″)	29	1′- 6″	2′- 3″
13½″ x 4½″ x 3″ No. 4 Arch	13½″ x 4½″ x (3″–1″)	15	0′- 4½″	1′- 1½″
STANDARD 13½″ x 6″ x 3″ SIZES				
13½″ x 6″ x 3″ Straight	13½″ x 6″ x 3″	...	.....	.....
13½″ x 6″ x 3″ No. 1 Arch	13½″ x 6″ x (3″–2¾″)	151	11′- 0″	12′- 0″
13½″ x 6″ x 3″ No. 2 Arch	13½″ x 6″ x (3″–2½″)	76	5′- 0″	6′- 0″
13½″ x 6″ x 3″ No. 3 Arch	13½″ x 6″ x (3″–2″)	38	2′- 0″	3′- 0″
13½″ x 6″ x 3″ No. 1-X Wedge	13½″ x 6″ x (3″–2⅞″)	679	51′- 9″	54′- 0″
13½″ x 6″ x 3″ No. 1 Wedge	13½″ x 6″ x (3″–2¾″)	340	24′- 9″	27′- 0″
13½″ x 6″ x 3″ No. 2 Wedge	13½″ x 6″ x (3″–2½″)	170	11′- 3″	13′- 6″
13½″ x 6″ x 3″ No. 3 Wedge	13½″ x 6″ x (3″–2″)	85	4′- 6″	6′- 9″
13½″ x 6″ x 3″ No. 1 Key	13½″ x (6″–5″) x 3″	85	11′- 3″	13′- 6″
13½″ x 6″ x 3″ No. 2 Key	13½″ x (6″–4⅜″) x 3″	52	6′- 0″	8′- 3″
13½″ x 6″ x 3″ No. 3 Key	13½″ x (6″–3″) x 3″	29	2′- 3″	4′- 6″

"Brick Combinations for Rings" are given on pages 536 to 558.

STANDARD SIZES IN *SILICA* REFRACTORIES

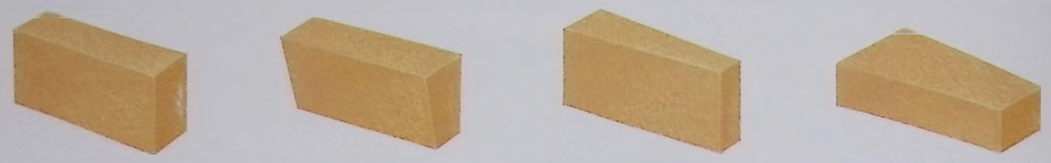
Name	Dimensions	Number Per Ring	Diameter of Ring	
			Inside	Outside
STANDARD 13½″ x 9″ x 3″ SIZES				
13½″ x 9″ x 3″ Straight	13½″ x 9″ x 3″	...	.....	.....
13½″ x 9″ x 3″ No. 1 Arch	13½″ x 9″ x (3″–2¾″)	227	16′- 6″	18′- 0″
13½″ x 9″ x 3″ No. 2 Arch	13½″ x 9″ x (3″–2½″)	113	7′- 6″	9′- 0″
13½″ x 9″ x 3″ No. 3 Arch	13½″ x 9″ x (3″–2″)	57	3′- 0″	4′- 6″
13½″ x 9″ x 3″ No. 1-X Wedge	13½″ x 9″ x (3″–2⅞″)	679	51′- 9″	54′- 0″
13½″ x 9″ x 3″ No. 1 Wedge	13½″ x 9″ x (3″–2¾″)	340	24′- 9″	27′- 0″
13½″ x 9″ x 3″ No. 2 Wedge	13½″ x 9″ x (3″–2½″)	170	11′- 3″	13′- 6″
13½″ x 9″ x 3″ No. 3 Wedge	13½″ x 9″ x (3″–2″)	85	4′- 6″	6′- 9″
STANDARD 15″ x 6″ x 3″ SIZES				
15″ x 6″ x 3″ Straight	15″ x 6″ x 3″	...	.....	.....
15″ x 6″ x 3″ No. 1-X Wedge	15″ x 6″ x (3″–2⅞″)	754	57′- 6″	60′- 0″
15″ x 6″ x 3″ No. 1 Wedge	15″ x 6″ x (3″–2¾″)	377	27′- 6″	30′- 0″
15″ x 6″ x 3″ No. 2 Wedge	15″ x 6″ x (3″–2½″)	189	12′- 6″	15′- 0″
15″ x 6″ x 3″ No. 3 Wedge	15″ x 6″ x (3″–2″)	95	5′- 0″	7′- 6″
STANDARD 15″ x 9″ x 3″ SIZES				
15″ x 9″ x 3″ Straight	15″ x 9″ x 3″	...	.....	.....
15″ x 9″ x 3″ No. 1-X Wedge	15″ x 9″ x (3″–2⅞″)	754	57′- 6″	60′- 0″
15″ x 9″ x 3″ No. 1 Wedge	15″ x 9″ x (3″–2¾″)	377	27′- 6″	30′- 0″
15″ x 9″ x 3″ No. 2 Wedge	15″ x 9″ x (3″–2½″)	189	12′- 6″	15′- 0″
15″ x 9″ x 3″ No. 3 Wedge	15″ x 9″ x (3″–2″)	95	5′- 0″	7′- 6″
STANDARD 18″ x 6″ x 3″ SIZES				
18″ x 6″ x 3″ Straight	18″ x 6″ x 3″	...	.....	.....
18″ x 6″ x 3″ No. 1-X Wedge	18″ x 6″ x (3″–2⅞″)	905	69′- 0″	72′- 0″
18″ x 6″ x 3″ No. 1 Wedge	18″ x 6″ x (3″–2¾″)	453	33′- 0″	36′- 0″
18″ x 6″ x 3″ No. 2 Wedge	18″ x 6″ x (3″–2½″)	227	15′- 0″	18′- 0″
18″ x 6″ x 3″ No. 3 Wedge	18″ x 6″ x (3″–2″)	113	6′- 0″	9′- 0″
STANDARD 18″ x 9″ x 3″ SIZES				
18″ x 9″ x 3″ Straight	18″ x 9″ x 3″	...	.....	.....
18″ x 9″ x 3″ No. 1-X Wedge	18″ x 9″ x (3″–2⅞″)	905	69′- 0″	72′- 0″
18″ x 9″ x 3″ No. 1 Wedge	18″ x 9″ x (3″–2¾″)	453	33′- 0″	36′- 0″
18″ x 9″ x 3″ No. 2 Wedge	18″ x 9″ x (3″–2½″)	227	15′- 0″	18′- 0″
18″ x 9″ x 3″ No. 3 Wedge	18″ x 9″ x (3″–2″)	113	6′- 0″	9′- 0″

"Brick Combinations for Rings" are given on pages 536 to 558.

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SIZES OTHER THAN STANDARD IN *SILICA* REFRACTORIES

TYPICAL STRAIGHT, ARCH, WEDGE, AND KEY BRICK



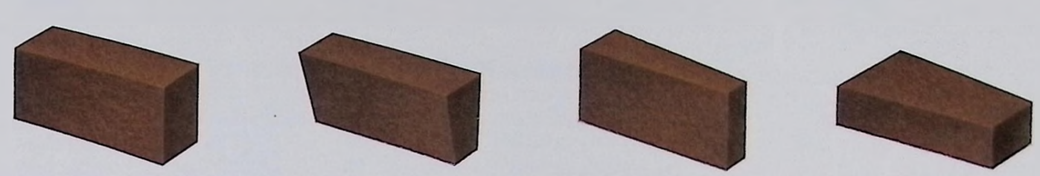
Straight *Arch* *Wedge* *Key*

Name	Dimensions	Number Per Ring	Diameter of Ring	
			Inside	Outside
9″ x 9″ x 2½″ Straight	9″ x 9″ x 2½″	...	.....	.....
9″ x 9″ x 2½″ No. 1-X Wedge	9″ x 9″ x (2½″–2¼″)	227	13′- 6″	15′- 0″
9″ x 9″ x 2½″ No. 1 Wedge	9″ x 9″ x (2½″–1⅞″)	91	4′- 6″	6′- 0″
9″ x 9″ x 2½″ No. 2 Wedge	9″ x 9″ x (2½″–1½″)	57	2′- 3″	3′- 9″
9″ x 9″ x 3″ Straight	9″ x 9″ x 3″	...	.....	.....
9″ x 9″ x 3″ No. 1 Wedge	9″ x 9″ x (3″–2¾″)	227	16′- 6″	18′- 0″
9″ x 9″ x 3″ No. 2 Wedge	9″ x 9″ x (3″–2½″)	113	7′- 6″	9′- 0″
9″ x 9″ x 3″ No. 3 Wedge	9″ x 9″ x (3″–2″)	57	3′- 0″	4′- 6″
13½″ x 4½″ x 2½″ Straight	13½″ x 4½″ x 2½″	...	.....	.....
13½″ x 4½″ x 2½″ No. 1 Arch	13½″ x 4½″ x (2½″–2⅛″)	76	4′- 3″	5′- 0″
13½″ x 4½″ x 2½″ No. 2 Arch	13½″ x 4½″ x (2½″–1¾″)	38	1′- 9″	2′- 6″
13½″ x 4½″ x 2½″ No. 3 Arch	13½″ x 4½″ x (2½″–1″)	19	0′- 6″	1′- 3″
13½″ x 4½″ x 3″ No. 1-X Wedge	13½″ x 4½″ x (3″–2⅞″)	679	51′- 9″	54′- 0″
13½″ x 4½″ x 3″ No. 1 Wedge	13½″ x 4½″ x (3″–2¾″)	340	24′- 9″	27′- 0″
13½″ x 4½″ x 3″ No. 2 Wedge	13½″ x 4½″ x (3″–2½″)	170	11′- 3″	13′- 6″
13½″ x 4½″ x 3″ No. 3 Wedge	13½″ x 4½″ x (3″–2″)	85	4′- 6″	6′- 9″
21″ x 6″ x 3″ Straight	21″ x 6″ x 3″	...	.....	.....
21″ x 6″ x 3″ No. 1-X Wedge	21″ x 6″ x (3″–2⅞″)	1056	80′- 6″	84′- 0″
21″ x 6″ x 3″ No. 1 Wedge	21″ x 6″ x (3″–2¾″)	528	38′- 6″	42′- 0″
21″ x 6″ x 3″ No. 2 Wedge	21″ x 6″ x (3″–2½″)	264	17′- 6″	21′- 0″
21″ x 6″ x 3″ No. 3 Wedge	21″ x 6″ x (3″–2″)	132	7′- 0″	10′- 6″
21″ x 9″ x 3″ Straight	21″ x 9″ x 3″	...	.....	.....
21″ x 9″ x 3″ No. 1-X Wedge	21″ x 9″ x (3″–2⅞″)	1056	80′- 6″	84′- 0″
21″ x 9″ x 3″ No. 1 Wedge	21″ x 9″ x (3″–2¾″)	528	38′- 6″	42′- 0″
21″ x 9″ x 3″ No. 2 Wedge	21″ x 9″ x (3″–2½″)	264	17′- 6″	21′- 0″
21″ x 9″ x 3″ No. 3 Wedge	21″ x 9″ x (3″–2″)	132	7′- 0″	10′- 6″

"Brick Combinations for Rings" are given on pages 536 to 558.

STANDARD SIZES IN *BASIC* REFRACTORIES

TYPICAL STRAIGHT, ARCH, WEDGE, AND KEY BRICK



Straight *Arch* *Wedge* *Key*

All STANDARD 9-INCH (9″ x 4½″ x 2½″) and 9″ x 4½″ x 3″ SIZES are listed on pages 478 and 479.
All OTHER STANDARD SIZES are listed on pages 491 to 493.

Some NONSTANDARD SIZES and SHAPES are listed on pages 494 to 496.

Name	Dimensions	Number Per Ring	Diameter of Ring	
			Inside	Outside
STANDARD LARGE 9-INCH (9″ x 6¾″ x 2½″) SIZES				
Large 9″ Straight	9″ x 6¾″ x 2½″	...	.....	.....
Large 9″ No. 1-X Wedge	9″ x 6¾″ x (2½″–2¼″)	227	13′- 6″	15′- 0″
Large 9″ No. 1 Wedge	9″ x 6¾″ x (2½″–1⅞″)	91	4′- 6″	6′- 0″
Large 9″ No. 2 Wedge	9″ x 6¾″ x (2½″–1½″)	57	2′- 3″	3′- 9″
STANDARD 9″ x 6¾″ x 3″ SIZES				
9″ x 6¾″ x 3″ Straight	9″ x 6¾″ x 3″	...	.....	.....
9″ x 6¾″ x 3″ No. 1 Wedge	9″ x 6¾″ x (3″–2¾″)	227	16′- 6″	18′- 0″
9″ x 6¾″ x 3″ No. 2 Wedge	9″ x 6¾″ x (3″–2½″)	113	7′- 6″	9′- 0″
9″ x 6¾″ x 3″ No. 3 Wedge	9″ x 6¾″ x (3″–2″)	57	3′- 0″	4′- 6″
STANDARD 13½″ x 4½″ x 3″ SIZES				
13½″ x 4½″ x 3″ Straight	13½″ x 4½″ x 3″	...	.....	.....
13½″ x 4½″ x 3″ No. 1 Arch	13½″ x 4½″ x (3″–2¾″)	113	8′- 3″	9′- 0″
13½″ x 4½″ x 3″ No. 2 Arch	13½″ x 4½″ x (3″–2½″)	57	3′- 9″	4′- 6″
13½″ x 4½″ x 3″ No. 3 Arch	13½″ x 4½″ x (3″–2″)	29	1′- 6″	2′- 3″
13½″ x 4½″ x 3″ No. 4 Arch	13½″ x 4½″ x (3″–1″)	15	0′- 4½″	1′- 1½″
13½″ x 4½″ x 3″ No. 1 Key	13½″ x (4½″–4″) x 3″	170	18′- 0″	20′- 3″
13½″ x 4½″ x 3″ No. 2 Key	13½″ x (4½″–3½″) x 3″	85	7′-10½″	10′- 1½″
13½″ x 4½″ x 3″ No. 3 Key	13½″ x (4½″–3″) x 3″	57	4′- 6″	6′- 9″
13½″ x 4½″ x 3″ No. 4 Key	13½″ x (4½″–2¼″) x 3″	38	2′- 3″	4′- 6″

"Brick Combinations for Rings" are given on pages 536 to 558.

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STANDARD SIZES IN *BASIC* REFRACTORIES

Name	Dimensions	Number Per Ring	Diameter of Ring	
			Inside	Outside
STANDARD 13½″ x 6″ x 3″ SIZES				
13½″ x 6″ x 3″ Straight	13½″ x 6″ x 3″	...	.....	.....
13½″ x 6″ x 3″ No. 1 Arch	13½″ x 6″ x (3″–2¾″)	151	11′- 0″	12′- 0″
13½″ x 6″ x 3″ No. 2 Arch	13½″ x 6″ x (3″–2½″)	76	5′- 0″	6′- 0″
13½″ x 6″ x 3″ No. 3 Arch	13½″ x 6″ x (3″–2″)	38	2′- 0″	3′- 0″
13½″ x 6″ x 3″ No. 1-X Wedge	13½″ x 6″ x (3″–2⅞″)	679	51′- 9″	54′- 0″
13½″ x 6″ x 3″ No. 1 Wedge	13½″ x 6″ x (3″–2¾″)	340	24′- 9″	27′- 0″
13½″ x 6″ x 3″ No. 2 Wedge	13½″ x 6″ x (3″–2½″)	170	11′- 3″	13′- 6″
13½″ x 6″ x 3″ No. 3 Wedge	13½″ x 6″ x (3″–2″)	85	4′- 6″	6′- 9″
13½″ x 6″ x 3″ No. 1 Key	13½″ x (6″–5″) x 3″	85	11′- 3″	13′- 6″
13½″ x 6″ x 3″ No. 2 Key	13½″ x (6″–4⅜″) x 3″	52	6′- 0″	8′- 3″
13½″ x 6″ x 3″ No. 3 Key	13½″ x (6″–3″) x 3″	29	2′- 3″	4′- 6″

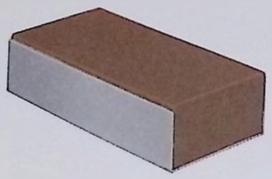
STANDARD MISCELLANEOUS STRAIGHTS

13½″ x 6¾″ x 3″ Straight	18″ x 4½″ x 3″ Straight	18″ x 6¾″ x 3″ Straight

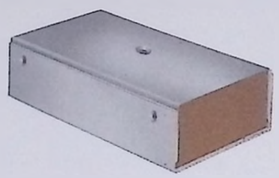
"Brick Combinations for Rings" are given on pages 536 to 558.

METALKASE BRICK

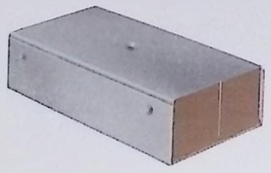
Sizes which are Standard in Basic Refractories are also Standard in Metalkase Brick



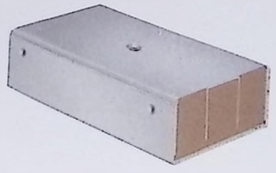
METALKASE BRICK
With 3-Sided Steel
Enclosure



METALKASE BRICK
With 4-Sided Steel
Enclosure



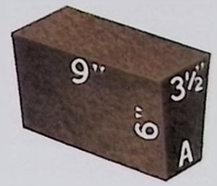
METALKASE BRICK XP
Metal Enclosed, With
One Internal Plate



METALKASE BRICK XXP
Metal Enclosed, With
Two Internal Plates

STANDARD SIZES IN *BASIC* REFRACTORIES

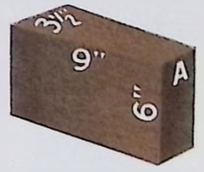
Name	Inside Chord "A"	Number Per Ring Using No. 16 Gauge Plates	Diameter of Ring	
			Inside	Outside
STANDARD 9″ x 6″ x 3½″ ARCH-TYPE ROTARY KILN BLOCKS				
30-A- 42	2½″	37	30″	42″
36-A- 48	2⅝″	42	36″	48″
42-A- 54	2 23/32″	47	42″	54″
48-A- 60	2 13/16″	52	48″	60″
54-A- 66	2⅞″	58	54″	66″
60-A- 72	2 29/32″	63	60″	72″
66-A- 78	2 31/32″	68	66″	78″
72-A- 84	3″	74	72″	84″
78-A- 90	3 1/32″	79	78″	90″
84-A- 96	3 1/16″	84	84″	96″
90-A-102	3 3/32″	89	90″	102″
96-A-108	3⅛″	95	96″	108″
102-A-114	3 3/16″	100	102″	114″
108-A-120	3 5/32″	105	108″	120″
114-A-126	3 7/32″	111	114″	126″
120-A-132	3 5/16″	116	120″	132″
123-A-135	3 5/16″	119	123″	135″
126-A-138	3 3/16″	121	126″	138″
132-A-144	3 7/32″	126	132″	144″
138-A-150	3 7/32″	132	138″	150″
144-A-156	3 7/32″	137	144″	156″
150-A-162	3¼″	142	150″	162″
156-A-168	3¼″	148	156″	168″



Length . . . . . 9 inches
Width . . . . . 6 inches
Outside Chord . . . . . 3½ inches

STANDARD 9″ x 6″ x 3½″ WEDGE-TYPE ROTARY KILN BLOCKS

36-W- 54	2 11/32″	47	36″	54″
42-W- 60	2 7/16″	52	42″	60″
48-W- 66	2 17/32″	58	48″	66″
54-W- 72	2⅝″	63	54″	72″
60-W- 78	2 11/16″	68	60″	78″
66-W- 84	2¾″	74	66″	84″
72-W- 90	2 13/16″	79	72″	90″
78-W- 96	2 27/32″	84	78″	96″
84-W-102	2⅞″	89	84″	102″
90-W-108	2 29/32″	95	90″	108″
96-W-114	2 15/16″	100	96″	114″
102-W-120	2 31/32″	105	102″	120″
108-W-126	3″	111	108″	126″
114-W-132	3 1/32″	116	114″	132″
117-W-135	3 1/32″	119	117″	135″
120-W-138	3 1/32″	121	120″	138″
126-W-144	3 1/16″	126	126″	144″
132-W-150	3 3/32″	132	132″	150″
144-W-162	3⅛″	142	144″	162″



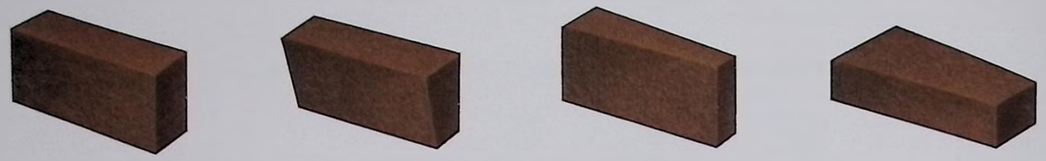
Length . . . . . 9 inches
Width . . . . . 6 inches
Outside Chord . . . . . 3½ inches

NOTE: To facilitate the keying of Arch-Type or Wedge-Type Rotary Kiln Blocks, Split Blocks are manufactured of both two-third (⅔) and three-quarter (¾) thickness. Two (2) each of these should be included for each ring of full size blocks. They are correctly specified by the Block Number followed by a dash and the fraction to indicate the thickness desired, thus, 84-A-96-⅔ and 84-A-96-¾ or 78-W-96-⅔ and 78-W-96-¾.

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SIZES OTHER THAN STANDARD IN *BASIC* REFRACTORIES

TYPICAL STRAIGHT, ARCH, WEDGE, AND KEY BRICK



Straight *Arch* *Wedge* *Key*

Name	Dimensions	Number Per Ring	Diameter of Ring	
			Inside	Outside
6″ x 4½″ x 2½″ No. 1 Key*	6″ x (4½″–3 27/32″) x 2½″	59	6′- 0″	7′- 0″
6″ x 4½″ x 2½″ No. 2 Key*	6″ x (4½″–2 11/16″) x 2½″	21	1′- 6″	2′- 6″
6″ x 4½″ x 3″ No. 1 Key*	6″ x (4½″–3 27/32″) x 3″	59	6′- 0″	7′- 0″
6″ x 4½″ x 3″ No. 2 Key*	6″ x (4½″–2 11/16″) x 3″	21	1′- 6″	2′- 6″
6″ x 4½″ x 4″ No. 1 Key*	6″ x (4½″–3 27/32″) x 4″	59	6′- 0″	7′- 0″
6″ x 4½″ x 4″ No. 2 Key*	6″ x (4½″–2 11/16″) x 4″	21	1′- 6″	2′- 6″
12″ x 4½″ x 3″ Straight	12″ x 4½″ x 3″	...	.....	.....
12″ x 4½″ x 3″ No. 1 Arch	12″ x 4½″ x (3″–2¾″)	113	8′- 3″	9′- 0″
12″ x 4½″ x 3″ No. 2 Arch	12″ x 4½″ x (3″–2½″)	57	3′- 9″	4′- 6″
12″ x 4½″ x 3″ No. 3 Arch	12″ x 4½″ x (3″–2″)	29	1′- 6″	2′- 3″
12″ x 4½″ x 3″ No. 1-X Wedge	12″ x 4½″ x (3″-2⅞″)	604	46′- 0″	48′- 0″
12″ x 4½″ x 3″ No. 1 Wedge	12″ x 4½″ x (3″–2¾″)	302	22′- 0″	24′- 0″
12″ x 4½″ x 3″ No. 2 Wedge	12″ x 4½″ x (3″–2½″)	151	10′- 0″	12′- 0″
12″ x 4½″ x 3″ No. 3 Wedge	12″ x 4½″ x (3″–2″)	76	4′- 0″	6′- 0″
12″ x 6″ x 3″ Straight	12″ x 6″ x 3″	...	.....	.....
12″ x 6″ x 3″ No. 1 Arch	12″ x 6″ x (3″–2¾″)	151	11′- 0″	12′- 0″
12″ x 6″ x 3″ No. 2 Arch	12″ x 6″ x (3″–2½″)	76	5′- 0″	6′- 0″
12″ x 6″ x 3″ No. 3 Arch	12″ x 6″ x (3″–2″)	38	2′- 0″	3′- 0″
12″ x 6″ x 3″ No. 1-X Wedge	12″ x 6″ x (3″–2⅞″)	604	46′- 0″	48′- 0″
12″ x 6″ x 3″ No. 1 Wedge	12″ x 6″ x (3″–2¾″)	302	22′- 0″	24′- 0″
12″ x 6″ x 3″ No. 2 Wedge	12″ x 6″ x (3″–2½″)	151	10′- 0″	12′- 0″
12″ x 6″ x 3″ No. 3 Wedge	12″ x 6″ x (3″–2″)	76	4′- 0″	6′- 0″
12″ x 6″ x 3″ No. 1 Key	12″ x (6″–5½″) x 3″	151	22′- 0″	24′- 0″
12″ x 6″ x 3″ No. 2 Key	12″ x (6″–5″) x 3″	76	10′- 0″	12′- 0″
12″ x 6″ x 3″ No. 3 Key	12″ x (6″–3″) x 3″	26	2′- 0″	4′- 0″

*NOTE: The key tapers are not of standard dimensions, and are applicable to basic refractories only.

"Brick Combinations for Rings" are given on pages 536 to 558.

SIZES OTHER THAN STANDARD IN *BASIC* REFRACTORIES

Name	Dimensions	Number Per Ring	Diameter of Ring	
			Inside	Outside
12″ x 9″ x 3″ Straight	12″ x 9″ x 3″	...	.....	.....
12″ x 9″ x 3″ No. 1-X Wedge	12″ x 9″ x (3″–2⅞″)	604	46′- 0″	48′- 0″
12″ x 9″ x 3″ No. 1 Wedge	12″ x 9″ x (3″–2¾″)	302	22′- 0″	24′- 0″
12″ x 9″ x 3″ No. 2 Wedge	12″ x 9″ x (3″–2½″)	151	10′- 0″	12′- 0″
12″ x 9″ x 3″ No. 3 Wedge	12″ x 9″ x (3″–2″)	76	4′- 0″	6′- 0″
13½″ x 4½″ x 2½″ Straight	13½″ x 4½″ x 2½″	...	.....	.....
13½″ x 4½″ x 2½″ No. 1 Arch	13½″ x 4½″ x (2½″–2⅛″)	76	4′- 3″	5′- 0″
13½″ x 4½″ x 2½″ No. 2 Arch	13½″ x 4½″ x (2½″–1¾″)	38	1′- 9″	2′- 6″
13½″ x 4½″ x 2½″ No. 3 Arch	13½″ x 4½″ x (2½″–1″)	19	0′- 6″	1′- 3″
13½″ x 6″ x 2½″ Straight	13½″ x 6″ x 2½″	...	.....	.....
13½″ x 6″ x 2½″ No. 1 Arch	13½″ x 6″ x (2½″–2⅛″)	101	5′- 8″	6′- 8″
13½″ x 6″ x 2½″ No. 2 Arch	13½″ x 6″ x (2½″–1¾″)	51	2′- 4″	3′- 4″
13½″ x 6″ x 2½″ No. 3 Arch	13½″ x 6″ x (2½″–1″)	26	0′- 8″	1′- 8″
13½″ x 6″ x 2½″ No. 1 Key	13½″ x (6″–5″) x 2½″	85	11′- 3″	13′- 6″
13½″ x 6″ x 2½″ No. 2 Key	13½″ x (6″–4⅜″) x 2½″	52	6′- 0″	8′- 3″
13½″ x 6″ x 2½″ No. 3 Key	13½″ x (6″–3″) x 2½″	29	2′- 3″	4′- 6″

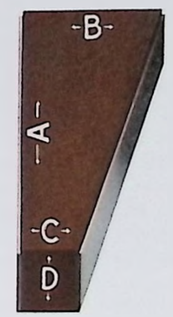
MISCELLANEOUS STRAIGHTS

13½″ x 6¾″ x 2½″ Straight	18″ x 4½″ x 2½″ Straight	18″ x 6¾″ x 2½″ Straight

"Brick Combinations for Rings" are given on pages 536 to 558.

METALKASE DOOR JAMB BRICK

Name	Dimensions			
	A	B	C	D
DJ-1-2½	9″	4½″	1½″	2½″
DJ-1-3	9″	4½″	1½″	3″
DJ-2-2½	9″	6¾″	3¾″	2½″
DJ-2-3	9″	6¾″	3¾″	3″
DJ-3-2½	9″	9″	6″	2½″
DJ-3-3	9″	9″	6″	3″
BS-115-2½	13½″	6¾″	2¾″	2½″
BS-115-3	13½″	6¾″	2¾″	3″
BS-116-2½	13½″	9″	5″	2½″
BS-116-3	13½″	9″	5″	3″
DJ-18-1-2½	18″	6¾″	2¾″	2½″
DJ-18-1-3	18″	6¾″	2¾″	3″
DJ-18-2-2½	18″	9″	5″	2½″
DJ-18-2-3	18″	9″	5″	3″



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STRAIGHTS AND KEYS IN *BASIC* REFRACTORIES FOR OPEN-HEARTH ROOFS

Name	Dimensions	Number Per Ring	Diameter of Ring	
			Inside	Outside
9″ x 4½″ x 3″ Straight	9″ x 4½″ x 3″	...	.....	.....
9″ x 4″ x 3″ Straight	9″ x 4″ x 3″	...	.....	.....
9″ x 3″ x 3″ Straight	9″ x 3″ x 3″	...	.....	.....
9″ x 3″ x 2¼″ Straight	9″ x 3″ x 2¼″	...	.....	.....
9″ x 4½″ x 3″ No. 5 Key	9″ x (4½″–4⁵⁄₁₆″) x 3″	302	34′- 6″	36′- 0″
9″ x 4½″ x 3″ No. 6 Key	9″ x (4½″–4⅛″) x 3″	151	16′- 6″	18′- 0″
9″ x 4½″ x 3″ No. 7 Key	9″ x (4½″–3¾″) x 3″	76	7′- 6″	9′- 0″
12″ x 4½″ x 3″ Straight	12″ x 4½″ x 3″	...	.....	.....
12″ x 4″ x 3″ Straight	12″ x 4″ x 3″	...	.....	.....
12″ x 3″ x 3″ Straight	12″ x 3″ x 3″	...	.....	.....
12″ x 3″ x 2¼″ Straight	12″ x 3″ x 2¼″	...	.....	.....
12″ x 4½″ x 3″ No. 5 Key	12″ x (4½″–4⁵⁄₁₆″) x 3″	403	46′- 0″	48′- 0″
12″ x 4½″ x 3″ No. 6 Key	12″ x (4½″–4⅛″) x 3″	201	22′- 0″	24′- 0″
12″ x 4½″ x 3″ No. 7 Key	12″ x (4½″–3¾″) x 3″	101	10′- 0″	12′- 0″
13½″ x 4½″ x 3″ Straight	13½″ x 4½″ x 3″	...	.....	.....
13½″ x 4″ x 3″ Straight	13½″ x 4″ x 3″	...	.....	.....
13½″ x 3″ x 3″ Straight	13½″ x 3″ x 3″	...	.....	.....
13½″ x 3″ x 2¼″ Straight	13½″ x 3″ x 2¼″	...	.....	.....
13½″ x 4½″ x 3″ No. 5 Key	13½″ x (4½″–4⁵⁄₁₆″) x 3″	453	51′- 9″	54′- 0″
13½″ x 4½″ x 3″ No. 6 Key	13½″ x (4½″–4⅛″) x 3″	227	24′- 9″	27′- 0″
13½″ x 4½″ x 3″ No. 7 Key	13½″ x (4½″–3¾″) x 3″	113	11′- 3″	13′- 6″
15″ x 4½″ x 3″ Straight	15″ x 4½″ x 3″	...	.....	.....
15″ x 4″ x 3″ Straight	15″ x 4″ x 3″	...	.....	.....
15″ x 3″ x 3″ Straight	15″ x 3″ x 3″	...	.....	.....
15″ x 3″ x 2¼″ Straight	15″ x 3″ x 2¼″	...	.....	.....
15″ x 4½″ x 3″ No. 5 Key	15″ x (4½″–4⁵⁄₁₆″) x 3″	503	57′- 6″	60′- 0″
15″ x 4½″ x 3″ No. 6 Key	15″ x (4½″–4⅛″) x 3″	252	27′- 6″	30′- 0″
15″ x 4½″ x 3″ No. 7 Key	15″ x (4½″–3¾″) x 3″	126	12′- 6″	15′- 0″
18″ x 4½″ x 3″ Straight	18″ x 4½″ x 3″	...	.....	.....
18″ x 4″ x 3″ Straight	18″ x 4″ x 3″	...	.....	.....
18″ x 3″ x 3″ Straight	18″ x 3″ x 3″	...	.....	.....
18″ x 3″ x 2¼″ Straight	18″ x 3″ x 2¼″	...	.....	.....
18″ x 4½″ x 3″ No. 5 Key	18″ x (4½″–4⁵⁄₁₆″) x 3″	604	69′- 0″	72′- 0″
18″ x 4½″ x 3″ No. 6 Key	18″ x (4½″–4⅛″) x 3″	302	33′- 0″	36′- 0″
18″ x 4½″ x 3″ No. 7 Key	18″ x (4½″–3¾″) x 3″	151	15′- 0″	18′- 0″

NOTE: All roof keys in the various lengths listed are also furnished in 3″ x 3″ cross section. These keys are designed to turn the same diameter ring as shown for the 4½″ x 3″ keys. For example, a 12″ x 3″ x 3″ No. 5 Key turns a 46′-0″ inside diameter and a 48′-0″ outside diameter, and requires 602 brick per ring (50 per cent more than for the 12″ x 4½″ x 3″ No. 5 Key).

STANDARD SIZES IN *INSULATING* REFRACTORIES

BRAND	STANDARD SIZES
H-W 16-20 H-W 20 H-W 23 H-W 23-LI H-W 26 H-W 28 H-W 30 H-W 33 LOTHERM	All Standard 9-Inch (9″ x 4½″ x 2½″) and 9″ x 4½″ x 3″ sizes are listed on pages 478 and 479.
VEGALITE	9″ x 4½″ x 2½″ Straight 9″ x 4½″ x 3″ Straight

STANDARD LOTHERM 9″ x 6″ x 3½″ ARCH-TYPE ROTARY KILN BLOCKS

Name	Inside Chord "A"	Number Per Ring	Diameter of Ring	
			Inside	Outside
30-A- 42	2½″	37	30″	42″
36-A- 48	2⅝″	43	36″	48″
42-A- 54	2²³⁄₃₂″	48	42″	54″
48-A- 60	2¹³⁄₁₆″	53	48″	60″
54-A- 66	2⅞″	59	54″	66″
60-A- 72	2²⁹⁄₃₂″	64	60″	72″
66-A- 78	2³¹⁄₃₂″	70	66″	78″
72-A- 84	3″	75	72″	84″
78-A- 90	3¹⁄₃₂″	80	78″	90″
84-A- 96	3¹⁄₁₆″	86	84″	96″
90-A-102	3³⁄₃₂″	91	90″	102″
96-A-108	3⅛″	96	96″	108″
102-A-114	3⅛″	102	102″	114″
108-A-120	3⁵⁄₃₂″	107	108″	120″
114-A-126	3⁵⁄₃₂″	113	114″	126″
120-A-132	3³⁄₁₆″	118	120″	132″
123-A-135	3³⁄₁₆″	121	123″	135″
126-A-138	3³⁄₁₆″	123	126″	138″
132-A-144	3⁷⁄₃₂″	129	132″	144″
138-A-150	3⁷⁄₃₂″	134	138″	150″
144-A-156	3⁷⁄₃₂″	140	144″	156″
150-A-162	3¼″	145	150″	162″
156-A-168	3¼″	150	156″	168″



Length . . . . . 9 inches
Width . . . . . 6 inches
Outside Chord . . . . . 3½ inches

For linings 9 inches thick, there are also regularly manufactured 9″ x 6″ x 3½″ Wedge-Type Rotary Kiln Blocks, as illustrated on pages 485 and 493.

NOTE: To facilitate the keying of Standard Arch-Type or Wedge-Type Rotary Kiln Blocks, Split Blocks are manufactured of both two-third (⅔) and three-quarter (¾) thickness. Two (2) each of these should be included for each ring of standard full size blocks. They are correctly specified by the Block Number followed by a dash and the fraction to indicate the thickness desired, thus, 84-A-96-⅔ and 84-A-96-¾ or 78-W-96-⅔ and 78-W-96-¾.

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STANDARD SIZES IN *ACID-PROOF* BRICK

All STANDARD 9-INCH (9″ x 4½″ x 2½″) and 9″ x 4½″ x 3″ SIZES are listed on pages 478 and 479.
All OTHER STANDARD SIZES are listed on pages 498 and 499.



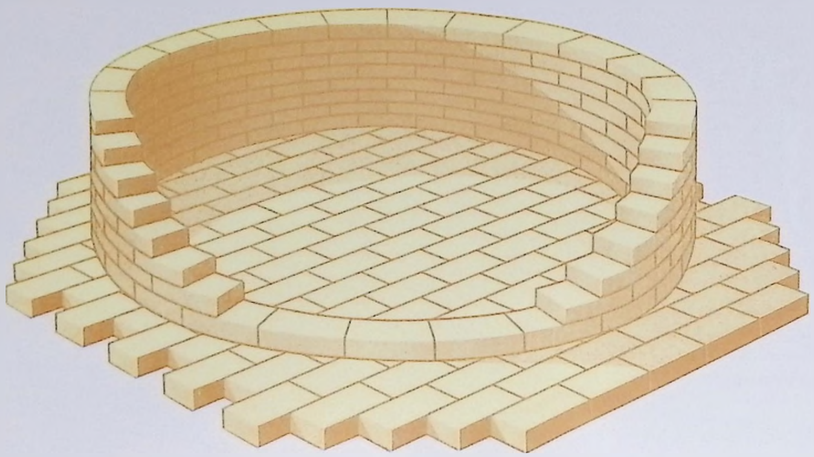
Outside Chord . . . . . 9 inches
Radial Dimension . . . . 4½ inches
Thickness . . . . . 2½ inches

Name	Inside Chord	Number Per Ring	Diameter of Ring: Inside	Diameter of Ring: Outside
STANDARD 9″ x 4½″ x 2½″ CIRCLE BRICK				
24- 33 Circle	6 17/32″	12	24″	33″
36- 45 Circle	7 3/16″	16	36″	45″
48- 57 Circle	7 19/32″	20	48″	57″
60- 69 Circle	7 13/16″	24	60″	69″
72- 81 Circle	8″	29	72″	81″
84- 93 Circle	8⅛″	33	84″	93″
96-105 Circle	8 7/32″	37	96″	105″
108-117 Circle	8 5/16″	41	108″	117″
120-129 Circle	8⅜″	45	120″	129″



Outside Chord . . . . . 9 inches
Radial Dimension . . . . 4½ inches
Thickness . . . . . 3 inches

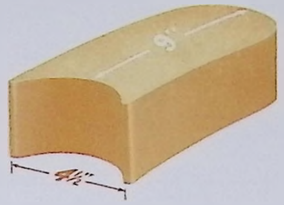
Name	Inside Chord	Number Per Ring	Diameter of Ring: Inside	Diameter of Ring: Outside
STANDARD 9″ x 4½″ x 3″ CIRCLE BRICK				
24- 33-3 Circle	6 17/32″	12	24″	33″
36- 45-3 Circle	7 3/16″	16	36″	45″
48- 57-3 Circle	7 19/32″	20	48″	57″
60- 69-3 Circle	7 13/16″	24	60″	69″
72- 81-3 Circle	8″	29	72″	81″
84- 93-3 Circle	8⅛″	33	84″	93″
96-105-3 Circle	8 7/32″	37	96″	105″
108-117-3 Circle	8 5/16″	41	108″	117″
120-129-3 Circle	8⅜″	45	120″	129″



Typical Assembly of Circle Brick

STANDARD SIZES IN *ACID-PROOF* BRICK

STANDARD UNIVERSAL CIRCLE BRICK FOR LININGS 4½″ THICK



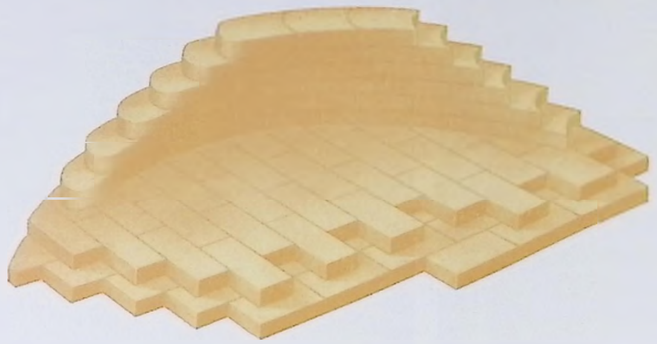
Universal Circle Brick

Shape Nos.

601-1¼ 601-2½ 601-3	Shape Numbers of the 601 Series serve for linings of 2′-0″ to 5′-5″ inside diameter.
600-1¼ 600-2½ 600-3	Shape Numbers of the 600 Series serve for linings of 5′-6″ to 30′-0″ inside diameter.

The suffix number following the serial number is the thickness of the brick in inches. The brick of 1¼″ thickness serve for breaking the horizontal joints in double linings.

I.D. of Ring	No. Per Ring	I.D. of Ring	No. Per Ring	I.D. of Ring	No. Per Ring	I.D. of Ring	No. Per Ring
601 SERIES							
2′-0″	10	3′-0″	15	4′-0″	19	5′-0″	23
2′-3″	11	3′-3″	16	4′-3″	20	5′-3″	24
2′-6″	12	3′-6″	17	4′-6″	21	5′-4″	24
2′-9″	13	3′-9″	18	4′-9″	22	5′-5″	25
600 SERIES							
5′-6″	25	11′-6″	50	17′-6″	75	23′-6″	100
5′-9″	26	11′-9″	51	17′-9″	76	23′-9″	101
6′-0″	27	12′-0″	52	18′-0″	77	24′-0″	103
6′-3″	28	12′-3″	53	18′-3″	78	24′-3″	104
6′-6″	29	12′-6″	54	18′-6″	79	24′-6″	105
6′-9″	30	12′-9″	55	18′-9″	81	24′-9″	106
7′-0″	31	13′-0″	56	19′-0″	82	25′-0″	107
7′-3″	32	13′-3″	57	19′-3″	83	25′-3″	108
7′-6″	33	13′-6″	59	19′-6″	84	25′-6″	109
7′-9″	34	13′-9″	60	19′-9″	85	25′-9″	110
8′-0″	35	14′-0″	61	20′-0″	86	26′-0″	111
8′-3″	37	14′-3″	62	20′-3″	87	26′-3″	112
8′-6″	38	14′-6″	63	20′-6″	88	26′-6″	113
8′-9″	39	14′-9″	64	20′-9″	89	26′-9″	114
9′-0″	40	15′-0″	65	21′-0″	90	27′-0″	115
9′-3″	41	15′-3″	66	21′-3″	91	27′-3″	116
9′-6″	42	15′-6″	67	21′-6″	92	27′-6″	117
9′-9″	43	15′-9″	68	21′-9″	93	27′-9″	118
10′-0″	44	16′-0″	69	22′-0″	94	28′-0″	119
10′-3″	45	16′-3″	70	22′-3″	95	28′-3″	120
10′-6″	46	16′-6″	71	22′-6″	96	28′-6″	121
10′-9″	47	16′-9″	72	22′-9″	97	28′-9″	122
11′-0″	48	17′-0″	73	23′-0″	98	29′-0″	123
11′-3″	49	17′-3″	74	23′-3″	99	29′-6″	126

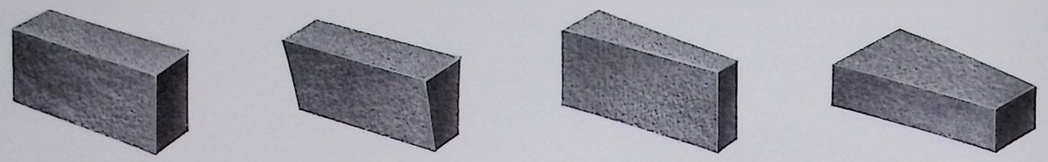


Typical Assembly of Universal Circle Brick for a Circular Shell

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STANDARD SIZES IN *SILICON CARBIDE* REFRACTORIES

TYPICAL STRAIGHT, ARCH, WEDGE, AND KEY BRICK



Straight *Arch* *Wedge* *Key*

All STANDARD 9-INCH (9″ x 4½″ x 2½″) and 9″ x 4½″ x 3″ SIZES are listed on pages 478 and 479.
All OTHER STANDARD SIZES are listed on pages 500 and 501.

Name	Dimensions	Number Per Ring	Diameter of Ring	
			Inside	Outside
ADDITIONAL STANDARD 9-INCH (9″ x 4½″ x 2½″) SIZES				
9″ Half Brick	4½″ x 4½″ x 2½″	...	.....	.....
9″–¾″ Split	9″ x 4½″ x ¾″	...	.....	.....
STANDARD 6″ x 4½″ x 2½″ SIZES				
6″ x 4½″ x 2½″ Straight	6″ x 4½″ x 2½″	...	.....	.....
6″ x 4½″ x 1¼″ Split	6″ x 4½″ x 1¼″	...	.....	.....
6″ x 4½″ x 2½″ Featheredge	6″ x 4½″ x (2½″–⅛″)	...	.....	.....
6″ x 4½″ x 2½″ No. 1 Arch	6″ x 4½″ x (2½″–2⅛″)	76	4′- 3″	5′- 0″
6″ x 4½″ x 2½″ No. 2 Arch	6″ x 4½″ x (2½″–1¾″)	38	1′- 9″	2′- 6″
6″ x 4½″ x 2½″ No. 1 Key	6″ x (4½″–4″) x 2½″	76	8′- 0″	9′- 0″
6″ x 4½″ x 2½″ No. 2 Key	6″ x (4½″–3½″) x 2½″	38	3′- 6″	4′- 6″
STANDARD LARGE 9-INCH (9″ x 6¾″ x 2½″) SIZES				
Large 9″ Straight	9″ x 6¾″ x 2½″	...	.....	.....
Large 9″ No. 1 Wedge	9″ x 6¾″ x (2½″–1⅞″)	91	4′- 6″	6′- 0″
Large 9″ No. 2 Wedge	9″ x 6¾″ x (2½″–1½″)	57	2′- 3″	3′- 9″
STANDARD 9″ x 6¾″ x 3″ SIZES				
9″ x 6¾″ x 3″ Straight	9″ x 6¾″ x 3″	...	.....	.....
9″ x 6¾″ x 3″ No. 1 Wedge	9″ x 6¾″ x (3″–2¾″)	227	16′- 6″	18′- 0″
9″ x 6¾″ x 3″ No. 2 Wedge	9″ x 6¾″ x (3″–2½″)	113	7′- 6″	9′- 0″
9″ x 6¾″ x 3″ No. 3 Wedge	9″ x 6¾″ x (3″–2″)	57	3′- 0″	4′- 6″
STANDARD 13½″ x 4½″ x 2½″ SIZES				
13½″ x 4½″ x 2½″ Straight	13½″ x 4½″ x 2½″	...	.....	.....
13½″ x 4½″ x 2½″ No. 1 Arch	13½″ x 4½″ x (2½″–2⅛″)	76	4′- 3″	5′- 0″
13½″ x 4½″ x 2½″ No. 2 Arch	13½″ x 4½″ x (2½″–1¾″)	38	1′- 9″	2′- 6″
13½″ x 4½″ x 2½″ Jamb	13½″ x 4½″ x 2½″	...	.....	.....

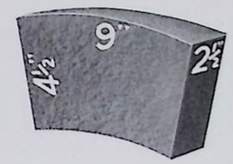
"Brick Combinations for Rings" are given on pages 536 to 558.

STANDARD SIZES IN *SILICON CARBIDE* REFRACTORIES

STANDARD 13½″ x 4½″ x 3″ SIZES

Name	Dimensions	Number Per Ring	Diameter of Ring	
			Inside	Outside
13½″ x 4½″ x 3″ Straight	13½″ x 4½″ x 3″	...	.....	.....
13½″ x 4½″ x 3″ No. 1 Arch	13½″ x 4½″ x (3″–2¾″)	113	8′- 3″	9′- 0″
13½″ x 4½″ x 3″ No. 2 Arch	13½″ x 4½″ x (3″–2½″)	57	3′- 9″	4′- 6″
13½″ x 4½″ x 3″ No. 3 Arch	13½″ x 4½″ x (3″–2″)	29	1′- 6″	2′- 3″

Name	Inside Chord	Number Per Ring	Diameter of Ring	
			Inside	Outside
STANDARD 9″ x 4½″ x 2½″ CIRCLE BRICK				
24- 33 Circle	6 17/32″	12	24″	33″
36- 45 Circle	7 3/16″	16	36″	45″
48- 57 Circle	7 19/32″	20	48″	57″
60- 69 Circle	7 13/16″	24	60″	69″
72- 81 Circle	8″	29	72″	81″
84- 93 Circle	8⅛″	33	84″	93″
96-105 Circle	8 7/32″	37	96″	105″
108-117 Circle	8 5/16″	41	108″	117″
120-129 Circle	8⅜″	45	120″	129″



Outside Chord . . . . . 9 inches
Radial Dimension . . . . . 4½ inches
Thickness . . . . . 2½ inches

Name	Inside Chord	Number Per Ring	Diameter of Ring	
			Inside	Outside
STANDARD 9″ x 4½″ x 3″ CIRCLE BRICK				
24- 33-3 Circle	6 17/32″	12	24″	33″
36- 45-3 Circle	7 3/16″	16	36″	45″
48- 57-3 Circle	7 19/32″	20	48″	57″
60- 69-3 Circle	7 13/16″	24	60″	69″
72- 81-3 Circle	8″	29	72″	81″
84- 93-3 Circle	8⅛″	33	84″	93″
96-105-3 Circle	8 7/32″	37	96″	105″
108-117-3 Circle	8 5/16″	41	108″	117″
120-129-3 Circle	8⅜″	45	120″	129″



Outside Chord . . . . . 9 inches
Radial Dimension . . . . . 4½ inches
Thickness . . . . . 3 inches

STANDARD SIZES IN *ZIRCON* REFRACTORIES

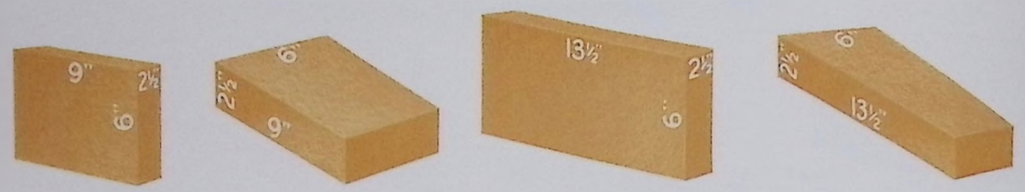
All STANDARD 9-INCH (9″ x 4½″ x 2½″) SIZES are listed on pages 478 and 479.

STANDARD MISCELLANEOUS STRAIGHTS

9″ x 4½″ x 3″ Straight	12″ x 6″ x 3″ Straight	13½″ x 6″ x 3″ Straight

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asbestosclaims.law/library/25270/254

TYPICAL SHAPES FOR BLAST-FURNACE LININGS



9" x 6" x 2½" Straight and 9" x 6" x 3" Straight

9" x 6" x 2½" Key and 9" x 6" x 3" Key

13½" x 6" x 2½" Straight and 13½" x 6" x 3" Straight

13½" x 6" x 2½" Key and 13½" x 6" x 3" Key

STANDARD SIZES

Name	Dimensions	Number Per Ring	Diameter of Ring	
			Inside	Outside
9" x 6" x 2½" Straight	9" x 6" x 2½"	...	.....	.....
9" x 6" x 2½" No. 1 Key	9" x (6"–5⅜") x 2½"	91	13′- 0"	14′- 6"
9" x 6" x 2½" No. 2 Key	9" x (6"–4 13/16") x 2½"	48	6′- 0"	7′- 6"
9" x 6" x 3" Straight	9" x 6" x 3"	...	.....	.....
9" x 6" x 3" No. 1 Key	9" x (6"–5⅜") x 3"	91	13′- 0"	14′- 6"
9" x 6" x 3" No. 2 Key	9" x (6"–4 13/16") x 3"	48	6′- 0"	7′- 6"
13½" x 6" x 2½" Straight	13½" x 6" x 2½"	...	.....	.....
13½" x 6" x 2½" No. 1 Key	13½" x (6"–5") x 2½"	85	11′- 3"	13′- 6"
13½" x 6" x 2½" No. 2 Key	13½" x (6"–4⅜") x 2½"	52	6′- 0"	8′- 3"
13½" x 6" x 3" Straight	13½" x 6" x 3"	...	.....	.....
13½" x 6" x 3" No. 1 Key	13½" x (6"–5") x 3"	85	11′- 3"	13′- 6"
13½" x 6" x 3" No. 2 Key	13½" x (6"–4⅜") x 3"	52	6′- 0"	8′- 3"

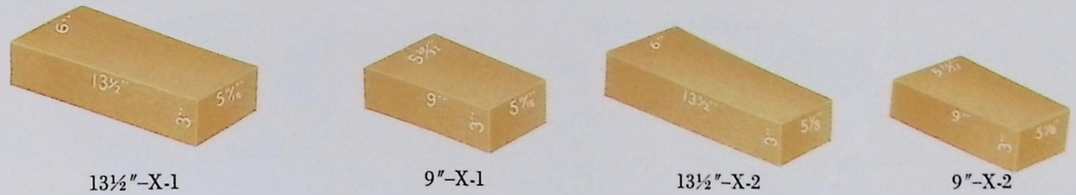
"Brick Combinations for Rings" are given on pages 536 to 558.

STANDARD BLAST-FURNACE BOTTOM BLOCKS—18" x 9" x 4½"

Number per course for blocks laid on end

Diameter of Hearth Jacket	No. of Blocks	Diameter of Hearth Jacket	No. of Blocks	Diameter of Hearth Jacket	No. of Blocks	Diameter of Hearth Jacket	No. of Blocks
17′- 6"	897	22′- 6"	1467	27′- 6"	2176	32′- 6"	3026
18′- 0"	947	23′- 0"	1531	28′- 0"	2255	33′- 0"	3119
18′- 6"	999	23′- 6"	1598	28′- 6"	2335	33′- 6"	3213
19′- 0"	1053	24′- 0"	1665	29′- 0"	2417	34′- 0"	3308
19′- 6"	1108	24′- 6"	1734	29′- 6"	2500	34′- 6"	3405
20′- 0"	1164	25′- 0"	1804	30′- 0"	2584	35′- 0"	3503
20′- 6"	1222	25′- 6"	1876	30′- 6"	2669	35′- 6"	3603
21′- 0"	1281	26′- 0"	1949	31′- 0"	2756	36′- 0"	3704
21′- 6"	1342	26′- 6"	2023	31′- 6"	2845	36′- 6"	3806
22′- 0"	1403	27′- 0"	2099	32′- 0"	2935	37′- 0"	3909

TYPICAL SHAPES FOR ALL-KEY BLAST-FURNACE LININGS



13½"–X-1 | 9"–X-1 | 13½"–X-2 | 9"–X-2

NOTE: Blast-Furnace keys X-1 and X-2 are also regularly manufactured in 6", 10½", 12", and 15" lengths. The brick combinations for rings (tabulated below) are applicable for X-1 and X-2 keys of all lengths.

BRICK COMBINATIONS FOR ALL-KEY LININGS

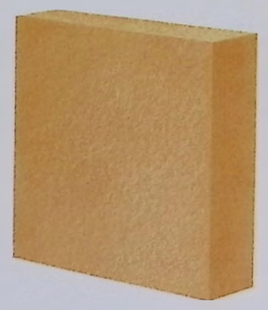
Diameter Inside Brickwork	Number Required Per Ring			Diameter Inside Brickwork	Number Required Per Ring		
	X-2	X-1	Total		X-2	X-1	Total
13′- 3"	98	—	98	27′- 0"	49	135	184
13′- 6"	96	3	99	27′- 6"	47	140	187
13′- 9"	95	6	101	28′- 0"	45	145	190
14′- 0"	95	8	103	28′- 6"	44	150	194
14′- 6"	93	13	106	29′- 0"	42	155	197
15′- 0"	91	18	109	29′- 6"	40	160	200
15′- 6"	89	23	112	30′- 0"	38	165	203
16′- 0"	87	28	115	30′- 6"	37	169	206
16′- 6"	85	33	118	31′- 0"	35	174	209
17′- 0"	84	37	121	31′- 6"	33	179	212
17′- 6"	82	42	124	32′- 0"	32	184	216
18′- 0"	80	48	128	32′- 6"	30	189	219
18′- 6"	79	52	131	33′- 0"	28	194	222
19′- 0"	77	57	134	33′- 6"	26	199	225
19′- 6"	75	62	137	34′- 0"	24	204	228
20′- 0"	73	67	140	34′- 6"	23	208	231
20′- 6"	71	72	143	35′- 0"	21	213	234
21′- 0"	70	76	146	35′- 6"	19	219	238
21′- 6"	68	82	150	36′- 0"	18	223	241
22′- 0"	66	87	153	36′- 6"	16	228	244
22′- 6"	65	91	156	37′- 0"	14	233	247
23′- 0"	63	96	159	37′- 6"	12	238	250
23′- 6"	61	101	162	38′- 0"	10	243	253
24′- 0"	59	106	165	38′- 6"	9	247	256
24′- 6"	57	111	168	39′- 0"	7	253	260
25′- 0"	56	116	172	39′- 6"	5	258	263
25′- 6"	54	121	175	40′- 0"	4	262	266
26′- 0"	52	126	178	40′- 6"	2	267	269
26′- 6"	51	130	181	41′- 0"	—	272	272

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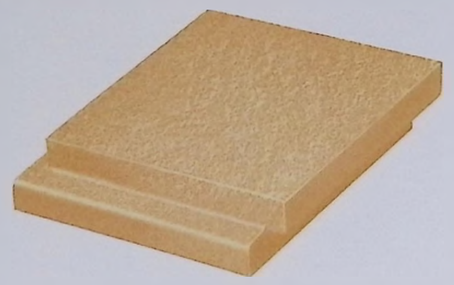
TYPICAL SHAPES FOR BOILER SETTINGS

SQUARE-EDGE TILE
or
RECTANGULAR BAFFLE TILE

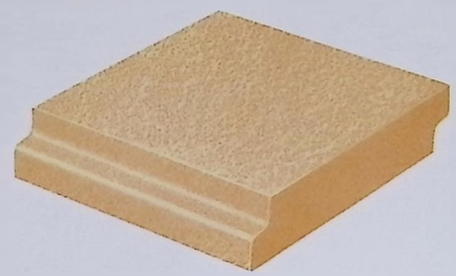
12″ x 6″ x 2″	18″ x 6″ x 2″
12″ x 6″ x 2½″	18″ x 6″ x 2½″
12″ x 6″ x 3″	18″ x 6″ x 3″
12″ x 9″ x 2″	18″ x 9″ x 2″
12″ x 9″ x 2½″	18″ x 9″ x 2½″
12″ x 9″ x 3″	18″ x 9″ x 3″
12″ x 12″ x 2″	18″ x 12″ x 2″
12″ x 12″ x 2½″	18″ x 12″ x 2½″
12″ x 12″ x 3″	18″ x 12″ x 3″



The above sizes are the ones most commonly used. However, square-edge tile are available in various other lengths, widths and thicknesses.



SHIPLAP TILE (SL-4)
(Lapped on four sides)



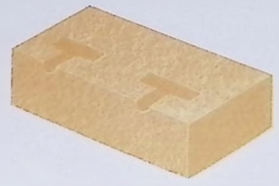
SHIPLAP TILE (SL-2)
(Lapped on two sides)

Shiplap Tile are made in various lengths, widths, and thicknesses. When ordering, specify the size and the number of sides to be lapped. When two sides only are to be lapped, specify which sides.

Sizes commonly used are carried in stock. Other sizes are made to order.

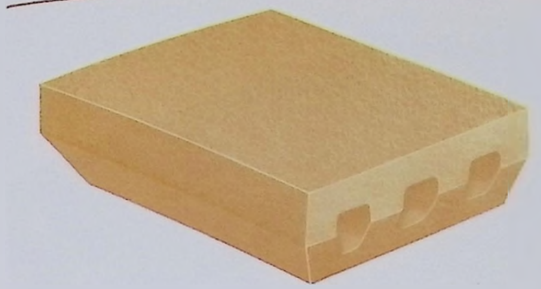


MARINE BOILER TILE
9″ x 4½″ x 2½″ Over-all Dimensions

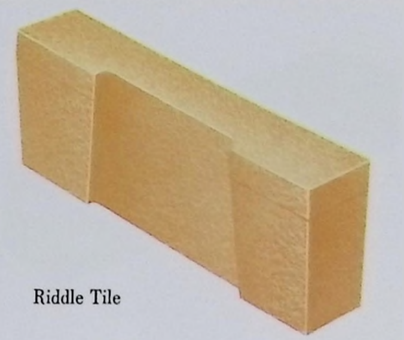


MARINE BOILER TILE
9″ x 4½″ x 2½″ Over-all Dimensions

TYPICAL SHAPES FOR CERAMIC KILNS



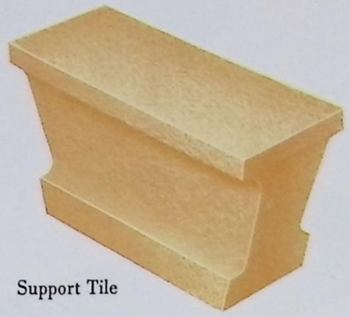
Car-Top Shape



Riddle Tile

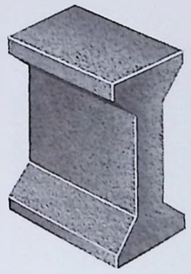


Car-Top Shape



Support Tile

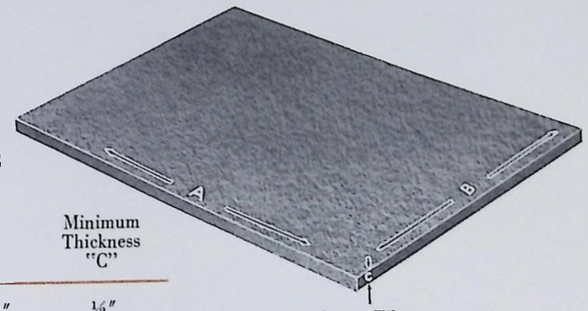
SILICON CARBIDE KILN-SETTING ACCESSORIES



Girder Tile

RANGE OF DIMENSIONS FOR SETTER TILE

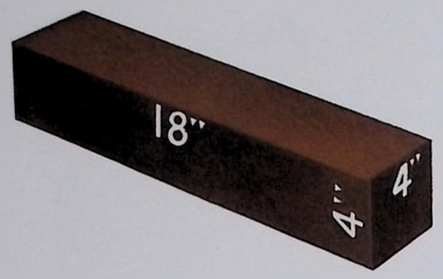
Length "A"	Width "B"	Minimum Thickness "C"
11″ to 13″	8″ to 10″	½″
13″ to 15″	10″ to 12″	9/16″
15″ to 17″	12″ to 14″	⅝″
17″ to 20″	14″ to 16″	¾″
20″ to 24″	16″ to 18″	⅞″
24″ to 28″	18″ to 21″	1″
28″ to 32″	21″ to 24″	1⅛″
32″ to 36″	24″ to 27″	1¼″ to 1⅜″
36″ to 40″	27″ to 31″	1⅜″ to 1½″
40″ to 44″	31″ to 35″	1½″ to 1¾″
44″ to 48″	35″ to 39″	1¾″ to 2″
48″ to 50″	39″ to 43″	2″ to 2¼″



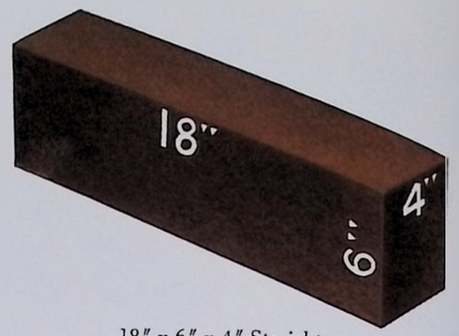
Setter Tile

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asbestosclaims.law/library/25270/256

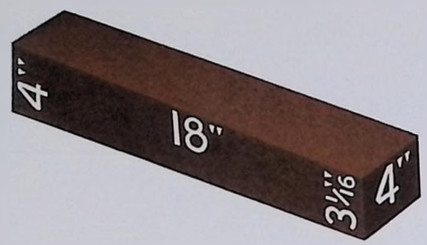
TYPICAL SHAPES FOR COPPER CONVERTERS



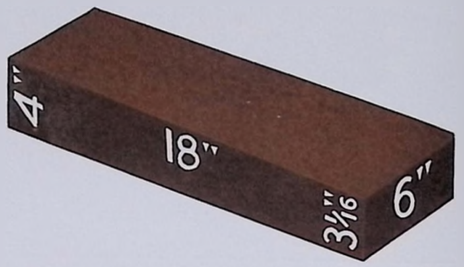
18″ x 4″ x 4″ Straight
and
15″ x 4″ x 4″ Straight
13″ x 4″ x 4″ Straight
12″ x 4″ x 4″ Straight



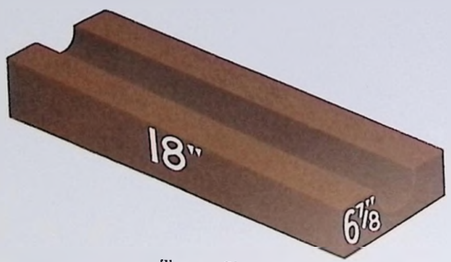
18″ x 6″ x 4″ Straight
and
15″ x 6″ x 4″ Straight



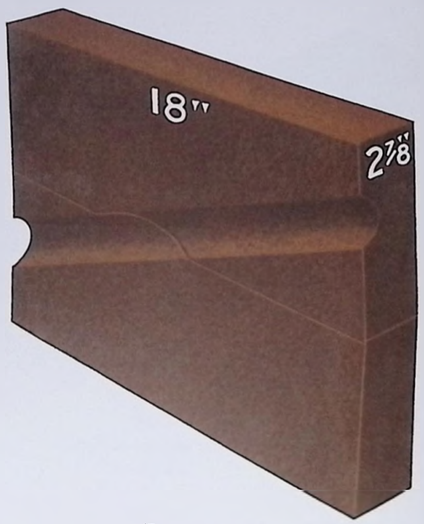
18″ x 4″ x (4″—3 1/16″) Wedge
and
18″ x 4″ x (4″—2 13/16″) Wedge
15″ x 4″ x (4″—3 1/4″) Wedge
13″ x 4″ x (4″—3 5/16″) Wedge
13″ x 4″ x (4″—3 3/32″) Wedge
13″ x 4″ x (4″—3″) Wedge



18″ x 6″ x (4″—3 1/16″) Wedge
and
15″ x 6″ x (4″—3 1/4″) Wedge



Tuyere Shape



Tuyere Shapes

TYPICAL DOME SHAPES AND INTERLOCKING TILE

EFR SHAPES FOR DOMES



Key—Arch

Available in—
9″ x 4½″ x 3″ Series
12″ x 6″ x 3″ Series
13½″ x 6″ x 3″ Series
15″ x 6″ x 3″ Series
in various arch, wedge, and key tapers.



Key—Wedge

INTERLOCKING TILE



Single Tongue and Groove
9″ x 4½″ x 2½″ or 9″ x 4½″ x 3″ Straight



Double Tongue and Groove
9″ x 4½″ x 2½″ or 9″ x 4½″ x 3″ Straight



Muffle-Wall Tile



Muffle-Wall Tile

For assembly of Muffle-Wall Tile see page 360.

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TYPICAL SKEWBACK SHAPES

STANDARD 9-INCH (9″ x 4½″ x 2½″) AND 9″ x 4½″ x 3-INCH SKEWS

9-INCH SIZES	9″ x 4½″ x 3-INCH SIZES
9″ Edge Skew	9″ x 4½″ x 3″ Edge Skew
9″—48° End Skew	9″ x 4½″ x 3″ 48° End Skew
9″—60° End Skew	9″ x 4½″ x 3″ 60° End Skew
9″—48° Side Skew	9″ x 4½″ x 3″ 48° Side Skew
9″—60° Side Skew	9″ x 4½″ x 3″ 60° Side Skew
See Illustrations Page 479.	See Page 479.

SKEWBACKS BUILT WITH STANDARD 9-INCH SIZES



For Arch 4½″ Thick
Rise 1½″ Per Foot of Span
Central Angle 56° 8.7′

Skewback consists of
1—9″—2″ Split
1—9″ Featheredge

See Illustrations, Pages 478 and 479.



For Arch 4½″ Thick
Rise 2.302″ (2 5/16″) Per Foot of Span
Central Angle 83° 58.5′

Skewback consists of
2—9″—48° End Skew
1—9″—48° Side Skew
1—9″ Soap

See Illustrations, Pages 478 and 479.



For Arch 9″ Thick
Rise 2.302″ (2 5/16″) Per Foot of Span
Central Angle 83° 58.5′

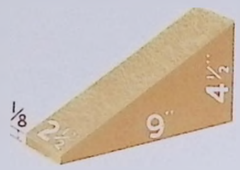
Skewback consists of
2—9″—48° End Skew
2—9″—48° Side Skew
1—9″ Soap

See Illustrations, Pages 478 and 479.

SKEWBACK SHAPES OTHER THAN STANDARD



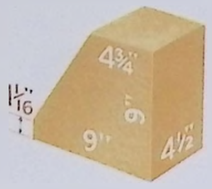
Angle "A" Skew
(9″—4½″) x 4½″ x 2½″
Central Angle 90°



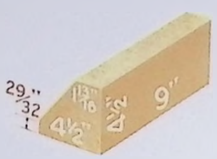
Angle "B" Skew
9″ x (4½″—⅛″) x 2½″
Central Angle 128° 9.0′



Angle "C" Skew
(9″—4½″) x 4½″ x 2½″
Central Angle 124° 21.1′



Shape 56-9
For Arch 9″ Thick
Rise 1½″ Per Foot of Span
Central Angle 56° 8.7′



Shape 74-4½
For Arch 4½″ Thick
Rise 2″ Per Foot of Span
Central Angle 73° 44.4′

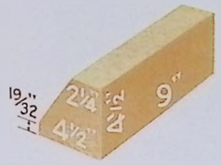


Shape 74-9
For Arch 9″ Thick
Rise 2″ Per Foot of Span
Central Angle 73° 44.4′

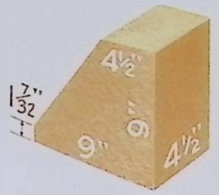
"Brick Combinations for Arches" are given on pages 560 to 576.

SKEWBACK SHAPES OTHER THAN STANDARD

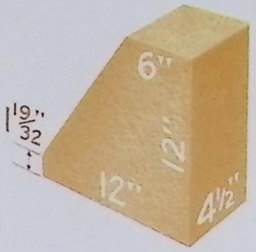
FOR ARCHES WITH 60-DEGREE CENTRAL ANGLE
RISE 1.608 (1 19/32) INCHES PER FOOT OF SPAN



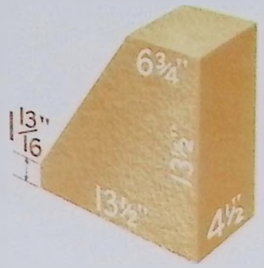
Shape 60-4½
For Arch 4½″ Thick



Shape 60-9
For Arch 9″ Thick

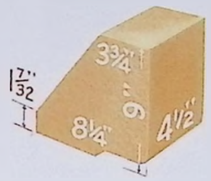


Shape 60-12
For Arch 12″ Thick

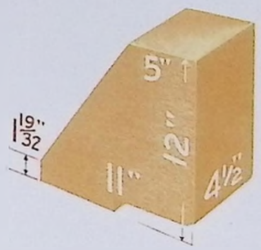


Shape 60-13½
For Arch 13½″ Thick

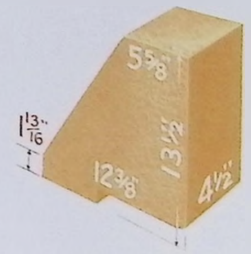
SKEWBACK BRICK WITH CUTOUTS FOR STEEL ANGLE SUPPORTING FRAMEWORK



Shape 60-9-A
For Arch 9″ Thick



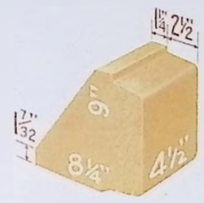
Shape 60-12-A
For Arch 12″ Thick



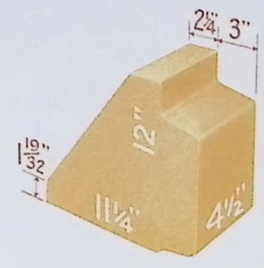
Shape 60-13½-A
For Arch 13½″ Thick

Skewback	Maximum Dimensions of Steel Angle	
	Shorter Leg	Thickness
60- 9-A	4″	3/4″
60-12-A	6″	1″
60-13½-A	8″	1⅛″

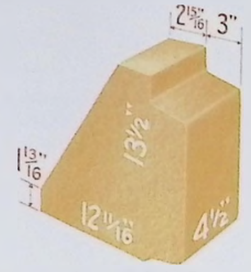
SKEWBACK BRICK WITH CUTOUTS FOR STEEL CHANNEL SUPPORTING FRAMEWORK



Shape 60-9-C
For Arch 9″ Thick



Shape 60-12-C
For Arch 12″ Thick



Shape 60-13½-C
For Arch 13½″ Thick

Skewback	Maximum Dimensions of Steel Channel		
	Channel Size	Flange Width	Web Thickness
60- 9-C	12″	3 13/32″	3/4″
60-12-C	12″	3 13/32″	3/4″
60-13½-C	15″	3 13/16″	13/16″

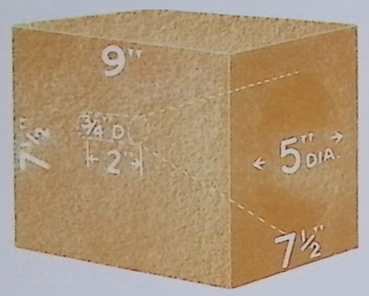
"Brick Combinations for Arches" are given on pages 560 to 576.

HARBISON-WALKER REFRACTORIES COMPANY

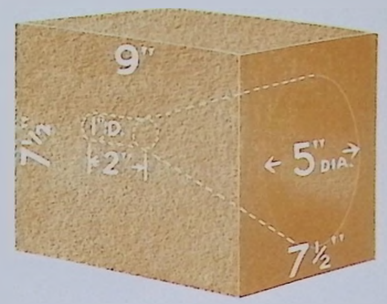
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TYPICAL TAP-OUT AND SLAG HOLE BLOCKS

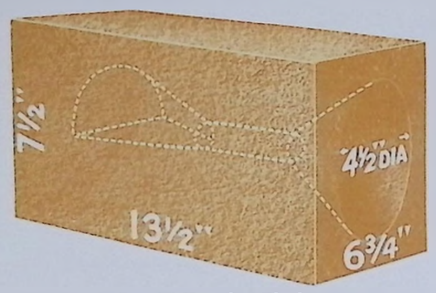
FOR MALLEABLE IRON AIR FURNACES



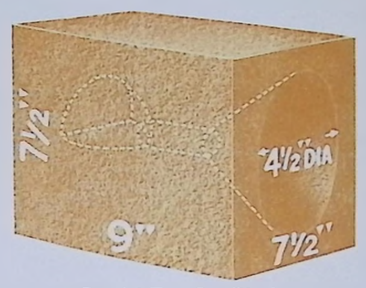
Tap-Out Block T.O.1.
9" x 7½" x 7½"
With ¾" hole for Hand ladles



Tap-Out Block T.O.2.
9" x 7½" x 7½"
With 1" hole for Bull ladles



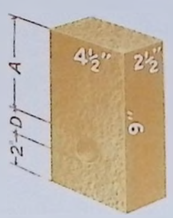
Special Tap-Out Block
13½" x 7½" x 6¾"



Special Tap-Out Block
9" x 7½" x 7½"

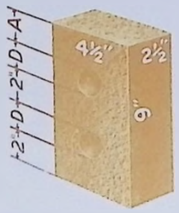
Standard Bung Brick for Malleable Iron Air Furnaces are listed and illustrated on page 482.

FOR CUPOLAS



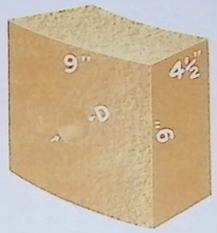
Tap-Out Block T-1
(One-Hole Type)

Name of Block	A	D
T-1-A	6½"	½"
T-1-B	6¼"	¾"
T-1-C	6"	1"
T-1-D	5¾"	1¼"
T-1-E	5½"	1½"
T-1-F	5⅜"	1⅝"



Tap-Out Block T-2
(Two-Hole Type)

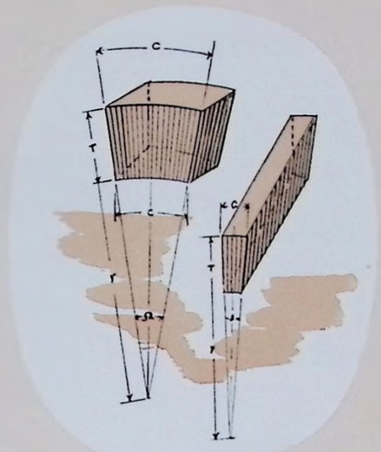
Name of Block	A	D
T-2-A	4"	½"
T-2-B	3½"	¾"
T-2-C	3"	1"
T-2-D	2½"	1¼"
T-2-E	2"	1½"
T-2-F	3¾"	5/8"



Slag Hole Block S-1

Name of Block	D	Inside Diam.	Outside Diam.
S-1-A	1½"	51"	60"
S-1-B	2"	51"	60"

Standard Cupola Blocks are listed and illustrated on page 484.
Standard Universal Cupola Blocks are listed and illustrated on page 483.



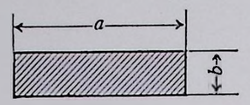
FORMULAS AND TABLES

HARBISON-WALKER REFRACTORIES COMPANY

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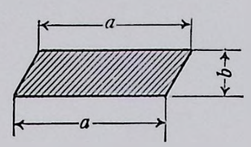
FORMULAS FOR CALCULATING AREAS AND VOLUMES

RECTANGLE



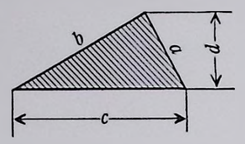
Area = ab

PARALLELOGRAM



Area = ab

TRIANGLE

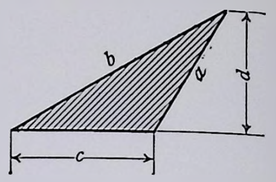


Area = ½ cd

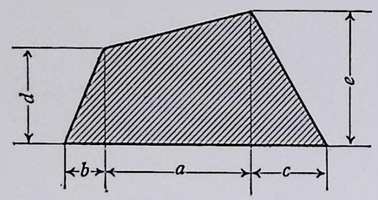
Area =

$$\sqrt{s\,(s-a)\,(s-b)\,(s-c)}$$

when s = ½ (a + b + c)



TRAPEZIUM

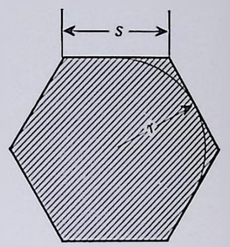


Area = ½ [a (e + d) + bd + ce]

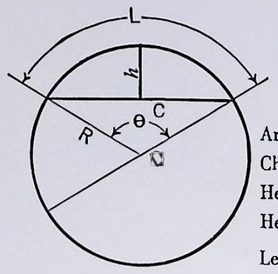
REGULAR POLYGON

Area = ½ nsr
when n = Number of sides.

Number of Sides	Area
6	2.5981 s^2 = 3.4641 r^2
8	4.8284 s^2 = 3.3137 r^2
9	6.1818 s^2 = 3.2757 r^2
10	7.6942 s^2 = 3.2492 r^2
12	11.1962 s^2 = 3.2154 r^2



CIRCLE

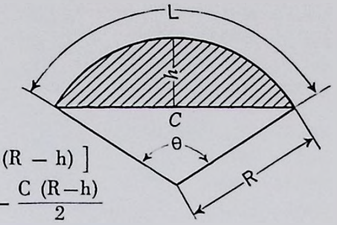


θ (Theta) = included angle in degrees.
π (pi) = 3.1416
Circumference =
$\pi D = 2\pi R = 2\sqrt{\pi \times \text{Area}}$
Diameter, $D = 2R = 2\sqrt{\text{Area} \div \pi}$
Radius, $R = \frac{1}{2} D = \sqrt{\text{Area} \div \pi}$
Radius, R = Circumference ÷ 2 π
Radius, $R = \frac{(C \div 2)^2 + h^2}{2\,h}$

Area = 0.7854 D^2 = π R^2
Chord, $C = 2\sqrt{h\,(D-h)} = 2\,R \times \text{sine } \frac{1}{2}\,\theta$
Height of Arc, $h = R - \sqrt{R^2 - (C \div 2)^2}$
Height of Arc, $h = R - \frac{1}{2}\sqrt{(2R+C)\,(2R-C)}$
Length of Arc, $L = \frac{\theta}{360} \times 2\pi R = 0.017453\,R\theta$
½ θ = 28.648 L ÷ R
Sine ½ θ = C ÷ 2R
1° = 0.017453 Radians, 1 radian = 57.296°

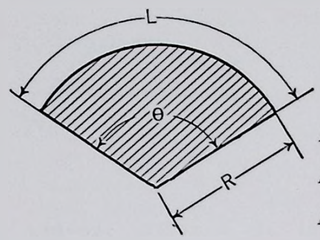
FORMULAS FOR CALCULATING AREAS AND VOLUMES—Continued

SEGMENT OF A CIRCLE



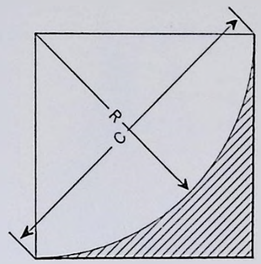
Tangent ¼ θ = $\frac{2h}{C}$
Area = ½ [LR − C (R − h)]
Area = $\pi R^2 \times \frac{\theta}{360} - \frac{C\,(R-h)}{2}$

SECTOR OF A CIRCLE



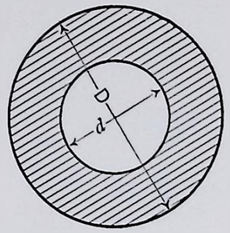
Area = ½ LR
Area = $\pi R^2 \times \frac{\theta}{360}$
Area = 0.0087266 R^2 θ

SPANDREL



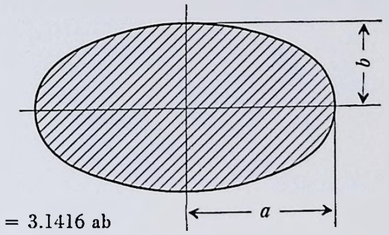
Area = 0.2146 R^2
Area = 0.1073 C^2

CIRCULAR RING



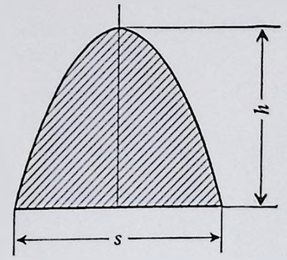
Area =
0.7854 (D^2 − d^2)
Area =
0.7854 (D + d) (D − d)

ELLIPSE



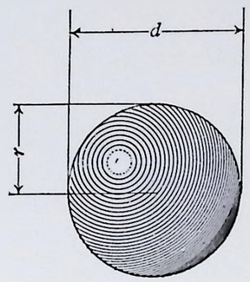
Area = πab = 3.1416 ab

PARABOLIC SEGMENT



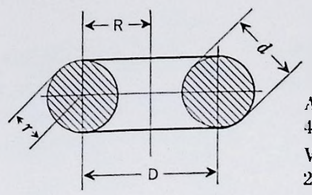
Area = ⅔ sh

SPHERE



Surface =
4 πr^2 = 12.566 r^2 = πd^2
Volume =
4/3 πr^3 = 4.1888 r^3
Volume =
⅙ πd^3 = 0.5236 d^3

RING OF CIRCULAR CROSS SECTION (Torus)

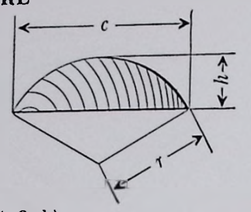


Area of Surface =
4π² Rr = 39.478 Rr
Volume =
2 π² Rr^2 = 19.739 Rr^2

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asbestosclaims.law/library/25270/260

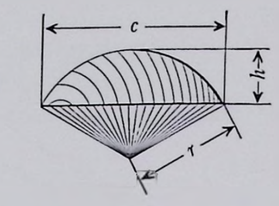
FORMULAS FOR CALCULATING AREAS AND VOLUMES—Continued

SEGMENT OF A SPHERE



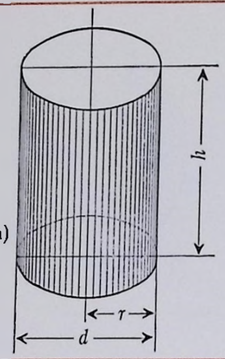
Spherical Surface =
$2\pi rh = 0.7854\ (c^2 + 4\ h^2)$
Total Surface $= 0.7854\ (c^2 + 8\ rh)$
Volume $= \frac{1}{6}\pi h^2\ (3\ r - h) = 1.0472\ h^2\ (3\ r - h)$
Volume $= \frac{1}{24}\pi h\ (3\ c^2 + 4\ h^2) = 0.1309\ h\ (3\ c^2 + 4\ h^2)$

SECTOR OF A SPHERE



Total Surface $= 1.5708\ r\ (4\ h + c)$
Volume $= \frac{2}{3}\pi r^2 h = 2.0944\ r^2 h$

CYLINDER

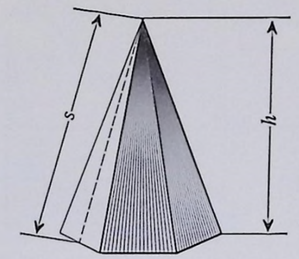


Cylindrical Surface =
$\pi dh = 2\pi rh = 6.2832\ rh$

Total Surface =
$2\pi r\ (r + h) = 6.2832\ r\ (r + h)$

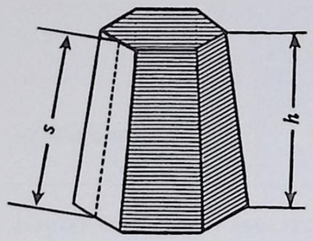
Volume =
$\pi r^2 h = \frac{1}{4}\pi d^2 h = 0.7854\ d^2 h$

PYRAMID



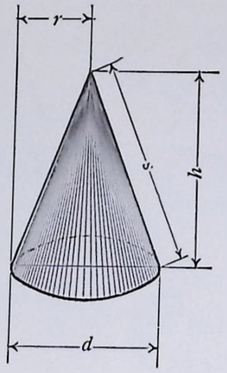
A = area of base
P = perimeter of base
Lateral Area $= \frac{1}{2}\ Ps$
Volume $= \frac{1}{3}\ Ah$

FRUSTUM OF A PYRAMID



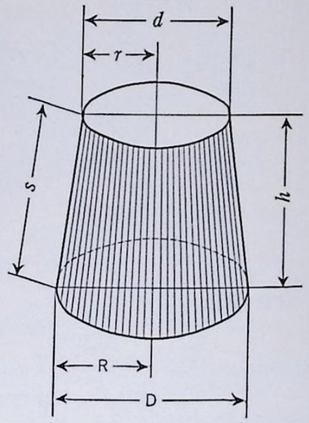
A = area of base
a = area of top
m = area of midsection
P = perimeter of base
p = perimeter of top
Lateral Area $= \frac{1}{2}\ s\ (P + p)$
Volume $= \frac{1}{3}\ h\ (a + A + \sqrt{aA})$
Volume $= \frac{1}{6}\ h\ (a + A + 4\ m)$

CONE



Conical Area =
$\pi rs = \pi r\sqrt{r^2 + h^2}$
Volume $= \frac{1}{3}\ \pi r^2 h =$
$1.0472\ r^2 h = 0.2618\ d^2 h$

FRUSTUM OF A CONE



A = area of base a = area of top
m = area of midsection
Area of Conical Surface $= \frac{1}{2}\ \pi s\ (D + d)$
Volume $= \frac{1}{3}\ \pi h\ (r^2 + rR + R^2)$
Volume $= \frac{1}{3}\ \pi h\ (a + \sqrt{aA} + A)$
Volume $= \frac{1}{6}\ h\ (a + 4m + A)$

CIRCUMFERENCES AND AREAS OF CIRCLES FOR GIVEN DIAMETERS

Diam.	Circum.	Area	Diam.	Circum.	Area	Diam.	Circum.	Area	Diam.	Circum.	Area
1/64	0.04909	0.00019	4	12.566	12.566	9 1/2	29.845	70.882	15	47.124	176.71
1/32	0.09818	0.00077	4 1/8	12.959	13.364	9 5/8	30.238	72.760	15 1/8	47.517	179.67
1/16	0.19635	0.00307	4 1/4	13.352	14.186	9 3/4	30.631	74.662	15 1/4	47.909	182.65
3/32	0.29452	0.00690	4 3/8	13.745	15.033	9 7/8	31.023	76.589	15 3/8	48.302	185.66
1/8	0.39270	0.01227	4 1/2	14.137	15.904	10	31.416	78.540	15 1/2	48.695	188.69
5/32	0.49087	0.01917	4 5/8	14.530	16.800	10 1/8	31.809	80.516	15 5/8	49.087	191.75
3/16	0.58905	0.02761	4 3/4	14.923	17.721	10 1/4	32.201	82.516	15 3/4	49.480	194.83
7/32	0.68722	0.03758	4 7/8	15.315	18.665	10 3/8	32.594	84.541	15 7/8	49.873	197.93
1/4	0.78540	0.04909	5	15.708	19.635	10 1/2	32.987	86.590	16	50.266	201.06
5/16	0.98175	0.07670	5 1/8	16.101	20.629	10 5/8	33.379	88.664	16 1/8	50.658	204.22
3/8	1.1781	0.11045	5 1/4	16.493	21.648	10 3/4	33.772	90.763	16 1/4	51.051	207.39
7/16	1.3745	0.15033	5 3/8	16.886	22.691	10 7/8	34.165	92.886	16 3/8	51.444	210.60
1/2	1.5708	0.19635	5 1/2	17.279	23.758	11	34.558	95.033	16 1/2	51.836	213.82
9/16	1.7672	0.24850	5 5/8	17.672	24.850	11 1/8	34.950	97.205	16 5/8	52.229	217.08
5/8	1.9635	0.30680	5 3/4	18.064	25.967	11 1/4	35.343	99.402	16 3/4	52.622	220.35
11/16	2.1598	0.37122	5 7/8	18.457	27.109	11 3/8	35.736	101.62	16 7/8	53.014	223.65
3/4	2.3562	0.44179	6	18.850	28.274	11 1/2	36.128	103.87	17	53.407	226.98
13/16	2.5525	0.51849	6 1/8	19.242	29.465	11 5/8	36.521	106.14	17 1/8	53.800	230.33
7/8	2.7489	0.60132	6 1/4	19.635	30.680	11 3/4	36.914	108.43	17 1/4	54.193	233.71
15/16	2.9452	0.69029	6 3/8	20.028	31.919	11 7/8	37.306	110.75	17 3/8	54.585	237.10
1	3.1416	0.78540	6 1/2	20.420	33.183	12	37.699	113.10	17 1/2	54.978	240.53
1 1/8	3.5343	0.99402	6 5/8	20.813	34.472	12 1/8	38.092	115.47	17 5/8	55.371	243.98
1 1/4	3.9270	1.2272	6 3/4	21.206	35.785	12 1/4	38.485	117.86	17 3/4	55.763	247.45
1 3/8	4.3197	1.4849	6 7/8	21.598	37.122	12 3/8	38.877	120.28	17 7/8	56.156	250.95
1 1/2	4.7124	1.7671	7	21.991	38.485	12 1/2	39.270	122.72	18	56.549	254.47
1 5/8	5.1051	2.0739	7 1/8	22.384	39.871	12 5/8	39.663	125.19	18 1/8	56.941	258.02
1 3/4	5.4978	2.4053	7 1/4	22.777	41.282	12 3/4	40.055	127.68	18 1/4	57.334	261.59
1 7/8	5.8905	2.7612	7 3/8	23.169	42.718	12 7/8	40.448	130.19	18 3/8	57.727	265.18
2	6.2832	3.1416	7 1/2	23.562	44.179	13	40.841	132.73	18 1/2	58.120	268.80
2 1/8	6.6759	3.5466	7 5/8	23.955	45.664	13 1/8	41.233	135.30	18 5/8	58.512	272.45
2 1/4	7.0686	3.9761	7 3/4	24.347	47.173	13 1/4	41.626	137.89	18 3/4	58.905	276.12
2 3/8	7.4613	4.4301	7 7/8	24.740	48.707	13 3/8	42.019	140.50	18 7/8	59.298	279.81
2 1/2	7.8540	4.9087	8	25.133	50.265	13 1/2	42.412	143.14	19	59.690	283.53
2 5/8	8.2467	5.4119	8 1/8	25.525	51.849	13 5/8	42.804	145.80	19 1/8	60.083	287.27
2 3/4	8.6394	5.9396	8 1/4	25.918	53.456	13 3/4	43.197	148.49	19 1/4	60.476	291.04
2 7/8	9.0321	6.4918	8 3/8	26.311	55.088	13 7/8	43.590	151.20	19 3/8	60.868	294.83
3	9.4248	7.0686	8 1/2	26.704	56.745	14	43.982	153.94	19 1/2	61.261	298.65
3 1/8	9.8175	7.6699	8 5/8	27.096	58.426	14 1/8	44.375	156.70	19 5/8	61.654	302.49
3 1/4	10.210	8.2958	8 3/4	27.489	60.132	14 1/4	44.768	159.48	19 3/4	62.047	306.35
3 3/8	10.603	8.9462	8 7/8	27.882	61.862	14 3/8	45.160	162.30	19 7/8	62.439	310.24
3 1/2	10.996	9.6211	9	28.274	63.617	14 1/2	45.553	165.13	20	62.832	314.16
3 5/8	11.388	10.321	9 1/8	28.667	65.397	14 5/8	45.946	167.99	20 1/8	63.225	318.10
3 3/4	11.781	11.045	9 1/4	29.060	67.201	14 3/4	46.339	170.87	20 1/4	63.617	322.06
3 7/8	12.174	11.793	9 3/8	29.452	69.029	14 7/8	46.731	173.78	20 3/8	64.010	326.05

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CIRCUMFERENCES AND AREAS OF CIRCLES FOR GIVEN DIAMETERS—Continued

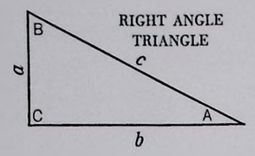
Diam.	Circum.	Area	Diam.	Circum.	Area	Diam.	Circum.	Area	Diam.	Circum.	Area
20½	64.403	330.06	26	81.681	530.93	31½	98.960	779.31	37	116.24	1075.2
20⅝	64.795	334.10	26⅛	82.074	536.05	31⅝	99.353	785.51	37⅛	116.63	1082.5
20¾	65.188	338.16	26¼	82.467	541.19	31¾	99.746	791.73	37¼	117.02	1089.8
20⅞	65.581	342.25	26⅜	82.860	546.35	31⅞	100.14	797.98	37⅜	117.42	1097.1
21	65.973	346.36	26½	83.252	551.55	32	100.53	804.25	37½	117.81	1104.5
21⅛	66.366	350.50	26⅝	83.645	556.76	32⅛	100.92	810.54	37⅝	118.20	1111.8
21¼	66.759	354.66	26¾	84.038	562.00	32¼	101.32	816.86	37¾	118.60	1119.2
21⅜	67.152	358.84	26⅞	84.430	567.27	32⅜	101.71	823.21	37⅞	118.99	1126.7
21½	67.544	363.05	27	84.823	572.56	32½	102.10	829.58	38	119.38	1134.1
21⅝	67.937	367.28	27⅛	85.216	577.87	32⅝	102.49	835.97	38⅛	119.77	1141.6
21¾	68.330	371.54	27¼	85.608	583.21	32¾	102.89	842.39	38¼	120.17	1149.1
21⅞	68.722	375.83	27⅜	86.001	588.57	32⅞	103.28	848.83	38⅜	120.56	1156.6
22	69.115	380.13	27½	86.394	593.96	33	103.67	855.30	38½	120.95	1164.2
22⅛	69.508	384.46	27⅝	86.787	599.37	33⅛	104.07	861.79	38⅝	121.34	1171.7
22¼	69.900	388.82	27¾	87.179	604.81	33¼	104.46	868.31	38¾	121.74	1179.3
22⅜	70.293	393.20	27⅞	87.572	610.27	33⅜	104.85	874.85	38⅞	122.13	1186.9
22½	70.686	397.61	28	87.965	615.75	33½	105.24	881.41	39	122.52	1194.6
22⅝	71.079	402.04	28⅛	88.357	621.26	33⅝	105.64	888.00	39⅛	122.92	1202.3
22¾	71.471	406.49	28¼	88.750	626.80	33¾	106.03	894.62	39¼	123.31	1210.0
22⅞	71.864	410.97	28⅜	89.143	632.36	33⅞	106.42	901.26	39⅜	123.70	1217.7
23	72.257	415.48	28½	89.535	637.94	34	106.81	907.92	39½	124.09	1225.4
23⅛	72.649	420.00	28⅝	89.928	643.55	34⅛	107.21	914.61	39⅝	124.49	1233.2
23¼	73.042	424.56	28¾	90.321	649.18	34¼	107.60	921.32	39¾	124.88	1241.0
23⅜	73.435	429.13	28⅞	90.714	654.84	34⅜	107.99	928.06	39⅞	125.27	1248.8
23½	73.827	433.74	29	91.106	660.52	34½	108.39	934.82	40	125.66	1256.6
23⅝	74.220	438.36	29⅛	91.499	666.23	34⅝	108.78	941.61	40⅛	126.06	1264.5
23¾	74.613	443.01	29¼	91.892	671.96	34¾	109.17	948.42	40¼	126.45	1272.4
23⅞	75.006	447.69	29⅜	92.284	677.71	34⅞	109.56	955.25	40⅜	126.84	1280.3
24	75.398	452.39	29½	92.677	683.49	35	109.96	962.11	40½	127.24	1288.2
24⅛	75.791	457.11	29⅝	93.070	689.30	35⅛	110.35	969.00	40⅝	127.63	1296.2
24¼	76.184	461.86	29¾	93.462	695.13	35¼	110.74	975.91	40¾	128.02	1304.2
24⅜	76.576	466.64	29⅞	93.855	700.98	35⅜	111.13	982.84	40⅞	128.41	1312.2
24½	76.969	471.44	30	94.248	706.86	35½	111.53	989.80	41	128.81	1320.3
24⅝	77.362	476.26	30⅛	94.641	712.76	35⅝	111.92	996.78	41⅛	129.20	1328.3
24¾	77.754	481.11	30¼	95.033	718.69	35¾	112.31	1003.8	41¼	129.59	1336.4
24⅞	78.147	485.98	30⅜	95.426	724.64	35⅞	112.71	1010.8	41⅜	129.98	1344.5
25	78.540	490.87	30½	95.819	730.62	36	113.10	1017.9	41½	130.38	1352.7
25⅛	78.933	495.79	30⅝	96.211	736.62	36⅛	113.49	1025.0	41⅝	130.77	1360.8
25¼	79.325	500.74	30¾	96.604	742.64	36¼	113.88	1032.1	41¾	131.16	1369.0
25⅜	79.718	505.71	30⅞	96.997	748.69	36⅜	114.28	1039.2	41⅞	131.55	1377.2
25½	80.111	510.71	31	97.389	754.77	36½	114.67	1046.3	42	131.95	1385.4
25⅝	80.503	515.72	31⅛	97.782	760.87	36⅝	115.06	1053.5	42⅛	132.34	1393.7
25¾	80.896	520.77	31¼	98.175	766.99	36¾	115.45	1060.7	42¼	132.73	1402.0
25⅞	81.289	525.84	31⅜	98.568	773.14	36⅞	115.85	1068.0	42⅜	133.13	1410.3

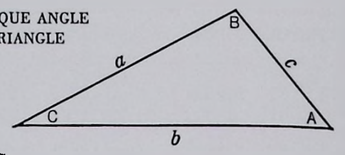
CIRCUMFERENCES AND AREAS OF CIRCLES FOR GIVEN DIAMETERS—Continued

Diam.	Circum.	Area	Diam.	Circum.	Area	Diam.	Circum.	Area	Diam.	Circum.	Area
42½	133.52	1418.6	47½	149.23	1772.1	60	188.50	2827.4	80	251.33	5026.5
42⅝	133.91	1427.0	47⅝	149.62	1781.4	60½	190.07	2874.8	80½	252.90	5089.6
42¾	134.30	1435.4	47¾	150.01	1790.8	61	191.64	2922.5	81	254.47	5153.0
42⅞	134.70	1443.8	47⅞	150.40	1800.1	61½	193.21	2970.6	81½	256.04	5216.8
43	135.09	1452.2	48	150.80	1809.6	62	194.78	3019.1	82	257.61	5281.0
43⅛	135.48	1460.7	48⅛	151.19	1819.0	62½	196.35	3068.0	82½	259.18	5345.6
43¼	135.87	1469.1	48¼	151.58	1828.5	63	197.92	3117.2	83	260.75	5410.6
43⅜	136.27	1477.6	48⅜	151.97	1837.9	63½	199.49	3166.9	83½	262.32	5476.0
43½	136.66	1486.2	48½	152.37	1847.5	64	201.06	3217.0	84	263.89	5541.8
43⅝	137.05	1494.7	48⅝	152.76	1857.0	64½	202.63	3267.5	84½	265.47	5607.9
43¾	137.45	1503.3	48¾	153.15	1866.5	65	204.20	3318.3	85	267.04	5674.5
43⅞	137.84	1511.9	48⅞	153.55	1876.1	65½	205.77	3369.6	85½	268.61	5741.5
44	138.23	1520.5	49	153.94	1885.7	66	207.35	3421.2	86	270.18	5808.8
44⅛	138.62	1529.2	49⅛	154.33	1895.4	66½	208.92	3473.2	86½	271.75	5876.5
44¼	139.02	1537.9	49¼	154.72	1905.0	67	210.49	3525.7	87	273.32	5944.7
44⅜	139.41	1546.6	49⅜	155.12	1914.7	67½	212.06	3578.5	87½	274.89	6013.2
44½	139.80	1555.3	49½	155.51	1924.4	68	213.63	3631.7	88	276.46	6082.1
44⅝	140.19	1564.0	49⅝	155.90	1934.2	68½	215.20	3685.3	88½	278.03	6151.4
44¾	140.59	1572.8	49¾	156.29	1943.9	69	216.77	3739.3	89	279.60	6221.1
44⅞	140.98	1581.6	49⅞	156.69	1953.7	69½	218.34	3793.7	89½	281.17	6291.2
45	141.37	1590.4	50	157.08	1963.5	70	219.91	3848.5	90	282.74	6361.7
45⅛	141.76	1599.3	50½	158.65	2003.0	70½	221.48	3903.6	90½	284.31	6432.6
45¼	142.16	1608.2	51	160.22	2042.8	71	223.05	3959.2	91	285.89	6503.9
45⅜	142.55	1617.0	51½	161.79	2083.1	71½	224.62	4015.2	91½	287.46	6575.5
45½	142.94	1626.0	52	163.36	2123.7	72	226.20	4071.5	92	289.03	6647.6
45⅝	143.34	1634.9	52½	164.93	2164.8	72½	227.77	4128.2	92½	290.60	6720.1
45¾	143.73	1643.9	53	166.50	2206.2	73	229.34	4185.4	93	292.17	6792.9
45⅞	144.12	1652.9	53½	168.08	2248.0	73½	230.91	4242.9	93½	293.74	6866.1
46	144.51	1661.9	54	169.65	2290.2	74	232.48	4300.8	94	295.31	6939.8
46⅛	144.91	1670.9	54½	171.22	2332.8	74½	234.05	4359.2	94½	296.88	7013.8
46¼	145.30	1680.0	55	172.79	2375.8	75	235.62	4417.9	95	298.45	7088.2
46⅜	145.69	1689.1	55½	174.36	2419.2	75½	237.19	4477.0	95½	300.02	7163.0
46½	146.08	1698.2	56	175.93	2463.0	76	238.76	4536.5	96	301.59	7238.2
46⅝	146.48	1707.4	56½	177.50	2507.2	76½	240.33	4596.3	96½	303.16	7313.8
46¾	146.87	1716.5	57	179.07	2551.8	77	241.90	4656.6	97	304.73	7389.8
46⅞	147.26	1725.7	57½	180.64	2596.7	77½	243.47	4717.3	97½	306.31	7466.2
47	147.66	1734.9	58	182.21	2642.1	78	245.04	4778.4	98	307.88	7543.0
47⅛	148.05	1744.2	58½	183.78	2687.8	78½	246.62	4839.8	98½	309.45	7620.1
47¼	148.44	1753.5	59	185.35	2734.0	79	248.19	4901.7	99	311.02	7697.7
47⅜	148.83	1762.7	59½	186.93	2780.5	79½	249.76	4963.9	99½	312.59	7775.6

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TRIGONOMETRIC SOLUTION OF TRIANGLES





RIGHT ANGLE TRIANGLES

Sine (sin) of angle A = opposite side divided by hypotenuse = a divided by c
Cosine (cos) of angle A = adjacent side divided by hypotenuse = b divided by c
Tangent (tan) of angle A = opposite side divided by adjacent side = a divided by b
Cotangent (cot) of angle A = adjacent side divided by opposite side = b divided by a
Sin B = cos A; cos B = sin A; tan B = cot A; cot B = tan A

Given	To Find	Formulas		
a, c	A, B, b	$\sin A = \frac{a}{c}$,	$\cos B = \frac{a}{c}$,	$b = \sqrt{c^2 - a^2}$
a, b	A, B, c	$\tan A = \frac{a}{b}$,	$\tan B = \frac{b}{a}$,	$c = \sqrt{a^2 + b^2}$
A, a	B, b, c	$B = 90° - A$,	$b = a \cot A$,	$c = \frac{a}{\sin A}$
A, b	B, a, c	$B = 90° - A$,	$a = b \tan A$,	$c = \frac{b}{\cos A}$
A, c	B, a, b	$B = 90° - A$,	$a = c \sin A$,	$b = c \cos A$

OBLIQUE ANGLE TRIANGLES

$s = \frac{1}{2}(a + b + c)$

Given	To Find	Formulas
a, b, c	A	$\sin \frac{1}{2}A = \sqrt{\frac{(s-b)(s-c)}{bc}}$, $\cos \frac{1}{2}A = \sqrt{\frac{s(s-a)}{bc}}$, $\tan \frac{1}{2}A = \sqrt{\frac{(s-b)(s-c)}{s(s-a)}}$
	B	$\sin \frac{1}{2}B = \sqrt{\frac{(s-a)(s-c)}{ac}}$, $\cos \frac{1}{2}B = \sqrt{\frac{s(s-b)}{ac}}$, $\tan \frac{1}{2}B = \sqrt{\frac{(s-a)(s-c)}{s(s-b)}}$
	C	$\sin \frac{1}{2}C = \sqrt{\frac{(s-a)(s-b)}{ab}}$, $\cos \frac{1}{2}C = \sqrt{\frac{s(s-c)}{ab}}$, $\tan \frac{1}{2}C = \sqrt{\frac{(s-a)(s-b)}{s(s-c)}}$
a, A, B	b, c	$b = \frac{a \sin B}{\sin A}$, $c = \frac{a \sin C}{\sin A} = \frac{a \sin (A + B)}{\sin A}$
a, b, A	B	$\sin B = \frac{b \sin A}{a}$
	c	$c = \frac{a \sin C}{\sin A} = \frac{b \sin C}{\sin B} = \sqrt{a^2 + b^2 - 2ab \cos C}$
a, b, C	A	$\tan A = \frac{a \sin C}{b - a \cos C}$, $\tan \frac{1}{2}(A - B) = \frac{a - b}{a + b} \cot \frac{1}{2}C$
	c	$c = \sqrt{a^2 + b^2 - 2ab \cos C} = \frac{a \sin C}{\sin A}$

TABLE OF NATURAL TRIGONOMETRIC FUNCTIONS

Degrees	Sines .00° 0′	.25° 15′	.50° 30′	.75° 45′	1.00° 60′	Cosines .00° 0′	.25° 15′	.50° 30′	.75° 45′	1.00° 60′	
0	0.00000	0.00436	0.00873	0.01309	0.01745	1.00000	0.99999	0.99996	0.99991	0.99985	89
1	0.01745	0.02181	0.02618	0.03054	0.03490	0.99985	0.99976	0.99966	0.99953	0.99939	88
2	0.03490	0.03926	0.04362	0.04798	0.05234	0.99939	0.99923	0.99905	0.99885	0.99863	87
3	0.05234	0.05669	0.06105	0.06540	0.06976	0.99863	0.99839	0.99813	0.99786	0.99756	86
4	0.06976	0.07411	0.07846	0.08281	0.08716	0.99756	0.99725	0.99692	0.99657	0.99619	85
5	0.08716	0.09150	0.09585	0.10019	0.10453	0.99619	0.99580	0.99540	0.99497	0.99452	84
6	0.10453	0.10887	0.11320	0.11754	0.12187	0.99452	0.99406	0.99357	0.99307	0.99255	83
7	0.12187	0.12620	0.13053	0.13485	0.13917	0.99255	0.99200	0.99144	0.99087	0.99027	82
8	0.13917	0.14349	0.14781	0.15212	0.15643	0.99027	0.98965	0.98902	0.98836	0.98769	81
9	0.15643	0.16074	0.16505	0.16935	0.17365	0.98769	0.98700	0.98629	0.98556	0.98481	80
10	0.17365	0.17794	0.18224	0.18652	0.19081	0.98481	0.98404	0.98325	0.98245	0.98163	79
11	0.19081	0.19509	0.19937	0.20364	0.20791	0.98163	0.98079	0.97992	0.97905	0.97815	78
12	0.20791	0.21218	0.21644	0.22070	0.22495	0.97815	0.97723	0.97630	0.97534	0.97437	77
13	0.22495	0.22920	0.23345	0.23769	0.24192	0.97437	0.97338	0.97237	0.97134	0.97030	76
14	0.24192	0.24615	0.25038	0.25460	0.25882	0.97030	0.96923	0.96815	0.96705	0.96593	75
15	0.25882	0.26303	0.26724	0.27144	0.27564	0.96593	0.96479	0.96363	0.96246	0.96126	74
16	0.27564	0.27983	0.28402	0.28820	0.29237	0.96126	0.96005	0.95882	0.95757	0.95630	73
17	0.29237	0.29654	0.30071	0.30486	0.30902	0.95630	0.95502	0.95372	0.95240	0.95106	72
18	0.30902	0.31316	0.31730	0.32144	0.32557	0.95106	0.94970	0.94832	0.94693	0.94552	71
19	0.32557	0.32969	0.33381	0.33792	0.34202	0.94552	0.94409	0.94264	0.94118	0.93969	70
20	0.34202	0.34612	0.35021	0.35429	0.35837	0.93969	0.93819	0.93667	0.93514	0.93358	69
21	0.35837	0.36244	0.36650	0.37056	0.37461	0.93358	0.93201	0.93042	0.92881	0.92718	68
22	0.37461	0.37865	0.38268	0.38671	0.39073	0.92718	0.92554	0.92388	0.92220	0.92050	67
23	0.39073	0.39474	0.39875	0.40275	0.40674	0.92050	0.91879	0.91706	0.91531	0.91355	66
24	0.40674	0.41072	0.41469	0.41866	0.42262	0.91355	0.91176	0.90996	0.90814	0.90631	65
25	0.42262	0.42657	0.43051	0.43445	0.43837	0.90631	0.90446	0.90259	0.90070	0.89879	64
26	0.43837	0.44229	0.44620	0.45010	0.45399	0.89879	0.89687	0.89493	0.89298	0.89101	63
27	0.45399	0.45787	0.46175	0.46561	0.46947	0.89101	0.88902	0.88701	0.88499	0.88295	62
28	0.46947	0.47332	0.47716	0.48099	0.48481	0.88295	0.88089	0.87882	0.87673	0.87462	61
29	0.48481	0.48862	0.49242	0.49622	0.50000	0.87462	0.87250	0.87036	0.86820	0.86603	60
30	0.50000	0.50377	0.50754	0.51129	0.51504	0.86603	0.86384	0.86163	0.85941	0.85717	59
31	0.51504	0.51877	0.52250	0.52621	0.52992	0.85717	0.85491	0.85264	0.85035	0.84805	58
32	0.52992	0.53361	0.53730	0.54097	0.54464	0.84805	0.84573	0.84339	0.84104	0.83867	57
33	0.54464	0.54829	0.55194	0.55557	0.55919	0.83867	0.83629	0.83389	0.83147	0.82904	56
34	0.55919	0.56280	0.56641	0.57000	0.57358	0.82904	0.82659	0.82413	0.82165	0.81915	55
35	0.57358	0.57715	0.58070	0.58425	0.58779	0.81915	0.81664	0.81412	0.81157	0.80902	54
36	0.58779	0.59131	0.59482	0.59832	0.60182	0.80902	0.80644	0.80386	0.80125	0.79864	53
37	0.60182	0.60529	0.60876	0.61222	0.61566	0.79864	0.79600	0.79335	0.79069	0.78801	52
38	0.61566	0.61909	0.62251	0.62592	0.62932	0.78801	0.78532	0.78261	0.77988	0.77715	51
39	0.62932	0.63271	0.63608	0.63944	0.64279	0.77715	0.77439	0.77162	0.76884	0.76604	50
40	0.64279	0.64612	0.64945	0.65276	0.65606	0.76604	0.76323	0.76041	0.75756	0.75471	49
41	0.65606	0.65935	0.66262	0.66588	0.66913	0.75471	0.75184	0.74896	0.74606	0.74314	48
42	0.66913	0.67237	0.67559	0.67880	0.68200	0.74314	0.74022	0.73728	0.73432	0.73135	47
43	0.68200	0.68518	0.68835	0.69151	0.69466	0.73135	0.72837	0.72537	0.72236	0.71934	46
44	0.69466	0.69779	0.70091	0.70401	0.70711	0.71934	0.71630	0.71325	0.71019	0.70711	45
	60′ 1.00°	45′ .75°	30′ .50°	15′ .25°	0′ .00°	60′ 1.00°	45′ .75°	30′ .50°	15′ .25°	0′ .00°	Degrees
	Cosines					Sines					

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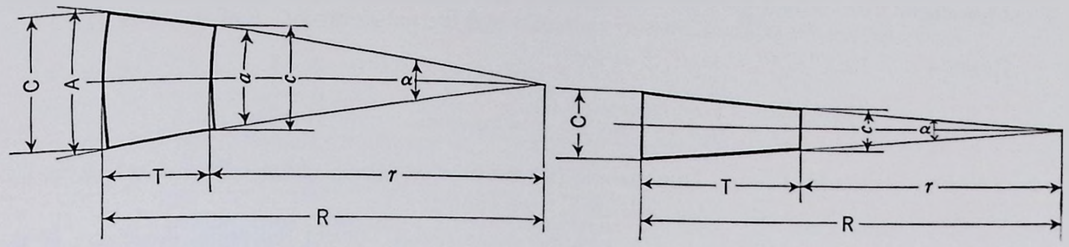
TABLE OF NATURAL TRIGONOMETRIC FUNCTIONS—Continued

Degrees	Tangents .00° 0′	.25° 15′	.50° 30′	.75° 45′	1.00° 60′	Cotangents .00° 0′	.25° 15′	.50° 30′	.75° 45′	1.00° 60′	Degrees
0	0.00000	0.00436	0.00873	0.01309	0.01746	Infinity	229.18	114.59	76.390	57.290	89
1	0.01746	0.02182	0.02619	0.03055	0.03492	57.290	45.829	38.188	32.730	28.636	88
2	0.03492	0.03929	0.04366	0.04803	0.05241	28.636	25.452	22.904	20.819	19.081	87
3	0.05241	0.05678	0.06116	0.06554	0.06993	19.081	17.611	16.350	15.257	14.301	86
4	0.06993	0.07431	0.07870	0.08309	0.08749	14.301	13.457	12.706	12.035	11.430	85
5	0.08749	0.09189	0.09629	0.10069	0.10510	11.430	10.883	10.385	9.9310	9.5144	84
6	0.10510	0.10952	0.11394	0.11836	0.12278	9.5144	9.1309	8.7769	8.4490	8.1443	83
7	0.12278	0.12722	0.13165	0.13609	0.14054	8.1443	7.8606	7.5958	7.3479	7.1154	82
8	0.14054	0.14499	0.14945	0.15391	0.15838	7.1154	6.8969	6.6912	6.4971	6.3138	81
9	0.15838	0.16286	0.16734	0.17183	0.17633	6.3138	6.1402	5.9758	5.8197	5.6713	80
10	0.17633	0.18083	0.18534	0.18986	0.19438	5.6713	5.5301	5.3955	5.2672	5.1446	79
11	0.19438	0.19891	0.20345	0.20800	0.21256	5.1446	5.0273	4.9152	4.8077	4.7046	78
12	0.21256	0.21712	0.22169	0.22628	0.23087	4.7046	4.6057	4.5107	4.4194	4.3315	77
13	0.23087	0.23547	0.24008	0.24470	0.24933	4.3315	4.2468	4.1653	4.0867	4.0108	76
14	0.24933	0.25397	0.25862	0.26328	0.26795	4.0108	3.9375	3.8667	3.7983	3.7321	75
15	0.26795	0.27263	0.27732	0.28203	0.28675	3.7321	3.6680	3.6059	3.5457	3.4874	74
16	0.28675	0.29147	0.29621	0.30097	0.30573	3.4874	3.4308	3.3759	3.3226	3.2709	73
17	0.30573	0.31051	0.31530	0.32010	0.32492	3.2709	3.2205	3.1716	3.1240	3.0777	72
18	0.32492	0.32975	0.33460	0.33945	0.34433	3.0777	3.0326	2.9887	2.9459	2.9042	71
19	0.34433	0.34922	0.35412	0.35904	0.36397	2.9042	2.8636	2.8239	2.7852	2.7475	70
20	0.36397	0.36892	0.37388	0.37887	0.38386	2.7475	2.7106	2.6746	2.6395	2.6051	69
21	0.38386	0.38888	0.39391	0.39896	0.40403	2.6051	2.5715	2.5386	2.5065	2.4751	68
22	0.40403	0.40911	0.41421	0.41933	0.42447	2.4751	2.4443	2.4142	2.3847	2.3559	67
23	0.42447	0.42963	0.43481	0.44001	0.44523	2.3559	2.3276	2.2998	2.2727	2.2460	66
24	0.44523	0.45047	0.45573	0.46101	0.46631	2.2460	2.2199	2.1943	2.1692	2.1445	65
25	0.46631	0.47163	0.47698	0.48234	0.48773	2.1445	2.1203	2.0965	2.0732	2.0503	64
26	0.48773	0.49315	0.49858	0.50404	0.50953	2.0503	2.0278	2.0057	1.9840	1.9626	63
27	0.50953	0.51503	0.52057	0.52613	0.53171	1.9626	1.9416	1.9210	1.9007	1.8807	62
28	0.53171	0.53732	0.54296	0.54862	0.55431	1.8807	1.8611	1.8418	1.8228	1.8040	61
29	0.55431	0.56003	0.56577	0.57155	0.57735	1.8040	1.7856	1.7675	1.7496	1.7321	60
30	0.57735	0.58318	0.58905	0.59494	0.60086	1.7321	1.7147	1.6977	1.6808	1.6643	59
31	0.60086	0.60681	0.61280	0.61882	0.62487	1.6643	1.6479	1.6319	1.6160	1.6003	58
32	0.62487	0.63095	0.63707	0.64322	0.64941	1.6003	1.5849	1.5697	1.5547	1.5399	57
33	0.64941	0.65563	0.66189	0.66818	0.67451	1.5399	1.5253	1.5108	1.4966	1.4826	56
34	0.67451	0.68088	0.68728	0.69372	0.70021	1.4826	1.4687	1.4550	1.4415	1.4281	55
35	0.70021	0.70673	0.71329	0.71990	0.72654	1.4281	1.4150	1.4019	1.3891	1.3764	54
36	0.72654	0.73323	0.73996	0.74674	0.75355	1.3764	1.3638	1.3514	1.3392	1.3270	53
37	0.75355	0.76042	0.76733	0.77428	0.78129	1.3270	1.3151	1.3032	1.2915	1.2799	52
38	0.78129	0.78834	0.79544	0.80258	0.80978	1.2799	1.2685	1.2572	1.2460	1.2349	51
39	0.80978	0.81703	0.82434	0.83169	0.83910	1.2349	1.2239	1.2131	1.2024	1.1918	50
40	0.83910	0.84656	0.85408	0.86166	0.86929	1.1918	1.1812	1.1708	1.1606	1.1504	49
41	0.86929	0.87698	0.88473	0.89253	0.90040	1.1504	1.1403	1.1303	1.1204	1.1106	48
42	0.90040	0.90834	0.91633	0.92439	0.93252	1.1106	1.1009	1.0913	1.0818	1.0724	47
43	0.93252	0.94071	0.94896	0.95729	0.96569	1.0724	1.0630	1.0538	1.0446	1.0355	46
44	0.96569	0.97416	0.98270	0.99131	1.00000	1.0355	1.0265	1.0176	1.0088	1.0000	45
	.60′ 1.00°	45′ .75°	30′ .50°	15′ .25°	0′ .00°	60′ 1.00°	45′ .75°	30′ .50°	15′ .25°	0′ .00°	
	Cotangents					Tangents					Degrees

RADIAL BRICK FORMULAS

CIRCLE-TYPE RADIAL BRICK (STANDARD CIRCLE, ROTARY KILN, CUPOLA, AND SPECIAL RADIAL BRICK).

WEDGE-TYPE RADIAL BRICK (STANDARD WEDGE, ARCH, KEY, AND SPECIAL RADIAL BRICK).



SYMBOLS

a = Inside arc of circle-type brick.
A = Outside arc of circle-type brick.
c = Inside chord of circle-type brick; or chord dimension of small end of wedge-type brick.
C = Outside chord of circle-type brick; or chord dimension of large end of wedge-type brick.
r = Inside radius of radial brick.
R = Outside radius of radial brick.
d = Inside diameter of ring formed by radial brick.
D = Outside diameter of ring formed by radial brick.
T = Radial dimension of brick.
α = Alpha, the included angle of brick.
π = Pi = 3.1416
N_r = Total number of a given radial brick required to form a ring.

FORMULAS

(1) $c = \dfrac{r\,C}{r + T} = \dfrac{r\,C}{R}$

(2) $C = \dfrac{(r + T)c}{r} = \dfrac{R\,c}{r}$

(3) $r = \dfrac{c\,T}{C - c}, \quad d = 2\,r$

(4) $R = r + T, \quad D = 2\,R$

(5) $\alpha = \dfrac{360°}{N_r}$

(6-a) *For circle-type radial brick:*

$\text{Sine } \frac{1}{2}\,\alpha = \dfrac{C}{2\,R} = \dfrac{c}{2\,r}$

(6-b) *For wedge-type radial brick:*

$\text{Tangent } \frac{1}{2}\,\alpha = \dfrac{C}{2\,R} = \dfrac{c}{2\,r}$

(7-a)† *For circle-type radial brick:*

$c = d \text{ sine } \frac{1}{2}\,\alpha; \quad C = D \text{ sine } \frac{1}{2}\,\alpha$

(7-b) *For wedge-type radial brick:*

$c = d \text{ tangent } \frac{1}{2}\,\alpha; \quad C = D \text{ tangent } \frac{1}{2}\,\alpha$

(8) $N_r = \dfrac{360°}{\alpha}$

(9)* $N_r = \dfrac{2\,\pi\,T}{C - c}$

(10)* $N_r = \dfrac{\pi\,D}{C} = \dfrac{\pi\,d}{c}$

* Approximate; close enough for most purposes.
† When N_r is known, refer to table on page 524 for value of sine $\frac{1}{2}\,\alpha$.

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USE OF RADIAL BRICK FORMULAS

1. *To find Inside Chord Dimension* (c) *when the outside chord dimension* (C), *inside radius* (r), *and radial dimension of brick* (T) *are known:*

Formula 1: $c = \frac{r\,C}{r + T}$

Multiply the inside radius (r) by the outside chord dimension (C) and divide the product by the sum of the inside radius (r) and the radial dimension of the brick (T).

Example: Let C = 9″, r = 6″, T = 4½″

Then, Inside Chord Dimension (c) $= \frac{6 \times 9}{6 + 4.5} = 5.1429'' = 5\frac{5}{32}''$

2. *To find Outside Chord Dimension* (C) *when the inside chord dimension* (c), *inside radius* (r), *and radial dimension of brick* (T) *are known:*

Formula 2: $C = \frac{(r + T)\,c}{r}$

To the inside radius (r) add the radial dimension of the brick (T); multiply the sum by the inside chord dimension (c); divide the product by the inside radius (r).

Example: Let c = 4½″, r = 6″, T = 4½″

Then, Outside Chord Dimension (C) $= \frac{(6 + 4.5)\ 4.5}{6} = 7.875'' = 7\frac{7}{8}''$

3. *To find Inside Radius* (r) *of ring formed by radial brick when the dimensions of the brick are known:*

Formula 3: $r = \frac{c\,T}{C - c}$; $d = 2r$

Multiply radial dimension (T) by the inside chord dimension (c); divide the product by the difference between the chord dimensions (C — c). To find the inside diameter (d) multiply the inside radius (r) by 2.

Example: To find the inside radius of a ring formed by a 9″ No. 1 wedge brick 9″ × 4½″ × (2½″ — 1⅞″); in this case T = 9″, C = 2½″, c = 1⅞″

Then, Inside Radius (r) $= \frac{1.875 \times 9}{2.5 - 1.875} = 27'' = 2'\text{-}3''$

Inside Diameter (d) = 2 × 27″ = 54″ = 4′-6″

4. *To find Outside Radius* (R) *of ring formed by radial brick when inside radius* (r) *and the dimensions of the brick are known:*

Formula 4: R = r + T; D = 2R

To the inside radius (r) add the radial dimension of the brick (T). To find the outside diameter (D) multiply the outside radius (R) by 2.

Example: Let r = 27″ (See example 3), T = 9″

Then, Outside Radius (R) = 27″ + 9″ = 36″ = 3′-0″

Outside Diameter (D) = 2 × 36″ = 72″ = 6′-0″

5. *To find Included Angle* (α) *of a radial brick when the number of pieces* (N_r) *required to form a ring is known:*

Formula 5: $\alpha = \frac{360°}{N_r}$

Divide 360° by the number of pieces (N_r) per ring.

Example: Let N_r = 45

Then, Included Angle (α) $= \frac{360°}{45} = 8°$

6. *To find Included Angle* (α) *when the outside chord dimension* (C) *and outside radius* (R) *are known:*

Formula 6-a:

For circle-type radial brick:

$\text{Sine } \frac{1}{2}\alpha = \frac{C}{2R}$

Divide outside chord dimension (C) by twice the outside radius (2R). The result is the sine of half the included angle (α). Determine the angle whose sine is equal to this figure by reference to a table of trigonometric functions.

Example: Let C = 6″, R = 36″: Then, Sine of ½ $\alpha = \frac{6}{2 \times 36} = 0.08333$

From table of functions on page 519, the angle having a sine of 0.08333 is 4.78°
Then, Included Angle (α) = 2 × 4.78° = 9.56° = 9° 33.6′

NOTE: The use of Formula 6-b is similar to that of Formula 6-a.

7. *To find Inside and Outside Chord Dimensions* (c *and* C) *when inside and outside diameters* (d *and* D) *and included angle* (α) *are known:*

Formula 7-a:

For circle-type radial brick:

$c = d \text{ sine } \frac{1}{2}\alpha$
$C = D \text{ sine } \frac{1}{2}\alpha$

To find the inside chord dimension (c) multiply the inside diameter (d) by the sine of ½ the included angle (α); to find the outside chord dimension (C) multiply the outside diameter (D) by the sine of ½ the included angle (α).

Example: Let d = 15″; D = 24″; α = 30°
From table of functions on page 519, the sine of ½ α = the sine of 15° = 0.25882
Then, Inside Chord Dimension (c) = 15 × 0.25882 = 3.8823″ = 3⅞″
Outside Chord Dimension (C) = 24 × 0.25882 = 6.2117″ = 6$\frac{7}{32}$″

NOTE: The use of Formula 7-b is similar to that of Formula 7-a.

8. *To find Number of Pieces* (N_r) *required to form a Ring when the included angle* (α) *is known:*

Formula 8: $N_r = \frac{360°}{\alpha}$

Divide 360° by the number of degrees in the included angle (α).

Example: Let α = 10°: Then, Number (N_r) required to form a ring = $\frac{360°}{10°} = 36$

9. **To find Number of Pieces* (N_r) *required to form a Ring when the dimensions of the brick are known:*

Formula 9: $N_r = \frac{2\pi\,T}{C - c}$

Multiply the radial dimension (T) by 2π (6.2832); divide the product by the difference between the chord dimensions (C — c) of the brick.

Example: Let T = 9″, C = 2½″, c = 1⅞″

Then, Number (N_r) required to form a ring = $\frac{6.2832 \times 9}{2\frac{1}{2} - 1\frac{7}{8}} = 90.4781 = 91$

10. **To find Number of Pieces* (N_r) *required to form a Ring when the outside diameter* (D) *and the outside chord dimension* (C) *are known:*

Formula 10: $N_r = \frac{\pi D}{C}$

Divide the outside circumference (πD) by the outside chord dimension (C).

Example: To find the number of 9″ No. 1 wedge brick 9″ × 4½″ × (2½″ — 1⅞″) required to form a ring. In this case D = 72″ (See example 4), C = 2½″

Then, Number (N_r) required to form a ring = $\frac{3.1416 \times 72}{2.5} = 90.4781 = 91$

* Approximate; close enough for most purposes.

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SPECIAL CIRCLE-TYPE RADIAL BRICK

The following table is applicable for designing special circle-type radial brick for circular linings of given outside diameters when an exact number of pieces per ring is desired. The approximate outer chord dimension of the radial brick is selected arbitrarily, generally as 3″, 4½″, 6″, or 9″, depending upon the diameter of the lining.

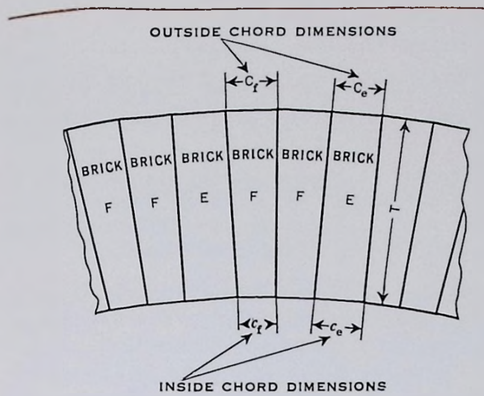
First, the approximate number of brick required to form one complete ring or course is determined by dividing the circumference (π D) by the arbitrarily selected chord dimension. The result will consist of a whole number plus a fraction. If the fraction is less than 0.5 it is usually dropped; if more than 0.5, the next larger number is generally taken. This gives the exact number of brick which will be used per ring.

It is now necessary to correct the arbitrarily chosen outer chord dimension in accordance with this exact number of brick per ring. Find this number in column 1 of the table and the corresponding "Sine of Half Angle" in column 2. Next, multiply the diameter of the lining by this "Sine of Half Angle." The result is the corrected chord dimension. The inner or any intermediate chord dimension is obtained by multiplying the corresponding diameter by the "Sine of Half Angle."

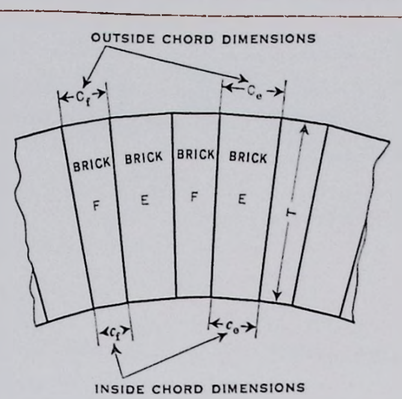
When a chord of approximately 9 inches is desired, the number of brick can be quickly determined for a given diameter by referring to the third column of the table.

Column 1 No. of Brick per Ring	Column 2 Sine of Half Angle	Column 3 Dia. for 9″ Chord	Column 1 No. of Brick per Ring	Column 2 Sine of Half Angle	Column 3 Dia. for 9″ Chord	Column 1 No. of Brick per Ring	Column 2 Sine of Half Angle	Column 3 Dia. for 9″ Chord
5	0.58779	15.31″	37	0.08481	106.12″	69	0.04552	197.72″
6	0.50000	18.00″	38	0.08258	108.99″	70	0.04486	200.62″
7	0.43388	20.74″	39	0.08047	111.84″	71	0.04423	203.48″
8	0.38268	23.52″	40	0.07846	114.71″	72	0.04362	206.33″
9	0.34202	26.31″	41	0.07655	117.57″	73	0.04302	209.21″
10	0.30902	29.12″	42	0.07473	120.43″	74	0.04244	212.06″
11	0.28173	31.95″	43	0.07299	123.30″	75	0.04188	214.90″
12	0.25882	34.77″	44	0.07134	126.16″	76	0.04132	217.81″
13	0.23932	37.61″	45	0.06976	129.01″	77	0.04079	220.64″
14	0.22252	40.45″	46	0.06825	131.87″	78	0.04027	223.49″
15	0.20791	43.29″	47	0.06680	134.73″	79	0.03975	226.42″
16	0.19509	46.13″	48	0.06540	137.61″	80	0.03926	229.24″
17	0.18375	48.98″	49	0.06407	140.47″	81	0.03878	232.08″
18	0.17365	51.83″	50	0.06279	143.33″	82	0.03830	234.99″
19	0.16459	54.68″	51	0.06156	146.20″	83	0.03784	237.84″
20	0.15643	57.53″	52	0.06038	149.06″	84	0.03739	240.71″
21	0.14904	60.39″	53	0.05924	151.92″	85	0.03695	243.57″
22	0.14231	63.24″	54	0.05815	154.77″	86	0.03652	246.44″
23	0.13616	66.10″	55	0.05709	157.65″	87	0.03610	249.31″
24	0.13053	68.95″	56	0.05607	160.51″	88	0.03569	252.17″
25	0.12533	71.81″	57	0.05508	163.40″	89	0.03529	255.03″
26	0.12054	74.66″	58	0.05414	166.24″	90	0.03490	257.88″
27	0.11609	77.53″	59	0.05322	169.11″	91	0.03452	260.72″
28	0.11197	80.38″	60	0.05234	171.95″	92	0.03414	263.62″
29	0.10812	83.24″	61	0.05147	174.86″	93	0.03377	266.51″
30	0.10453	86.10″	62	0.05065	177.69″	94	0.03341	269.38″
31	0.10117	88.96″	63	0.04985	180.54″	95	0.03306	272.23″
32	0.09802	91.82″	64	0.04907	183.41″	96	0.03272	275.06″
33	0.09506	94.68″	65	0.04832	186.26″	97	0.03238	277.95″
34	0.09227	97.54″	66	0.04758	189.16″	98	0.03205	280.81″
35	0.08964	100.40″	67	0.04687	192.02″	99	0.03173	283.64″
36	0.08716	103.26″	68	0.04618	194.89″	100	0.03141	286.53″

COMBINATIONS OF TWO SIZES OF BRICK TO FORM A RING



COMBINATION OF A STRAIGHT BRICK (E) AND A RADIAL BRICK (F) TO FORM A RING.



COMBINATION OF TWO RADIAL BRICK (E AND F) TO FORM A RING. BRICK E TURNS A LARGER DIAMETER THAN BRICK F.

SYMBOLS

E = Either a straight brick or a radial brick used with a companion brick F; when brick E is radial it turns a larger diameter than brick F.
F = A radial brick; used with a companion brick E which may be either straight or radial; in the latter case brick F turns a smaller diameter than brick E.
T = Radial dimension common to both brick E and F.
D_e = Outside diameter of ring formed by brick E.
D_f = Outside diameter of ring formed by brick F.
D_g = A given outside diameter larger than D_f; if brick E is radial, D_g must lie between D_e and D_f.
d_g = A given inside diameter.
C_e = Outside chord dimension of brick E.
C_f = Outside chord dimension of brick F.
c_e = Inside chord dimension of brick E.
c_f = Inside chord dimension of brick F.
N_e = Number of pieces of brick E, when used in combination with brick F, to form a ring having a given outside diameter D_g.
N_f = Number of pieces of brick F, when used in combination with brick E, to form a ring having a given outside diameter D_g.
N_t = Total number of pieces of brick E and F used in combination, to form a ring having a given outside diameter D_g.
N_x = Number of pieces of brick E required to form a complete ring having an outside diameter D_e.
N_y = Number of pieces of brick F required to form a complete ring having an outside diameter D_f.

FORMULAS

(11-a) $N_f = \dfrac{2\pi\ T}{C_f - c_f}$ (11-b) $N_e = \dfrac{\pi\ D_g - N_f\ C_f}{C_e}$ (11-c) $N_t = N_e + N_f$

(12-a) $N_t = \dfrac{\pi\ D_g}{C_e} = \dfrac{\pi\ D_g}{C_f}$ (12-b) $N_e = \dfrac{\pi\ d_g - N_t\ c_f}{c_e - c_f}$ (12-c) $N_f = N_t - N_e$

(13-a) $N_e\ C_e + N_f\ C_f = \pi\ D_g$ (13-b) $N_e\ c_e + N_f\ c_f = \pi\ d_g$ (13-c) $N_t = N_e + N_f$

(14-a) $N_e = \dfrac{N_x}{D_e - D_f}(D_g - D_f)$ (14-b) $N_f = \dfrac{N_y}{D_e - D_f}(D_e - D_g)$ (14-c) $N_t = N_e + N_f$

NOTES: 1. When one brick E is a straight and the other brick F is radial, *use Formulas 11-a, 11-b, and 11-c.*
2. When both brick E and F are radial, and the outside chord dimensions (C_e and C_f) are equal, and the inside chord dimensions (c_e and c_f) are unequal, *use Formulas 12-a, 12-b, and 12-c.*
3. When both brick E and F are radial, and the outside and inside chord dimensions of brick E differ from the corresponding chord dimensions of brick F:
For a single combination — *Use Formulas 13-a, 13-b, and 13-c*
For a series of combinations — *Use Formulas 14-a, 14-b, and 14-c*

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USE OF FORMULAS FOR COMBINATIONS OF TWO SIZES OF BRICK REQUIRED TO FORM A RING

11. To find the Number of Pieces (N_e *and* N_t) *of Straight Brick E and Radial Brick F required when used in combination to form a ring having a given inside diameter* (d_g) *or outside diameter* (D_g):

Formula 11-a: $N_t = \dfrac{2\pi T}{C_t - c_t}$

To find the Number of Pieces (N_t) of Radial Brick F: multiply the radial dimension (T) by 2π (6.2832) and divide the product by the difference between the outside and inside chord dimensions ($C_t - c_t$) of the Radial brick.

Formula 11-b: $N_e = \dfrac{\pi D_g - N_t C_t}{C_e}$

To find the Number of Pieces (N_e) of Straight Brick E: from the given outside circumference (πD_g) subtract the product of the number of pieces (N_t) of the Radial brick F multiplied by the outside chord dimension (C_t) of brick F; divide the remainder by the outside chord dimension (C_e) of the Straight brick E.

Formula 11-c: $N_t = N_e + N_t$

To find the Total Number of Pieces (N_t): add the number of pieces (N_t) of Radial brick F to the number of pieces (N_e) of Straight brick E.

Example: To find the number of 9″ Straight brick 9″ × 4½″ × 2½″ required in combination with 9″ No. 1-X Wedge brick 9″ × 4½″ × (2½″ — 2¼″) to form a ring 15′-0″ inside diameter (d_g) or 16′-6″ outside diameter (D_g). In this case the Straight brick = E; the Wedge brick = F; $d_g = 180''$; $D_g = 198''$; $C_e = C_t = 2\frac{1}{2}''$; $c_t = 2\frac{1}{4}''$; $T = 9''$.

Then, Number of 9″ No. 1-X Wedge $(N_t) = \dfrac{2 \times 3.1416 \times 9}{2.5 - 2.25} = 226.195 = 227$

Number of 9″ Straights $(N_e) = \dfrac{(3.1416 \times 198) - (227 \times 2.5)}{2.5} = 21.8147 = 22$

Total Number per ring $(N_t) = 227 + 22 = 249$

NOTE: In the example given, C_e equals C_t. However, Formulas 11-a, 11-b, and 11-c are also applicable when C_e does not equal C_t.

12. To find the Number of Pieces (N_e *and* N_t) *of two Radial Brick* E *and* F *having equal outside chord dimensions* (C_e *and* C_t) *and unequal inside chord dimensions* (c_e *and* c_t) *when the two brick are used in combination to form a ring with a given inside diameter* (d_g) *or outside diameter* (D_g):

Formula 12-a: $N_t = \dfrac{\pi D_g}{C_e} = \dfrac{\pi D_g}{C_t}$

To find the total Number of Pieces (N_t): divide the given outside circumference (πD_g) by the common outside chord dimension (C_e or C_t).

Formula 12-b: $N_e = \dfrac{\pi d_g - N_t c_t}{c_e - c_t}$

To find the Number of Pieces (N_e) of the brick E which turns the larger diameter: from the given inside circumference (πd_g) subtract the product of the total number of pieces (N_t) multiplied by the inside chord dimension (c_t) of brick F; divide the remainder by the difference between the inside chord dimensions ($c_e - c_t$) of brick E and brick F.

Formula 12-c: $N_t = N_t - N_e$

To find the Number of Pieces (N_t) of brick F which turns the smaller diameter: subtract the number of pieces (N_e) of brick E from the total number of brick (N_t), required to form a ring.

Example: To find the number of 9″ No. 1 Wedge brick 9″ × 4½″ × (2½″ — 1⅞″) and 9″ No. 2 Wedge brick 9″ × 4½″ × (2½″ — 1½″) when used in combination to form a ring 4′-0″ inside diameter (d_g). Then the No. 1 Wedge brick = brick E; No. 2 Wedge brick = brick F; $d_g = 48''$; $D_g = 66''$; $C_e = C_t = 2\frac{1}{2}''$; $c_e = 1\frac{7}{8}''$; $c_t = 1\frac{1}{2}''$.

Then, Total Number per ring $(N_t) = \dfrac{3.1416 \times 66}{2.5} = 82.9382 = 83$

Number of 9″ No. 1 Wedge $(N_e) = \dfrac{(3.1416 \times 48) - (82.9382 \times 1.5)}{1.875 - 1.5} = 70.3720 = 70$

Number of 9″ No. 2 Wedge $(N_t) = 82.9382 - 70.3720 = 12.5662 = 13$

13. To find Number of Pieces each of Two Radial Brick (E *and* F) *having different chord dimensions at both the outside ends* (C_e *and* C_t) *and inside ends* (c_e *and* c_t) *when used in combination to form a ring of a given inside diameter* (d_g) *or outside diameter* (D_g):

Formulas: 13-a $N_e C_e + N_t C_t = \pi D_g$; 13-b $N_e c_e + N_t c_t = \pi d_g$

To find the Number of Pieces (N_e and N_t) of brick E and F: solve the two simultaneous equations, 13-a and 13-b.

Formula: 13-c $N_t = N_e + N_t$

To find the total Number of Pieces N_t: add the number of pieces (N_e) of brick E to the number of pieces (N_t) of brick F.

The two simultaneous equations are set up as follows:

13-a The number of pieces N_e of brick E multiplied by the outside chord dimension (C_e) of brick E plus the number of pieces N_t of brick F multiplied by the outside chord dimension (C_t) of brick F equals the outside circumference (πD_g).

13-b The number of pieces N_e of brick E multiplied by the inside chord dimension (c_e) of brick E plus the number of pieces N_t of brick F multiplied by the inside chord dimension (c_t) of brick F equals the inside circumference (πd_g).

Example: Let $d_g = 48''$, $D_g = 66''$, $T = 9''$

Dimensions of brick E: Outside chord dimension (C_e) = 3¼″; inside chord dimension (c_e) = 2½″

Dimensions of brick F: Outside chord dimension (C_t) = 3⅜″; inside chord dimension (c_t) = 2¼″

Substituting the proper values in equations 13-a and 13-b:

13-a $3.25\ N_e + 3.375\ N_t = 3.1416 \times 66 = 207.3456$
13-b $2.5\ N_e + 2.25\ N_t = 3.1416 \times 48 = 150.7968$

Multiply equation 13-b by 1.5 and solve for N_e:

$3.25\ N_e + 3.375 N_t = 207.3456$
$3.75\ N_e + 3.375 N_t = 226.1952$
$-.5\ N_e = -18.8496$; $N_e = 37.6992$

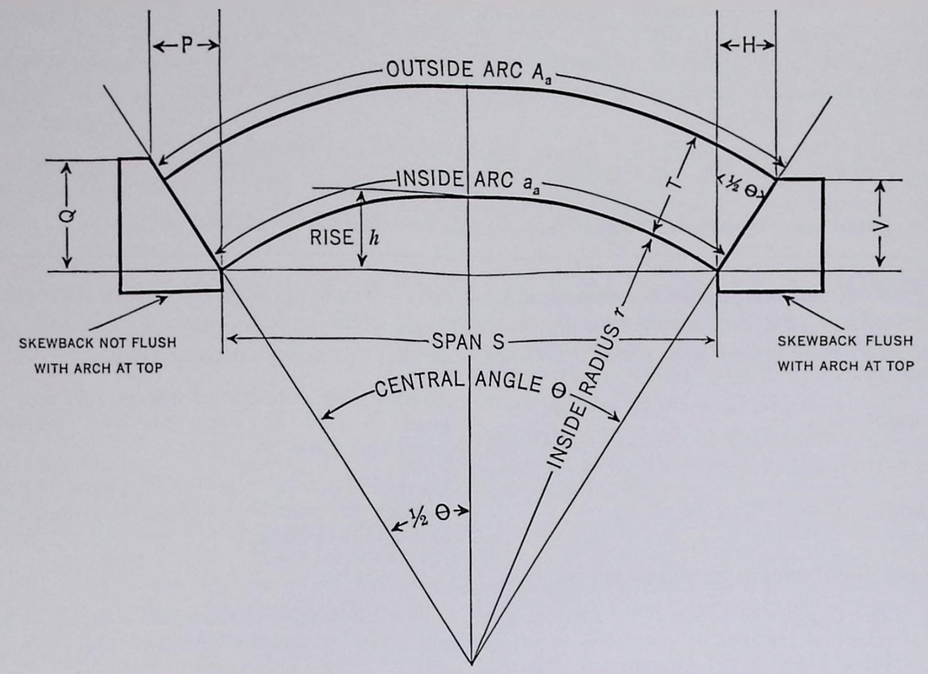
Substituting 37.6992 for N_e in equation 13-b:

$94.2480 + 2.25 N_t = 150.7968$; $2.25 N_t = 56.5488$; $N_t = 25.1328$

Then, Total Number of pieces $(N_t) = N_e + N_t = 37.6992 + 25.1328 = 62.8320 = 63$
Number of pieces (N_e) of brick E = 37.6992 = 38
Number of pieces (N_t) of brick F = 25.1328 = 25

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ELEMENTS OF A CIRCULAR ARC SPRUNG ARCH



SYMBOLS

a_a = Length of inside arc of arch.

A_a = Length of outside arc of arch.

R = Outside radius of arch.

S = Span of arch.

d = Rise of arch in inches per foot of span.

h = Total rise of arch.

T = Thickness of arch.

Θ = Theta, the central angle of arch.

E = Either a straight brick or a radial brick used with a companion brick F to form a course of an arch; when brick E is radial it turns a larger diameter than brick F.

F = A radial brick used with a companion brick E to form a course of an arch. E may be either a straight or a radial brick; in the latter case brick F turns a smaller diameter than brick E.

C = The outside chord dimension common to brick E and brick F.

r = Inside radius of arch.

c_e = Inside chord dimension of brick E.

c_f = Inside chord dimension of brick F.

N_e = Number of pieces of brick E required when used in combination with brick F, to form a complete ring of 360°.

N_f = Number of pieces of brick F required, when used in combination with brick E, to form a complete ring of 360°.

N_t = Total number of brick E and F required to form a complete ring of 360°.

n_e = Number of pieces of brick E required per course of arch.

n_f = Number of pieces of brick F required per course of arch.

n_t = Total number of brick E and F per course of arch.

H, V, P, and Q = Skewback dimensions.

ARCH FORMULAS

(15) $r = \frac{S^2}{8h} + \frac{h}{2}$

(16) $R = r + T$

(17) $h = r - \sqrt{r^2 - \left(\frac{S}{2}\right)^2}$

(18) Sine ½ Θ $= \frac{S}{2r}$

(19) Tangent ¼ Θ $= \frac{2h}{S}$

(20) Tangent ¼ Θ $= \frac{d}{6}$

(21) Part of circle $= \frac{\Theta}{360°}$

(22) $d = 6$ tangent ¼ Θ

(23-a) $a_a = 2\pi r \frac{\Theta}{360°}$

(23-b) $A_a = 2\pi R \frac{\Theta}{360°}$

(24-a) $n_t = N_t \frac{\Theta}{360°}$

(24-b) $n_e = N_e \frac{\Theta}{360°}$

(24-c) $n_f = N_f \frac{\Theta}{360°}$

(25-a) $n_t = \frac{A_a}{C}$

(25-b) $n_e = \frac{a_a - n_t c_f}{c_e - c_f}$

(25-c) $n_f = n_t - n_e$

(26-a) H = T Sine ½ Θ

(26-b) V = T Cosine ½ Θ

(27) P = Q Tangent ½ Θ

NOTE: Approximate formula for arches with rise of 1 to 3 inches per foot of span, $\Theta = 180 \frac{h}{S}\left(2.62 - \frac{h}{S}\right)$

ARCH CONSTANTS FOR GIVEN RISES PER FOOT OF SPAN

Rise in Inches Per Foot of Span (d)	Inside Radius (r)	Central Angle (Θ)		Inside Arc (a_a)	Difference Between Outside and Inside Arcs ($A_a - a_a$)	Skewback		
		Degrees	Part of Circle			H	V	P
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1″	1.54167 S	37° 50.9′	0.10514	1.01840 S	0.66059 T	0.32432 T	0.94595 T	0.34286 Q
1¼″	1.25208 S	47° 4.4′	0.13076	1.02868 S	0.82157 T	0.39933 T	0.91681 T	0.43557 Q
1½″	1.06250 S	56° 8.7′	0.15596	1.04117 S	0.97992 T	0.47059 T	0.88235 T	0.53333 Q
1.608″	1.00000 S	60° 00.0′	0.16667	1.04720 S	1.04720 T	0.50000 T	0.86603 T	0.57735 Q
1¾″	0.93006 S	65° 2.5′	0.18067	1.05579 S	1.13519 T	0.53760 T	0.84320 T	0.63757 Q
2″	0.83333 S	73° 44.4′	0.20483	1.07251 S	1.28701 T	0.60000 T	0.80000 T	0.75000 Q
2¼″	0.76042 S	82° 13.4′	0.22840	1.09125 S	1.43507 T	0.65753 T	0.75342 T	0.87273 Q
2.302″	0.74742 S	83° 58.5′	0.23326	1.09544 S	1.46563 T	0.66896 T	0.74329 T	0.90000 Q
2½″	0.70417 S	90° 28.8′	0.25133	1.11200 S	1.57918 T	0.71006 T	0.70414 T	1.00840 Q
2¾″	0.66004 S	98° 29.7′	0.27360	1.13464 S	1.71906 T	0.75753 T	0.65280 T	1.16044 Q
3″	0.62500 S	106° 15.6′	0.29517	1.15912 S	1.85459 T	0.80000 T	0.60000 T	1.33333 Q

NOTE: The factors in the above tables are the following functions of Θ: Column 2, ½ cosecant ½ Θ; column 4, Θ divided by 360°; column 5, ½ cosecant ½ Θ times included radians; column 6, included radians; column 7, sine ½ Θ; column 8, cosine ½ Θ; column 9, tangent ½ Θ.

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USE OF ARCH FORMULAS

15. ***To find Inside Radius*** (r) *when rise* (h) *and span* (S) *are known:*

Formula 15: $r = \frac{S^2}{8h} + \frac{h}{2}$ Divide the square of the span (S^2) by 8 times the rise (8h). Add half the rise $\left(\frac{h}{2}\right)$.

Example: Let S = 54″, h = 9″

Then, Inside Radius (r) $= \frac{(54)^2}{8 \times 9} + \frac{9}{2} = 40.5 + 4.5 = 45'' = 3'\text{-}9''$

16. ***To find Outside Radius*** (R) *when inside radius* (r) *and thickness* (T) *are known:*

Formula 16: R = r + T Add to the inside radius (r) the thickness (T) of the arch.

Example: Let r = 45″, T = 9″

Then, Outside Radius (R) = 45″ + 9″ = 54″

17. ***To find Rise*** (h) *when inside radius* (r) *and span* (S) *are known:*

Formula 17: $h = r - \sqrt{r^2 - \left(\frac{S}{2}\right)^2}$ Subtract the square of half the span $\left(\frac{S}{2}\right)^2$ from the square of the inside radius (r^2); extract the square root of the difference. Subtract this square root from the inside radius (r).

Example: Let r = 45″, S = 54″

Then, Rise (h) $= 45 - \sqrt{45^2 - 27^2} = 45'' - 36'' = 9''$

18. ***To find Central Angle*** (Θ) *when span* (S) *and inside radius* (r) *are known:*

Formula 18: Sine ½ Θ $= \frac{S}{2\ r}$ Divide the span (S) by twice the inside radius (2 r). This gives the sine of ½ the angle (Θ). From a table of trigonometric functions determine the angle corresponding to this sine and multiply by 2 to find the angle (Θ).

Example: Let S = 54″, r = 45″

Then, Sine ½ Θ $= \frac{54}{2 \times 45} = 0.60000$. From table of functions on page 519 the angle having a sine of 0.60000 = 36.87° = 36° 52.2′

Central Angle (Θ) = 2 × 36.87° = 73.74° = 73° 44.4′

19. ***To find Central Angle*** (Θ) *when the span* (S) *and rise* (h) *are known:*

Formula 19: Tangent ¼ Θ $= \frac{2\ h}{S}$ Divide twice the rise (2 h) by the span (S). This gives the tangent of ¼ the angle (Θ). From a table of trigonometric functions on page 520 determine the angle corresponding to this tangent and multiply by 4 to find the angle (Θ).

Example: Let S = 54″, h = 9″

Then, Tangent ¼ Θ $= \frac{2 \times 9}{54} = 0.33333$. By interpolation from figures given in table of functions on page 520, the angle having a tangent of 0.33333 = 18.435°

Central Angle (Θ) = 4 × 18.435° = 73.74° = 73° 44.4′

NOTE: When the span (S) and rise (h) are given, Θ can be determined approximately, without reference to trigonometric tables, by use of the formula:

$$\Theta = \text{approximately } 180\,\frac{h}{S}\left(2.62 - \frac{h}{S}\right)$$

Example: *Using the above example,*

$$\Theta = \text{approximately } 180\,\frac{9}{54}\left(2.62 - \frac{9}{54}\right) = 30\ (2.62 - 0.167) = 30 \times 2.453 = 73.59°$$

True value of Θ = 73.74°

Error in determination of Θ, 73.74° — 73.59° = 0.15° = 0° 09′

20. ***To find Central Angle*** (Θ) *when rise in inches per foot of span* (d) *is known:*

Formula 20: Tangent ¼ Θ $= \frac{d}{6}$ Divide the rise in inches per foot of span (d) by 6. This gives the tangent of ¼ the central angle (Θ). From the table of trigonometric functions on page 520 determine the corresponding angle and multiply by 4 to find the central angle.

Example: Let the rise per foot of span (d) equal 2 inches.

Then, Tangent ¼ Θ $= \frac{2.0}{6} = 0.33333$

From table of functions on page 520, the angle having a tangent of 0.33333 = 18.435°

Central Angle (Θ) = 4 × 18.435° = 73.74° = 73° 44.4′

21. ***To find Part of Circle*** *when the central angle* (Θ) *is known:*

Formula 21: Part of Circle $= \frac{\Theta}{360°}$ Divide the central angle (Θ) by 360°

Example: Let Θ = 73.74° = 73° 44.4′

Then, Part of Circle $\left(\frac{\Theta}{360°}\right) = \frac{73.74°}{360°} = 0.20483$

22. ***To find the Rise in Inches per Foot*** (d) *when the central angle* (Θ) *is known:*

Formula 22: d = 6 tangent ¼ Θ From the table of trigonometric functions on page 520 determine the tangent of ¼ the central angle (tangent ¼ Θ). The rise in inches per foot of span is 6 times this figure.

Example: Let Θ = 60°, then ¼ Θ = 15°

From table on page 520, the tangent of 15° is 0.26795

The rise in inches per foot of span (d) = 6 × 0.26795 = 1.6077″ = $1^{19}/_{32}$″

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23. *To find Length of Arcs* (a_a *and* A_a) *when the inside and outside radii* (r *and* R) *and the central angle* (θ) *of the arch are known:*

Formula 23-a: $a_a = 2\pi\ r \dfrac{\theta}{360°}$

To determine the inside arc (a_a) multiply the inside circumference (2π r) by the part of the circle $\left(\dfrac{\theta}{360°}\right)$

Formula 23-b: $A_a = 2\pi\ R \dfrac{\theta}{360°}$

To determine the outside arc (A_a) multiply the outside circumference (2π R) by the part of the circle $\left(\dfrac{\theta}{360°}\right)$.

Example: Let r = 45″, T = 9″, R = 54″, θ = 73° 44.4′, $\dfrac{\theta}{360°} = 0.20483$

Then, Inside arc (a_a) = 6.2832 × 45″ × 0.20483 = 57.9145″ = 4′-9$^{29}\!/_{32}$″

Outside arc (A_a) = 6.2832 × 54″ × 0.20483 = 69.4973″ = 5′-9½″

24. *To find the Number of Pieces per Course* (n_t, n_e, *and* n_f) *of brick* E *and* F *when the inside radius* (r) *and the central angle* (θ) *are known:*

Formula 24-a: $n_t = N_t \dfrac{\theta}{360°}$

Formula 24-b: $n_e = N_e \dfrac{\theta}{360°}$

Formula 24-c: $n_f = N_f \dfrac{\theta}{360°}$

To find the Total Number (n_t) and the number of each (n_e and n_f) of the two sizes of brick E and F required per course: find the number (N_t, N_e, and N_f) of brick required to form a complete ring of the given inside diameter. When brick E and F are standard sizes having equal outside chord dimensions, use the brick tables on pages 536 to 558. When brick E and F are standard sizes having unequal outside chord dimensions, or if they are special radial brick, use the formulas given on page 525. To find the numbers (n_e, n_f, and n_t) required per course of arch, multiply the quantities so determined by the part of a circle $\left(\dfrac{\theta}{360°}\right)$ included in the given arch.

Example: Let r = 45″, T = 9″, Inside diameter = 7′-6″, θ = 73° 44.4′, $\dfrac{\theta}{360°} = 0.20483$

Using 9″ Wedge brick, it is seen from the table on page 542 that a complete ring of 7′-6″ inside diameter requires 76 pieces of 9″ No. 1-X Wedge brick (N_e) and 60 pieces of 9″ No. 1 Wedge brick (N_f), or a total of 136 pieces (N_t). In this case the No. 1-X Wedge brick = E, and the No. 1 Wedge brick = F.

Then, Total Number per course of arch (n_t) = 136 × 0.20483 = 27.8569 = 28
Number of 9″ No. 1-X Wedge brick (n_e) = 76 × 0.20483 = 15.5671 = 16
Number of 9″ No. 1 Wedge brick (n_f) = 60 × 0.20483 = 12.2898 = 12

25. *To find the Number of Pieces per Course* (n_t, n_e, *and* n_f) *of brick* E *and* F *when the inside radius* (r) *and the inside and outside arcs* (a_a *and* A_a) *are known:*

Formula 25-a: $n_t = \dfrac{A_a}{C}$

To find the total number of pieces per course (n_t): divide the outside arc (A_a) by the outside chord dimension (C).

Formula 25-b: $n_e = \dfrac{a_a - n_t\ c_f}{c_e - c_f}$

To find the number of pieces (n_e) of brick E (the straight brick or the radial brick which turns the larger diameter): multiply the total number of pieces per course (n_t) by the inside chord dimension (c_f) of brick F and subtract the product from the inside arc (a_a); divide the value so found by the difference between the inside chord dimensions ($c_e - c_f$) of brick E and F.

Formula 25-c: $n_f = n_t - n_e$

To find the number of pieces (n_f) of brick F: subtract the number of pieces (n_e) of brick E from the total number (n_t) per course.

Example: Let r = 45″, T = 9″, a_a = 57.9145″, A_a = 69.4973″

Using 9″ Wedge brick (page 578), it is seen from the table on page 542 that an arch for the given inside diameter of 7′-6″ requires 9″ No. 1-X Wedge brick and 9″ No. 1 Wedge brick for its construction. In this case the No. 1-X Wedge brick = E and the No. 1 Wedge brick = F.

Then, Total Number per course (n_t) = $\dfrac{69.4973}{2.5} = 27.7989 = 28$

Number of 9″ No. 1-X Wedge (n_e) = $\dfrac{57.9145 - (27.7989 \times 1.875)}{2.25 - 1.875} = 15.4443 = 16$

Number of 9″ No. 1 Wedge (n_f) = 27.7989 — 15.4443 = 12.3546 = 12

NOTE: The counts derived from this method are somewhat more accurate than are counts derived from the usual method (formulas 24-a, 24-b, and 24-c); however, the usual method gives results which are sufficiently accurate.
This method is applicable only when the outside dimensions (C) of the two brick used are equal. If they are unequal the brick count can be determined by setting up two simultaneous equations as in formulas and example 13 on page 527, substituting arcs for circumferences.

26. *To find Dimensions* (H *and* V) *of the Skewback to fit an arch when the central angle* (θ) *and the thickness* (T) *are known:*

Formula 26-a: H = T sine ½ θ

To find the dimension (H): multiply the thickness (T) by the sine of ½ the central angle (θ).

Formula 26-b: V = T cosine ½ θ

To find the dimension (V): multiply the thickness (T) by the cosine of ½ the central angle (θ). (The sine and cosine may be found in the table of trigonometric functions on page 519.)

Example: Let θ = 73.74° = 73° 44.4′, T = 9″. From table of functions on page 519, Sine ½ θ = sine 36.87° = 0.60000, cosine ½ θ = cosine 36.87° = 0.80000

Then, Dimension H = 9 × 0.60000 = 5.4″ = 5$^{13}\!/_{32}$″ Dimension V = 9 × 0.80000 = 7.2″ = 7$^{3}\!/_{16}$″

27. *To find Dimension* (P) *of the Skewback to fit an arch when the vertical dimension* (Q) *and the central angle* (θ) *are known:*

Formula 27: P = Q tangent ½ θ

To find the dimension (P): multiply the dimension (Q) by the tangent of ½ the central angle (θ). (The tangent may be found in the table of trigonometric functions on page 520.)

Example: Let Q = 9″, θ = 73.74° = 73° 44.4′. From table of functions on page 520, tangent ½ θ = tangent 36.87° = 0.75000

Then, Dimension P = 9 × 0.75000 = 6.75″ = 6$^{3}\!/_{4}$″

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USE OF ARCH CONSTANTS

The use of the table on page 529 is illustrated by the following specific example:

Let

Span (S) = 6′-0″ = 72″ — Thickness (T) = 9″

Rise per foot of span (d) = 2″ — Total Rise (h) = 2″ × 6 = 12″

1. *To find the Arch Dimensions:*

From table:

Inside radius (r) = 0.83333 × 72″ = 60.0″ = 5′-0″ (See column 2 for factor)
(The inside radius can also be found from the table on page 569.)

Part of circle $\left(\frac{\theta}{360°}\right)$ = 0.20483 (From column 4)

Central angle (θ) = 73° 44.4′ (From column 3)
Inside arc (a_a) = 1.07251 × 72″ = 77.2207″ = 6′-5 7/32″ (See column 5 for factor)
Difference between arcs ($A_a - a_a$) = 1.28701 × 9″ = 11.5831″ = 11 19/32″ (See column 6 for factor)
Then outside arc (A_a) = inside arc (a_a) + difference ($A_a - a_a$) = 77.2207″ + 11.5831″ = 88.8038″ = 7′-4 13/16″

2. *To find Dimensions of Skewback:*

When skewback is flush with arch at top; and T = 9″, then,

Dimension H = 0.60000 × 9″ = 5.4000″ = 5 13/32″ (See column 7 for factor)
Dimension V = 0.80000 × 9″ = 7.2000″ = 7 3/16″ (See column 8 for factor)

In the event that skewback is not flush with arch at top, and Q = 9″, then
Dimension (P) = 0.75000 × 9″ = 6.75000″ = 6 3/4″ (See column 9 for factor)

3. *To find the Number of Brick per Course of Arch:*

(a) If standard 9″ brick are to be used, refer to table on page 569.
For a span of 6′-0″, it is shown that the following number of pieces is required per course:

9″ No. 1 Wedge	7
9″ No. 1-X Wedge	29
Total pieces	36

(b) If standard 9″ brick of the 3″ Series are to be used, refer to table on page 570.
For a span of 6′-0″, it is shown that the following number of pieces is required per course:

9″ x 4½″ x 3″ No. 2 Wedge	17
9″ x 4½″ x 3″ No. 1 Wedge	13
Total pieces	30

NOTE: The tables on pages 560 to 576 can be used only when the rise per foot of span is 1½″, 1 19/32″, 2″, or 2 5/16″. For any other rise, proceed as follows:

Determine the central angle θ from formula 19 or 20, page 529. Using this value, calculate the number of brick required per course of arch from formulas 24-a, 24-b, and 24-c, page 529.



BRICK COMBINATIONS

FOR RINGS

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BRICK COMBINATIONS REQUIRED FOR RINGS

In estimating the quantities of brick required for the construction of circular linings, roofs and arches, the various tables on the following pages will be found useful. These tables give the combinations of brick sizes required for rings of given diameters.

In calculating the tables, fractional parts equal to or greater than one-tenth of a brick were counted as entire brick; no allowance was made for mortar or expansion joints or for size deviations of the brick. For these reasons the brick combinations shown may lay up to diameters which differ slightly from the theoretical diameters; and the number of brick required for a ring, as given in the tables, may be slightly in excess of the number actually required.

Generally, in laying a ring course of brick, it is necessary to cut one or two pieces, and sometimes several pieces, to complete the ring.

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Key Brick	9″ x 4½″ x 3″	546
Key Brick	9″ x 6″ x 2½″	547
Key Brick	9″ x 6″ x 3″	547
Rotary Kiln Blocks	9″ x 9″ x 4″	548
12″ Linings		
Wedge Brick	12″ x 4½″ x 3″	549
Wedge Brick	12″ x 6″ x 3″	549
Wedge Brick	12″ x 9″ x 3″	549
Key Brick	12″ x 6″ x 3″	551
13½″ Linings		
Wedge Brick	13½″ x 4½″ x 3″	552
Wedge Brick	13½″ x 6″ x 3″	552
Wedge Brick	13½″ x 9″ x 3″	552
Key Brick	13½″ x 6″ x 2½″	554
Key Brick	13½″ x 6″ x 3″	554
15″ Linings		
Wedge Brick	15″ x 6″ x 3″	555
Wedge Brick	15″ x 9″ x 3″	555
18″ Linings		
Wedge Brick	18″ x 6″ x 3″	557
Wedge Brick	18″ x 9″ x 3″	557

4½″ LINING—2½″ ARCH BRICK

9″ x 4½″ x 2½″ or 13½″ x 4½″ x 2½″

Diameter Inside Brickwork	Number Required Per Ring: No. 3 Arch	No. 2 Arch	No. 1 Arch	Straight	Total
0′- 6″	19	...	...	...	19
0′- 7″	18	3	...	...	21
0′- 8″	17	5	...	...	22
0′- 9″	15	8	...	...	23
0′-10″	14	10	...	...	24
0′-11″	13	13	...	...	26
1′- 0″	12	15	...	...	27
1′- 1″	10	18	...	...	28
1′- 2″	9	20	...	...	29
1′- 3″	8	23	...	...	31
1′- 4″	7	25	...	...	32
1′- 5″	5	28	...	...	33
1′- 6″	4	30	...	...	34
1′- 7″	3	33	...	...	36
1′- 8″	2	35	...	...	37
1′- 9″	...	38	...	...	38
1′-10″	...	36	3	...	39
1′-11″	...	36	5	...	41
2′- 0″	...	34	8	...	42
2′- 1″	...	33	10	...	43
2′- 2″	...	31	13	...	44
2′- 3″	...	31	15	...	46
2′- 4″	...	29	18	...	47
2′- 5″	...	28	20	...	48
2′- 6″	...	26	23	...	49
2′- 7″	...	26	25	...	51
2′- 8″	...	24	28	...	52
2′- 9″	...	23	30	...	53
2′-10″	...	21	33	...	54
2′-11″	...	20	36	...	56
3′- 0″	...	19	38	...	57
3′- 1″	...	18	40	...	58
3′- 2″	...	16	43	...	59
3′- 3″	...	15	46	...	61
3′- 4″	...	14	48	...	62
3′- 5″	...	13	50	...	63
3′- 6″	...	11	53	...	64
3′- 7″	...	10	56	...	66
3′- 8″	...	9	58	...	67
3′- 9″	...	8	60	...	68
3′-10″	...	7	63	...	70
3′-11″	...	5	66	...	71
4′- 0″	...	4	68	...	72
4′- 1″	...	3	70	...	73
4′- 2″	...	2	73	...	75
4′- 3″	...	...	76	...	76
4′- 4″	...	...	76	1	77
4′- 6″	...	...	76	4	80
4′- 8″	...	...	76	6	82
4′-10″	...	...	76	9	85
5′- 0″	...	...	76	11	87
5′- 2″	...	...	76	14	90
5′- 4″	...	...	76	16	92
5′- 6″	...	...	76	19	95
5′- 8″	...	...	76	21	97
5′-10″	...	...	76	24	100

Diameter Inside Brickwork	Number Required Per Ring: No. 3 Arch	No. 2 Arch	No. 1 Arch	Straight	Total
6′- 0″	...	...	76	26	102
6′- 2″	...	...	76	29	105
6′- 4″	...	...	76	31	107
6′- 6″	...	...	76	34	110
6′- 8″	...	...	76	36	112
6′-10″	...	...	76	39	115
7′- 0″	...	...	76	41	117
7′- 2″	...	...	76	44	120
7′- 4″	...	...	76	46	122
7′- 6″	...	...	76	49	125
7′- 8″	...	...	76	51	127
7′-10″	...	...	76	54	130
8′- 0″	...	...	76	56	132
8′- 2″	...	...	76	59	135
8′- 4″	...	...	76	61	137
8′- 6″	...	...	76	64	140
8′- 8″	...	...	76	66	142
8′-10″	...	...	76	69	145
9′- 0″	...	...	76	71	147
9′- 2″	...	...	76	74	150
9′- 4″	...	...	76	76	152
9′- 6″	...	...	76	79	155
9′- 8″	...	...	76	81	157
9′-10″	...	...	76	84	160
10′- 0″	...	...	76	87	163
10′- 2″	...	...	76	89	165
10′- 4″	...	...	76	92	168
10′- 6″	...	...	76	94	170
10′- 8″	...	...	76	97	173
10′-10″	...	...	76	99	175
11′- 0″	...	...	76	102	178
11′- 2″	...	...	76	104	180
11′- 4″	...	...	76	107	183
11′- 6″	...	...	76	109	185
11′- 8″	...	...	76	112	188
11′-10″	...	...	76	114	190
12′- 0″	...	...	76	117	193
12′- 2″	...	...	76	119	195
12′- 4″	...	...	76	122	198
12′- 6″	...	...	76	124	200
12′- 8″	...	...	76	127	203
12′-10″	...	...	76	129	205
13′- 0″	...	...	76	132	208
13′- 2″	...	...	76	134	210
13′- 4″	...	...	76	137	213
13′- 6″	...	...	76	139	215
13′- 8″	...	...	76	142	218
13′-10″	...	...	76	144	220
14′- 0″	...	...	76	147	223
14′- 2″	...	...	76	149	225
14′- 4″	...	...	76	152	228
14′- 6″	...	...	76	154	230
14′- 8″	...	...	76	157	233
14′-10″	...	...	76	159	235
15′- 0″	...	...	76	162	238

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4½″ LINING—3″ ARCH BRICK

9″ x 4½″ x 3″ or 13½″ x 4½″ x 3″

Diameter Inside Brickwork	Number Required Per Ring					
	No. 4 Arch	No. 3 Arch	No. 2 Arch	No. 1 Arch	Straight	Total
0′- 4½″	15	...	...	...	...	15
0′- 5″	14	1	...	...	...	15
0′- 6″	13	3	...	...	...	16
0′- 7″	12	5	...	...	...	17
0′- 8″	11	7	...	...	...	18
0′- 9″	10	9	...	...	...	19
0′-10″	8	12	...	...	...	20
0′-11″	7	14	...	...	...	21
1′- 0″	6	16	...	...	...	22
1′- 1″	5	18	...	...	...	23
1′- 2″	4	20	...	...	...	24
1′- 3″	4	22	...	...	...	26
1′- 4″	3	24	...	...	...	27
1′- 5″	1	27	...	...	...	28
1′- 6″	...	29	...	...	...	29
1′- 7″	...	28	2	...	...	30
1′- 8″	...	26	5	...	...	31
1′- 9″	...	25	7	...	...	32
1′-10″	...	24	9	...	...	33
1′-11″	...	23	11	...	...	34
2′- 0″	...	22	13	...	...	35
2′- 1″	...	21	15	...	...	36
2′- 2″	...	20	17	...	...	37
2′- 3″	...	19	19	...	...	38
2′- 4″	...	18	21	...	...	39
2′- 5″	...	17	23	...	...	40
2′- 6″	...	16	25	...	...	41
2′- 7″	...	15	27	...	...	42
2′- 8″	...	14	29	...	...	43
2′- 9″	...	13	31	...	...	44
2′-10″	...	12	33	...	...	45
2′-11″	...	10	36	...	...	46
3′- 0″	...	10	38	...	...	48
3′- 1″	...	9	40	...	...	49
3′- 2″	...	8	42	...	...	50
3′- 3″	...	7	44	...	...	51
3′- 4″	...	6	46	...	...	52
3′- 5″	...	5	48	...	...	53
3′- 6″	...	3	51	...	...	54
3′- 7″	...	2	53	...	...	55
3′- 8″	...	1	55	...	...	56
3′- 9″	...	...	57	...	...	57
3′-10″	...	...	56	2	...	58
3′-11″	...	...	55	4	...	59
4′- 0″	...	...	54	6	...	60
4′- 1″	...	...	52	9	...	61
4′- 2″	...	...	51	11	...	62
4′- 3″	...	...	50	13	...	63
4′- 4″	...	...	49	15	...	64
4′- 5″	...	...	48	17	...	65

Diameter Inside Brickwork	Number Required Per Ring					
	No. 4 Arch	No. 3 Arch	No. 2 Arch	No. 1 Arch	Straight	Total
4′- 6″	...	...	47	19	...	66
4′- 7″	...	...	46	21	...	67
4′- 8″	...	...	45	23	...	68
4′- 9″	...	...	44	26	...	70
4′-10″	...	...	43	28	...	71
4′-11″	...	...	42	30	...	72
5′- 0″	...	...	41	32	...	73
5′- 1″	...	...	40	34	...	74
5′- 2″	...	...	39	36	...	75
5′- 3″	...	...	38	38	...	76
5′- 4″	...	...	37	40	...	77
5′- 5″	...	...	36	42	...	78
5′- 6″	...	...	35	44	...	79
5′- 7″	...	...	34	46	...	80
5′- 8″	...	...	33	48	...	81
5′- 9″	...	...	32	50	...	82
5′-10″	...	...	31	52	...	83
5′-11″	...	...	29	55	...	84
6′- 0″	...	...	28	57	...	85
6′- 1″	...	...	27	59	...	86
6′- 2″	...	...	26	61	...	87
6′- 3″	...	...	25	63	...	88
6′- 4″	...	...	24	65	...	89
6′- 5″	...	...	23	67	...	90
6′- 6″	...	...	22	70	..	92
6′- 7″	...	...	21	72	...	93
6′- 8″	...	...	20	74	...	94
6′- 9″	...	...	19	76	...	95
6′-10″	..	...	18	78	...	96
6′-11″	...	...	17	80	...	97
7′- 0″	...	...	16	82	...	98
7′- 1″	...	...	15	84	...	99
7′- 2″	...	...	14	86	...	100
7′- 3″	...	...	13	88	...	101
7′- 4″	...	...	12	90	...	102
7′- 5″	...	...	11	92	...	103
7′- 6″	...	...	10	94	...	104
7′- 7″	...	...	9	96	...	105
7′- 8″	...	...	7	99	...	106
7′- 9″	...	...	6	101	...	107
7′-10″	...	...	5	103	...	108
7′-11″	...	...	4	105	...	109
8′- 0″	...	...	3	107	...	110
8′- 1″	...	...	2	109	...	111
8′- 2″	...	...	1	111	...	112
8′- 3″	...	...	...	113	...	113
8′- 6″	...	...	...	113	4	117
9′- 0″	...	...	...	113	10	123
10′- 0″	...	...	...	113	22	135
11′- 0″	...	...	...	113	35	148
12′- 0″	...	...	...	113	48	161
13′- 0″	...	...	...	113	60	173
14′- 0″	...	...	...	113	73	186
15′- 0″	...	...	...	113	85	198

4½″ LINING—2½″ or 3″ CIRCLE BRICK

9″ x 4½″ x 2½″ or 9″ x 4½″ x 3″*

Diameter Inside Brickwork	Number Required Per Ring					
	24-33 Circle	36-45 Circle	48-57 Circle	60-69 Circle	72-81 Circle	Total
2′- 0″	12	...	...	...	...	12
2′- 1″	11	1	...	...	...	12
2′- 2″	10	3	...	...	...	13
2′- 3″	9	4	...	...	...	13
2′- 4″	8	5	...	...	...	13
2′- 5″	7	7	...	...	...	14
2′- 6″	6	8	...	...	...	14
2′- 7″	5	9	...	...	...	14
2′- 8″	4	11	...	...	...	15
2′- 9″	3	12	...	...	...	15
2′-10″	2	13	...	...	...	15
2′-11″	1	15	...	...	...	16
3′- 0″	...	16	...	...	...	16
3′- 1″	...	14	2	...	...	16
3′- 2″	...	13	4	...	...	17
3′- 3″	...	12	5	...	...	17
3′- 4″	...	11	7	...	...	18
3′- 5″	...	9	9	...	...	18
3′- 6″	...	8	10	...	...	18
3′- 7″	...	7	12	...	...	19
3′- 8″	...	5	14	...	...	19
3′- 9″	...	4	15	...	...	19
3′-10″	...	3	17	...	...	20
3′-11″	...	2	18	...	...	20
4′- 0″	...	...	20	...	...	20
4′- 1″	...	...	19	2	...	21
4′- 2″	...	...	17	4	...	21
4′- 3″	...	...	15	6	...	21
4′- 4″	...	...	14	8	...	22
4′- 5″	...	...	12	10	...	22
4′- 6″	...	...	10	12	...	22
4′- 7″	...	...	9	14	...	23
4′- 8″	...	...	7	16	...	23
4′- 9″	...	...	5	18	...	23
4′-10″	...	...	4	20	...	24
4′-11″	...	...	2	22	...	24
5′- 0″	...	...	...	24	...	24
5′- 1″	...	...	...	22	3	25
5′- 2″	...	...	...	20	5	25
5′- 3″	...	...	...	18	8	26
5′- 4″	...	...	...	16	10	26
5′- 5″	...	...	...	14	12	26
5′- 6″	...	...	...	12	15	27
5′- 7″	...	...	...	10	17	27
5′- 8″	...	...	...	8	19	27
5′- 9″	...	...	...	6	22	28
5′-10″	...	...	...	4	24	28
5′-11″	...	...	...	2	26	28

Diameter Inside Brickwork	Number Required Per Ring					
	72-81 Circle	84-93 Circle	96-105 Circle	108-117 Circle	120-129 Circle	Total
6′- 0″	29	...	...	...	...	29
6′- 1″	26	3	...	...	...	29
6′- 2″	24	5	...	...	...	29
6′- 3″	22	8	...	...	...	30
6′- 4″	19	11	...	...	...	30
6′- 5″	16	14	...	...	...	30
6′- 6″	14	17	...	...	...	31
6′- 7″	12	19	...	...	...	31
6′- 8″	9	22	...	...	...	31
6′- 9″	7	25	...	...	...	32
6′-10″	5	27	...	...	...	32
6′-11″	3	30	...	...	...	33
7′- 0″	...	33	...	...	...	33
7′- 1″	...	30	3	...	...	33
7′- 2″	...	27	7	...	...	34
7′- 3″	...	25	9	...	...	34
7′- 4″	...	22	12	...	...	34
7′- 5″	...	19	16	...	...	35
7′- 6″	...	16	19	...	...	35
7′- 7″	...	14	21	...	...	35
7′- 8″	...	11	25	...	...	36
7′- 9″	...	8	28	...	...	36
7′-10″	...	5	31	...	...	36
7′-11″	...	3	34	...	...	37
8′- 0″	...	...	37	...	...	37
8′- 1″	...	...	34	3	...	37
8′- 2″	...	...	31	7	...	38
8′- 3″	...	...	28	10	...	38
8′- 4″	...	...	24	14	...	38
8′- 5″	...	...	22	17	...	39
8′- 6″	...	...	18	21	...	39
8′- 7″	...	...	15	24	...	39
8′- 8″	...	...	12	28	...	40
8′- 9″	...	...	9	31	...	40
8′-10″	...	...	7	34	...	41
8′-11″	...	...	3	38	...	41
9′- 0″	...	...	...	41	...	41
9′- 1″	...	...	...	38	4	42
9′- 2″	...	...	...	34	8	42
9′- 3″	...	...	...	31	11	42
9′- 4″	...	...	...	28	15	43
9′- 5″	...	...	...	24	19	43
9′- 6″	...	...	...	20	23	43
9′- 7″	...	...	...	17	27	44
9′- 8″	...	...	...	14	30	44
9′- 9″	...	...	...	10	34	44
9′-10″	...	...	...	7	38	45
9′-11″	...	...	...	4	41	45
10′- 0″	...	...	...	...	45	45

* NOTE: 9″ x 4½″ x 3″ Circle Brick are specified by inserting "3" in the name thus, 24-33-3 Circle.

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6″ LINING—3″ ARCH BRICK

12″ x 6″ x 3″ or 13½″ x 6″ x 3″

Diameter Inside Brickwork	Number Required Per Ring				
	No. 3 Arch	No. 2 Arch	No. 1 Arch	Straight	Total
2′- 0″	38	...	...	...	38
2′- 1″	37	2	...	...	39
2′- 2″	36	4	...	...	40
2′- 3″	35	6	...	...	41
2′- 4″	34	8	...	...	42
2′- 5″	32	11	...	...	43
2′- 6″	31	13	...	...	44
2′- 7″	30	15	...	...	45
2′- 8″	29	17	...	...	46
2′- 9″	29	19	...	...	48
2′-10″	28	21	...	...	49
2′-11″	27	23	...	...	50
3′- 0″	26	25	...	...	51
3′- 1″	24	28	...	...	52
3′- 2″	23	30	...	...	53
3′- 3″	22	32	...	...	54
3′- 4″	21	34	...	...	55
3′- 5″	20	36	...	...	56
3′- 6″	19	38	...	...	57
3′- 7″	18	40	...	...	58
3′- 8″	17	42	...	...	59
3′- 9″	16	44	...	...	60
3′-10″	15	46	...	...	61
3′-11″	14	48	...	...	62
4′- 0″	13	50	...	...	63
4′- 1″	12	52	...	...	64
4′- 2″	11	54	...	...	65
4′- 3″	9	57	...	...	66
4′- 4″	8	59	...	...	67
4′- 5″	7	61	...	...	68
4′- 6″	7	63	...	...	70
4′- 7″	6	65	...	...	71
4′- 8″	5	67	...	...	72
4′- 9″	4	69	...	...	73
4′-10″	2	72	...	...	74
4′-11″	1	74	...	...	75
5′- 0″	...	76	...	...	76
5′- 1″	...	75	2	...	77
5′- 2″	...	74	4	...	78
5′- 3″	...	72	7	...	79
5′- 4″	...	71	9	...	80
5′- 5″	...	70	11	...	81
5′- 6″	...	69	13	...	82
5′- 7″	...	68	15	...	83
5′- 8″	...	67	17	...	84
5′- 9″	...	66	19	...	85
5′-10″	...	65	21	...	86
5′-11″	...	64	23	...	87
6′- 0″	...	63	25	...	88
6′- 1″	...	62	27	...	89
6′- 2″	...	61	29	...	90
6′- 3″	...	60	32	...	92
6′- 4″	...	59	34	...	93
6′- 5″	...	58	36	...	94
6′- 6″	...	57	38	...	95
6′- 7″	...	56	40	...	96
6′- 8″	...	55	42	...	97

Diameter Inside Brickwork	Number Required Per Ring				
	No. 3 Arch	No. 2 Arch	No. 1 Arch	Straight	Total
6′- 9″	...	54	44	...	98
6′-10″	...	53	46	...	99
6′-11″	...	52	48	...	100
7′- 0″	...	51	50	...	101
7′- 1″	...	49	53	...	102
7′- 2″	...	48	55	...	103
7′- 3″	...	47	57	...	104
7′- 4″	...	46	59	...	105
7′- 5″	...	45	61	...	106
7′- 6″	...	44	63	...	107
7′- 7″	...	43	65	...	108
7′- 8″	...	42	67	...	109
7′- 9″	...	41	69	...	110
7′-10″	...	40	71	...	111
7′-11″	...	39	73	...	112
8′- 0″	...	38	75	...	113
8′- 1″	...	37	78	...	115
8′- 2″	...	36	80	...	116
8′- 3″	...	35	82	...	117
8′- 4″	...	34	84	...	118
8′- 5″	...	33	86	...	119
8′- 6″	...	32	88	...	120
8′- 7″	...	31	90	...	121
8′- 8″	...	30	92	...	122
8′- 9″	...	29	94	...	123
8′-10″	...	27	97	...	124
8′-11″	...	26	99	...	125
9′- 0″	...	25	101	...	126
9′- 1″	...	24	103	...	127
9′- 2″	...	23	105	...	128
9′- 3″	...	22	107	...	129
9′- 4″	...	21	109	...	130
9′- 5″	...	20	111	...	131
9′- 6″	...	19	113	...	132
9′- 7″	...	18	115	...	133
9′- 8″	...	17	117	...	134
9′- 9″	...	16	119	...	135
9′-10″	...	15	122	...	137
9′-11″	...	14	124	...	138
10′- 0″	...	13	126	...	139
10′- 1″	...	12	128	...	140
10′- 2″	...	11	130	...	141
10′- 3″	...	10	132	...	142
10′- 4″	...	9	134	...	143
10′- 5″	...	8	136	...	144
10′- 6″	...	7	138	...	145
10′- 7″	...	5	141	...	146
10′- 8″	...	4	143	...	147
10′- 9″	...	3	145	...	148
10′-10″	...	2	147	...	149
10′-11″	...	1	149	...	150
11′- 0″	...	...	151	...	151
12′- 0″	...	...	151	13	164
13′- 0″	...	...	151	25	176
14′- 0″	...	...	151	38	189
15′- 0″	...	...	151	50	201

6″ LINING—ROTARY KILN OR CUPOLA BLOCKS

9″ x 6″ x 4″

Diameter Inside Brickwork	Number Required Per Ring		
	30-42	36-48	Total
2′- 6″	15	..	15
2′- 7″	12	3	15
2′- 8″	10	6	16
2′- 9″	7	9	16
2′-10″	5	11	16
2′-11″	3	14	17
	36-48	42-54	
3′- 0″	17	..	17
3′- 1″	14	4	18
3′- 2″	11	7	18
3′- 3″	8	10	18
3′- 4″	6	13	19
3′- 5″	3	16	19
	42-54	48-60	
3′- 6″	19	..	19
3′- 7″	16	4	20
3′- 8″	13	7	20
3′- 9″	9	11	20
3′-10″	7	14	21
3′-11″	3	18	21
	48-60	54-66	
4′- 0″	21	..	21
4′- 1″	18	4	22
4′- 2″	14	8	22
4′- 3″	10	12	22
4′- 4″	7	16	23
4′- 5″	4	19	23
	54-66	60-72	
4′- 6″	23	..	23
4′- 7″	20	4	24
4′- 8″	15	9	24
4′- 9″	11	13	24
4′-10″	8	17	25
4′-11″	4	21	25
	60-72	66-78	
5′- 0″	26	..	26
5′- 1″	21	5	26
5′- 2″	17	9	26
5′- 3″	13	14	27
5′- 4″	9	18	27
5′- 5″	4	23	27

Diameter Inside Brickwork	Number Required Per Ring		
	66-78	72-84	Total
5′- 6″	28	..	28
5′- 7″	23	5	28
5′- 8″	18	10	28
5′- 9″	14	15	29
5′-10″	9	20	29
5′-11″	5	24	29
	72-84	78-90	
6′- 0″	30	..	30
6′- 1″	25	5	30
6′- 2″	20	10	30
6′- 3″	15	16	31
6′- 4″	10	21	31
6′- 5″	5	26	31
	78-90	84-96	
6′- 6″	32	..	32
6′- 7″	26	6	32
6′- 8″	21	12	33
6′- 9″	16	17	33
6′-10″	11	22	33
6′-11″	6	28	34
	84-96	90-102	
7′- 0″	34	..	34
7′- 1″	28	6	34
7′- 2″	23	12	35
7′- 3″	17	18	35
7′- 4″	11	24	35
7′- 5″	6	30	36
	90-102	96-108	
7′- 6″	36	..	36
7′- 7″	30	6	36
7′- 8″	24	13	37
7′- 9″	18	19	37
7′-10″	12	25	37
7′-11″	6	32	38
	96-108	102-114	
8′- 0″	38	..	38
8′- 1″	31	7	38
8′- 2″	25	14	39
8′- 3″	19	20	39
8′- 4″	13	26	39
8′- 5″	7	33	40

Diameter Inside Brickwork	Number Required Per Ring		
	102-114	108-120	Total
8′- 6″	40	..	40
8′- 7″	34	7	41
8′- 8″	27	14	41
8′- 9″	20	21	41
8′-10″	14	28	42
8′-11″	7	35	42
	108-120	114-126	
9′- 0″	42	..	42
9′- 1″	35	8	43
9′- 2″	28	15	43
9′- 3″	21	22	43
9′- 4″	14	30	44
9′- 5″	7	37	44
	114-126	120-132	
9′- 6″	44	..	44
9′- 7″	37	8	45
9′- 8″	29	16	45
9′- 9″	22	23	45
9′-10″	15	31	46
9′-11″	7	39	46
	120-132	123-135	
10′- 0″	46	..	46
10′- 1″	31	16	47
10′- 2″	15	32	47
	123-135	126-138	
10′- 3″	48	..	48
10′- 4″	32	16	48
10′- 5″	16	32	48
	126-138	132-144	
10′- 6″	49	..	49
10′- 7″	40	9	49
10′- 8″	32	17	49
10′- 9″	24	26	50
10′-10″	16	34	50
10′-11″	8	42	50
	132-144	138-150	
11′- 0″	51	..	51
11′- 1″	42	9	51
11′- 2″	34	17	51
11′- 3″	25	27	52
11′- 4″	17	35	52
11′- 5″	8	44	52
11′- 6″	..	53	53

NOTE: In orders, the complete names of the blocks desired should be given, as for example "30-42 RKB" or "30-42 Cupola."

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9″ LINING—2½″ WEDGE BRICK

9″ x 4½″ x 2½″, 9″ x 6¾″ x 2½″, or 9″ x 9″ x 2½″

Diameter Inside Brickwork	Number Required Per Ring				
	No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Straight	Total
2′- 3″	57	...	...	...	57
2′- 4″	55	3	...	...	58
2′- 5″	52	7	...	...	59
2′- 6″	51	10	...	...	61
2′- 7″	48	14	...	...	62
2′- 8″	46	17	...	...	63
2′- 9″	44	20	...	...	64
2′-10″	42	24	...	...	66
2′-11″	40	27	...	...	67
3′- 0″	38	30	...	...	68
3′- 1″	36	34	...	...	70
3′- 2″	34	37	...	...	71
3′- 3″	32	40	...	...	72
3′- 4″	29	44	...	...	73
3′- 5″	28	47	...	...	75
3′- 6″	25	51	...	...	76
3′- 7″	23	54	...	...	77
3′- 8″	21	57	...	...	78
3′- 9″	19	61	...	...	80
3′-10″	17	64	...	...	81
3′-11″	15	67	...	...	82
4′- 0″	13	70	...	...	83
4′- 1″	11	74	...	...	85
4′- 2″	9	77	...	...	86
4′- 3″	6	81	...	...	87
4′- 4″	4	84	...	...	88
4′- 5″	2	88	...	...	90
4′- 6″	...	91	...	...	91
4′- 7″	...	90	2	...	92
4′- 8″	...	89	4	...	93
4′- 9″	...	88	7	...	95
4′-10″	...	87	9	...	96
4′-11″	...	86	11	...	97
5′- 0″	...	85	13	...	98
5′- 1″	...	85	15	...	100
5′- 2″	...	84	17	...	101
5′- 3″	...	83	19	...	102
5′- 4″	...	82	21	...	103
5′- 5″	...	82	23	...	105
5′- 6″	...	81	25	...	106
5′- 7″	...	80	27	...	107
5′- 8″	...	79	29	...	108
5′- 9″	...	78	32	...	110
5′-10″	...	77	34	...	111
5′-11″	...	76	36	...	112
6′- 0″	...	75	38	...	113
6′- 1″	...	75	40	...	115
6′- 2″	...	74	42	...	116
6′- 3″	...	73	44	...	117
6′- 4″	...	72	47	...	119
6′- 5″	...	72	48	...	120

Diameter Inside Brickwork	Number Required Per Ring				
	No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Straight	Total
6′- 6″	...	71	50	...	121
6′- 7″	...	70	52	...	122
6′- 8″	...	69	55	...	124
6′- 9″	...	68	57	...	125
6′-10″	...	67	59	...	126
6′-11″	...	66	61	...	127
7′- 0″	...	66	63	...	129
7′- 1″	...	65	65	...	130
7′- 2″	...	64	67	...	131
7′- 3″	...	63	69	...	132
7′- 4″	...	62	72	...	134
7′- 5″	...	61	74	...	135
7′- 6″	...	60	76	...	136
7′- 7″	...	59	78	...	137
7′- 8″	...	59	80	...	139
7′- 9″	...	58	82	...	140
7′-10″	...	57	84	...	141
7′-11″	...	56	86	...	142
8′- 0″	...	56	88	...	144
8′- 1″	...	55	90	...	145
8′- 2″	...	54	92	...	146
8′- 3″	...	53	94	...	147
8′- 4″	...	52	97	...	149
8′- 5″	...	51	99	...	150
8′- 6″	...	50	101	...	151
8′- 7″	...	49	103	...	152
8′- 8″	...	49	105	...	154
8′- 9″	...	48	107	...	155
8′-10″	...	47	109	...	156
8′-11″	...	46	111	...	157
9′- 0″	...	46	113	...	159
9′- 1″	...	45	115	...	160
9′- 2″	...	44	117	...	161
9′- 3″	...	43	120	...	163
9′- 4″	...	42	122	...	164
9′- 5″	...	41	124	...	165
9′- 6″	...	40	126	...	166
9′- 7″	...	40	128	...	168
9′- 8″	...	39	130	...	169
9′- 9″	...	38	132	...	170
9′-10″	...	37	134	...	171
9′-11″	...	36	137	...	173
10′- 0″	...	35	139	...	174
10′- 1″	...	35	140	...	175
10′- 2″	...	34	142	...	176
10′- 3″	...	33	145	...	178
10′- 4″	...	32	147	...	179
10′- 5″	...	31	149	...	180

9″ LINING—2½″ WEDGE BRICK

9″ x 4½″ x 2½″, 9″ x 6¾″ x 2½″, or 9″ x 9″ x 2½″—CONTINUED

Diameter Inside Brickwork	Number Required Per Ring				
	No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Straight	Total
10′- 6″	...	30	151	...	181
10′- 7″	...	30	153	...	183
10′- 8″	...	29	155	...	184
10′- 9″	...	28	157	...	185
10′-10″	...	27	159	...	186
10′-11″	...	26	162	...	188
11′- 0″	...	25	164	...	189
11′- 1″	...	24	166	...	190
11′- 2″	...	23	168	...	191
11′- 3″	...	23	170	...	193
11′- 4″	...	22	172	...	194
11′- 5″	...	21	174	...	195
11′- 6″	...	20	176	...	196
11′- 7″	...	20	178	...	198
11′- 8″	...	19	180	...	199
11′- 9″	...	18	182	...	200
11′-10″	...	17	184	...	201
11′-11″	...	16	187	...	203
12′- 0″	...	15	189	...	204
12′- 1″	...	14	191	...	205
12′- 2″	...	13	193	...	206
12′- 3″	...	13	195	...	208
12′- 4″	...	12	197	...	209
12′- 5″	...	11	199	...	210
12′- 6″	...	10	202	...	212
12′- 7″	...	10	203	...	213
12′- 8″	...	9	205	...	214
12′- 9″	...	8	207	...	215
12′-10″	...	7	210	...	217
12′-11″	...	6	212	...	218
13′- 0″	...	5	214	...	219
13′- 1″	...	4	216	...	220
13′- 2″	...	4	218	...	222
13′- 3″	...	3	220	...	223
13′- 4″	...	2	222	...	224
13′- 5″	...	1	224	...	225
13′- 6″	...	...	227	...	227
13′- 7″	...	...	227	1	228
13′- 8″	...	...	227	2	229
13′- 9″	...	...	227	3	230
13′-10″	...	...	227	5	232
13′-11″	...	...	227	6	233
14′- 0″	...	...	227	7	234
14′- 6″	...	...	227	15	242
15′- 0″	...	...	227	22	249
15′- 6″	...	...	227	30	257
16′- 0″	...	...	227	37	264
16′- 6″	...	...	227	45	272
17′- 0″	...	...	227	52	279
17′- 6″	...	...	227	60	287
18′- 0″	...	...	227	67	294
18′- 6″	...	...	227	75	302

Diameter Inside Brickwork	Number Required Per Ring				
	No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Straight	Total
19′- 0″	...	...	227	83	310
19′- 6″	...	...	227	90	317
20′- 0″	...	...	227	98	325
20′- 6″	...	...	227	105	332
21′- 0″	...	...	227	113	340
21′- 6″	...	...	227	120	347
22′- 0″	...	...	227	128	355
22′- 6″	...	...	227	135	362
23′- 0″	...	...	227	143	370
23′- 6″	...	...	227	150	377
24′- 0″	...	...	227	158	385
24′- 6″	...	...	227	165	392
25′- 0″	...	...	227	173	400
25′- 6″	...	...	227	181	408
26′- 0″	...	...	227	188	415
26′- 6″	...	...	227	196	423
27′- 0″	...	...	227	203	430
27′- 6″	...	...	227	211	438
28′- 0″	...	...	227	218	445
28′- 6″	...	...	227	226	453
29′- 0″	...	...	227	233	460
29′- 6″	...	...	227	241	468
30′- 0″	...	...	227	248	475
30′- 6″	...	...	227	256	483
31′- 0″	...	...	227	263	490
31′- 6″	...	...	227	271	498
32′- 0″	...	...	227	279	506
32′- 6″	...	...	227	286	513
33′- 0″	...	...	227	294	521
33′- 6″	...	...	227	301	528
34′- 0″	...	...	227	309	536
34′- 6″	...	...	227	316	543
35′- 0″	...	...	227	324	551
35′- 6″	...	...	227	331	558
36′- 0″	...	...	227	339	566
36′- 6″	...	...	227	346	573
37′- 0″	...	...	227	354	581
37′- 6″	...	...	227	362	589
38′- 0″	...	...	227	369	596
38′- 6″	...	...	227	377	604
39′- 0″	...	...	227	384	611
39′- 6″	...	...	227	392	619
40′- 0″	...	...	227	399	626
40′- 6″	...	...	227	407	634
41′- 0″	...	...	227	414	641
41′- 6″	...	...	227	422	649
42′- 0″	...	...	227	429	656
42′- 6″	...	...	227	437	664
43′- 0″	...	...	227	444	671
43′- 6″	...	...	227	452	679
44′- 0″	...	...	227	460	687
44′- 6″	...	...	227	467	694
45′- 0″	...	...	227	475	702

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9″ LINING—3″ WEDGE BRICK

9″ x 4½″ x 3″, 9″ x 6¾″ x 3″, or 9″ x 9″ x 3″

This table can be used also for **13½″ x 9″ x 3″ arch brick** by substituting No. 1, 2, and 3 arch brick for the corresponding wedge brick.

Diameter Inside Brickwork	Number Required Per Ring				
	No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	Straight	Total
3′- 0″	57	...	...	...	57
3′- 1″	56	2	...	...	58
3′- 2″	55	4	...	...	59
3′- 3″	54	6	...	...	60
3′- 4″	52	9	...	...	61
3′- 5″	51	11	...	...	62
3′- 6″	50	13	...	...	63
3′- 7″	49	15	...	...	64
3′- 8″	48	17	...	...	65
3′- 9″	47	19	...	...	66
3′-10″	46	21	...	...	67
3′-11″	45	23	...	...	68
4′- 0″	44	26	...	...	70
4′- 1″	43	28	...	...	71
4′- 2″	42	30	...	...	72
4′- 3″	41	32	...	...	73
4′- 4″	40	34	...	...	74
4′- 5″	39	36	...	...	75
4′- 6″	38	38	...	...	76
4′- 7″	37	40	...	...	77
4′- 8″	36	42	...	...	78
4′- 9″	35	44	...	...	79
4′-10″	34	46	...	...	80
4′-11″	33	48	...	...	81
5′- 0″	32	50	...	...	82
5′- 1″	31	52	...	...	83
5′- 2″	29	55	...	...	84
5′- 3″	28	57	...	...	85
5′- 4″	27	59	...	...	86
5′- 5″	26	61	...	...	87
5′- 6″	25	63	...	...	88
5′- 7″	24	65	...	...	89
5′- 8″	23	67	...	...	90
5′- 9″	22	70	...	...	92
5′-10″	21	72	...	...	93
5′-11″	20	74	...	...	94
6′- 0″	19	76	...	...	95
6′- 1″	18	78	...	...	96
6′- 2″	17	80	...	...	97
6′- 3″	16	82	...	...	98
6′- 4″	15	84	...	...	99
6′- 5″	14	86	...	...	100
6′- 6″	13	88	...	...	101
6′- 7″	12	90	...	...	102
6′- 8″	11	92	...	...	103
6′- 9″	10	94	...	...	104
6′-10″	9	96	...	...	105
6′-11″	7	99	...	...	106

Diameter Inside Brickwork	Number Required Per Ring				
	No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	Straight	Total
7′- 0″	6	101	...	...	107
7′- 1″	5	103	...	...	108
7′- 2″	4	105	...	...	109
7′- 3″	3	107	...	...	110
7′- 4″	2	109	...	...	111
7′- 5″	1	111	...	...	112
7′- 6″	...	113	...	...	113
7′- 7″	...	112	3	...	115
7′- 8″	...	111	5	...	116
7′- 9″	...	110	7	...	117
7′-10″	...	109	9	...	118
7′-11″	...	108	11	...	119
8′- 0″	...	107	13	...	120
8′- 1″	...	106	15	...	121
8′- 2″	...	105	17	...	122
8′- 3″	...	104	19	...	123
8′- 4″	...	103	21	...	124
8′- 5″	...	102	23	...	125
8′- 6″	...	101	25	...	126
8′- 7″	...	100	27	...	127
8′- 8″	...	99	29	...	128
8′- 9″	...	97	32	...	129
8′-10″	...	96	34	...	130
8′-11″	...	95	36	...	131
9′- 0″	...	94	38	...	132
9′- 1″	...	93	40	...	133
9′- 2″	...	92	42	...	134
9′- 3″	...	91	44	...	135
9′- 4″	...	90	47	...	137
9′- 5″	...	89	49	...	138
9′- 6″	...	88	51	...	139
9′- 7″	...	87	53	...	140
9′- 8″	...	86	55	...	141
9′- 9″	...	85	57	...	142
9′-10″	...	84	59	...	143
9′-11″	...	83	61	...	144
10′- 0″	...	82	63	...	145
10′- 1″	...	81	65	...	146
10′- 2″	...	80	67	...	147
10′- 3″	...	79	69	...	148
10′- 4″	...	78	71	...	149
10′- 5″	...	77	73	...	150
10′- 6″	...	76	75	...	151
10′- 7″	...	74	78	...	152
10′- 8″	...	73	80	...	153
10′- 9″	...	72	82	...	154
10′-10″	...	71	84	...	155
10′-11″	...	70	86	...	156

9″ LINING—3″ WEDGE BRICK

9″ x 4½″ x 3″, 9″ x 6¾″ x 3″, or 9″ x 9″ x 3″—CONTINUED

This table can be used also for **13½″ x 9″ x 3″ arch brick** by substituting No. 1, 2, and 3 arch brick for the corresponding wedge brick.

Diameter Inside Brickwork	Number Required Per Ring				
	No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	Straight	Total
11′- 0″	...	69	88	...	157
11′- 1″	...	69	90	...	159
11′- 2″	...	67	93	...	160
11′- 3″	...	66	95	...	161
11′- 4″	...	65	97	...	162
11′- 5″	...	64	99	...	163
11′- 6″	...	63	101	...	164
11′- 7″	...	62	103	...	165
11′- 8″	...	61	105	...	166
11′- 9″	...	60	107	...	167
11′-10″	...	59	109	...	168
11′-11″	...	58	111	...	169
12′- 0″	...	57	113	...	170
12′- 1″	...	56	115	...	171
12′- 2″	...	55	117	...	172
12′- 3″	...	54	119	...	173
12′- 4″	...	52	122	...	174
12′- 5″	...	51	124	...	175
12′- 6″	...	50	126	...	176
12′- 7″	...	49	128	...	177
12′- 8″	...	48	130	...	178
12′- 9″	...	47	132	...	179
12′-10″	...	47	134	...	181
12′-11″	...	45	137	...	182
13′- 0″	...	44	139	...	183
13′- 1″	...	43	141	...	184
13′- 2″	...	42	143	...	185
13′- 3″	...	41	145	...	186
13′- 4″	...	40	147	...	187
13′- 5″	...	39	149	...	188
13′- 6″	...	38	151	...	189
13′- 7″	...	37	153	...	190
13′- 8″	...	36	155	...	191
13′- 9″	...	35	157	...	192
13′-10″	...	34	159	...	193
13′-11″	...	33	161	...	194
14′- 0″	...	32	163	...	195
14′- 1″	...	30	166	...	196
14′- 2″	...	29	168	...	197
14′- 3″	...	28	170	...	198
14′- 4″	...	27	172	...	199
14′- 5″	...	26	174	...	200
14′- 6″	...	25	176	...	201
14′- 7″	...	25	178	...	203
14′- 8″	...	23	181	...	204
14′- 9″	...	22	183	...	205
14′-10″	...	21	185	...	206
14′-11″	...	20	187	...	207
15′- 0″	...	19	189	...	208
15′- 1″	...	18	191	...	209
15′- 2″	...	17	193	...	210
15′- 3″	...	16	195	...	211
15′- 4″	...	15	197	...	212
15′- 5″	...	14	199	...	213

Diameter Inside Brickwork	Number Required Per Ring				
	No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	Straight	Total
15′- 6″	...	13	201	...	214
15′- 7″	...	12	203	...	215
15′- 8″	...	11	205	...	216
15′- 9″	...	10	207	...	217
15′-10″	...	8	210	...	218
15′-11″	...	7	212	...	219
16′- 0″	...	6	214	...	220
16′- 1″	...	5	216	...	221
16′- 2″	...	4	218	...	222
16′- 3″	...	3	220	...	223
16′- 4″	...	3	222	...	225
16′- 5″	...	1	225	...	226
16′- 6″	...	...	227	...	227
17′- 0″	...	...	227	6	233
17′- 6″	...	...	227	12	239
18′- 0″	...	...	227	18	245
18′- 6″	...	...	227	25	252
19′- 0″	...	...	227	31	258
19′- 6″	...	...	227	37	264
20′- 0″	...	...	227	44	271
20′- 6″	...	...	227	50	277
21′- 0″	...	...	227	56	283
21′- 6″	...	...	227	62	289
22′- 0″	...	...	227	69	296
22′- 6″	...	...	227	75	302
23′- 0″	...	...	227	81	308
23′- 6″	...	...	227	88	315
24′- 0″	...	...	227	94	321
24′- 6″	...	...	227	100	327
25′- 0″	...	...	227	106	333
25′- 6″	...	...	227	113	340
26′- 0″	...	...	227	119	346
26′- 6″	...	...	227	125	352
27′- 0″	...	...	227	132	359
27′- 6″	...	...	227	138	365
28′- 0″	...	...	227	144	371
28′- 6″	...	...	227	150	377
29′- 0″	...	...	227	157	384
29′- 6″	...	...	227	163	390
30′- 0″	...	...	227	169	396
30′- 6″	...	...	227	176	403
31′- 0″	...	...	227	182	409
31′- 6″	...	...	227	188	415
32′- 0″	...	...	227	194	421
32′- 6″	...	...	227	201	428
33′- 0″	...	...	227	207	434
33′- 6″	...	...	227	213	440
34′- 0″	...	...	227	220	447
34′- 6″	...	...	227	226	453
35′- 0″	...	...	227	232	459
35′- 6″	...	...	227	238	465
36′- 0″	...	...	227	245	472
36′- 6″	...	...	227	251	478

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9″ LINING—2½″ or 3″ KEY BRICK

9″ x 4½″ x 2½″ or 9″ x 4½″ x 3″

Diameter Inside Brickwork	Number Required Per Ring					
	No. 4 Key	No. 3 Key	No. 2 Key	No. 1 Key	Straight	Total
1′- 6″	26	...	...	...	...	26
1′- 8″	23	4	...	...	...	27
1′-10″	20	8	...	...	...	28
2′- 0″	17	13	...	...	...	30
2′- 2″	14	17	...	...	...	31
2′- 4″	12	21	...	...	...	33
2′- 6″	9	25	...	...	...	34
2′- 8″	6	29	...	...	...	35
2′-10″	3	34	...	...	...	37
3′- 0″	...	38	...	...	...	38
3′- 2″	...	35	4	...	...	39
3′- 4″	...	32	9	...	...	41
3′- 6″	...	29	13	...	...	42
3′- 8″	...	27	17	...	...	44
3′-10″	...	24	21	...	...	45
4′- 0″	...	21	25	...	...	46
4′- 2″	...	18	30	...	...	48
4′- 4″	...	15	34	...	...	49
4′- 6″	...	13	38	...	...	51
4′- 8″	...	10	42	...	...	52
4′-10″	...	7	46	...	...	53
5′- 0″	...	4	51	...	...	55
5′- 2″	...	1	55	...	...	56
5′- 3″	...	...	57	...	...	57
5′- 4″	...	...	56	2	...	58
5′- 6″	...	...	55	4	...	59
5′- 8″	...	...	53	7	...	60
5′-10″	...	...	52	10	...	62
6′- 0″	...	...	50	13	...	63
6′- 2″	...	...	49	16	...	65
6′- 4″	...	...	48	18	...	66
6′- 6″	...	...	46	21	...	67
6′- 8″	...	...	45	24	...	69
6′-10″	...	...	43	27	...	70
7′- 0″	...	...	42	30	...	72
7′- 2″	...	...	41	32	...	73
7′- 4″	...	...	39	35	...	74
7′- 6″	...	...	38	38	...	76
7′- 8″	...	...	36	41	...	77
7′-10″	...	...	35	44	...	79
8′- 0″	...	...	34	46	...	80
8′- 2″	...	...	32	49	...	81
8′- 4″	...	...	31	52	...	83
8′- 6″	...	...	29	55	...	84
8′- 8″	...	...	28	58	...	86
8′-10″	...	...	27	60	...	87
9′- 0″	...	...	25	63	...	88
9′- 2″	...	...	24	66	...	90
9′- 4″	...	...	22	69	...	91
9′- 6″	...	...	21	72	...	93
9′- 8″	...	...	20	74	...	94
9′-10″	...	...	18	77	...	95
10′- 0″	...	...	17	80	...	97
10′- 2″	...	...	15	83	...	98
10′- 4″	...	...	14	86	...	100

Diameter Inside Brickwork	Number Required Per Ring					
	No. 4 Key	No. 3 Key	No. 2 Key	No. 1 Key	Straight	Total
10′- 6″	...	...	13	88	...	101
10′- 8″	...	...	11	91	...	102
10′-10″	...	...	10	94	...	104
11′- 0″	...	...	9	96	...	105
11′- 2″	...	...	7	100	...	107
11′- 4″	...	...	6	102	...	108
11′- 6″	...	...	4	105	...	109
11′- 8″	...	...	3	108	...	111
11′-10″	...	...	2	110	...	112
12′- 0″	...	...	...	113	...	113
12′- 6″	...	...	...	113	5	118
13′- 0″	...	...	...	113	9	122
13′- 6″	...	...	...	113	13	126
14′- 0″	...	...	...	113	17	130
14′- 6″	...	...	...	113	21	134
15′- 0″	...	...	...	113	26	139
15′- 6″	...	...	...	113	30	143
16′- 0″	...	...	...	113	34	147
16′- 6″	...	...	...	113	38	151
17′- 0″	...	...	...	113	42	155
17′- 6″	...	...	...	113	47	160
18′- 0″	...	...	...	113	51	164
18′- 6″	...	...	...	113	55	168
19′- 0″	...	...	...	113	59	172
19′- 6″	...	...	...	113	63	176
20′- 0″	...	...	...	113	68	181
20′- 6″	...	...	...	113	72	185
21′- 0″	...	...	...	113	76	189
21′- 6″	...	...	...	113	80	193
22′- 0″	...	...	...	113	84	197
22′- 6″	...	...	...	113	88	201
23′- 0″	...	...	...	113	93	206
23′- 6″	...	...	...	113	97	210
24′- 0″	...	...	...	113	101	214
24′- 6″	...	...	...	113	105	218
25′- 0″	...	...	...	113	109	222
25′- 6″	...	...	...	113	114	227
26′- 0″	...	...	...	113	118	231
26′- 6″	...	...	...	113	122	235
27′- 0″	...	...	...	113	126	239
27′- 6″	...	...	...	113	130	243
28′- 0″	...	...	...	113	135	248
28′- 6″	...	...	...	113	139	252
29′- 0″	...	...	...	113	143	256
29′- 6″	...	...	...	113	147	260
30′- 0″	...	...	...	113	151	264
30′- 6″	...	...	...	113	155	268
31′- 0″	...	...	...	113	160	273
31′- 6″	...	...	...	113	164	277
32′- 0″	...	...	...	113	168	281
32′- 6″	...	...	...	113	172	285
33′- 0″	...	...	...	113	176	289
33′- 6″	...	...	...	113	181	294
34′- 0″	...	...	...	113	185	298
35′- 0″	...	...	...	113	193	306

9″ LINING—2½″ or 3″ KEY BRICK

9″ x 6″ x 2½″ or 9″ x 6″ x 3″

Diameter Inside Brickwork*	Number Required Per Ring				
	No. 3 Key	No. 2 Key	No. 1 Key	Straight	Total
1′- 6″	19	...	...	...	19
1′- 8″	18	2	...	...	20
1′-10″	18	3	...	...	21
2′- 0″	17	5	...	...	22
2′- 2″	16	7	...	...	23
2′- 4″	15	9	...	...	24
2′- 6″	15	11	...	...	26
2′- 8″	14	13	...	...	27
2′-10″	14	14	...	...	28
3′- 0″	13	16	...	...	29
3′- 2″	12	18	...	...	30
3′- 4″	12	19	...	...	31
3′- 6″	11	21	...	...	32
3′- 8″	10	23	...	...	33
3′-10″	9	25	...	...	34
4′- 0″	9	26	...	...	35
4′- 2″	8	28	...	...	36
4′- 4″	7	30	...	...	37
4′- 6″	7	31	...	...	38
4′- 8″	6	33	...	...	39
4′-10″	5	35	...	...	40
5′- 0″	5	36	...	...	41
5′- 2″	4	38	...	...	42
5′- 4″	3	40	...	...	43
5′- 6″	2	42	...	...	44
5′- 8″	2	43	...	...	45
5′-10″	1	45	...	...	46
6′- 0″	...	48	...	...	48
6′- 2″	...	47	2	...	49
6′- 4″	...	46	4	...	50
6′- 6″	...	45	6	...	51
6′- 8″	...	44	8	...	52
6′-10″	...	43	10	...	53
7′- 0″	...	41	13	...	54
7′- 2″	...	40	15	...	55
7′- 4″	...	39	17	...	56
7′- 6″	...	38	19	...	57
7′- 8″	...	37	21	...	58
7′-10″	...	36	23	...	59
8′- 0″	...	34	26	...	60
8′- 2″	...	33	28	...	61
8′- 4″	...	32	30	...	62
8′- 6″	...	31	32	...	63
8′- 8″	...	30	34	...	64
8′-10″	...	28	37	...	65
9′- 0″	...	27	39	...	66
9′- 2″	...	26	41	...	67
9′- 4″	...	25	43	...	68
9′- 6″	...	24	46	...	70
9′- 8″	...	23	48	...	71
9′-10″	...	22	50	...	72

Diameter Inside Brickwork	Number Required Per Ring				
	No. 3 Key	No. 2 Key	No. 1 Key	Straight	Total
10′- 0″	...	21	52	...	73
10′- 2″	...	19	55	...	74
10′- 4″	...	18	57	...	75
10′- 6″	...	17	59	...	76
10′- 8″	...	16	61	...	77
10′-10″	...	15	63	...	78
11′- 0″	...	13	66	...	79
11′- 2″	...	12	68	...	80
11′- 4″	...	11	70	...	81
11′- 6″	...	10	72	...	82
11′- 8″	...	9	74	...	83
11′-10″	...	8	76	...	84
12′- 0″	...	6	79	...	85
12′- 2″	...	5	81	...	86
12′- 4″	...	4	83	...	87
12′- 6″	...	3	85	...	88
12′- 8″	...	2	87	...	89
12′-10″	...	...	90	...	90
13′- 0″	...	...	91	...	91
13′- 6″	...	...	91	4	95
14′- 0″	...	...	91	7	98
14′- 6″	...	...	91	10	101
15′- 0″	...	...	91	13	104
15′- 6″	...	...	91	16	107
16′- 0″	...	...	91	19	110
16′- 6″	...	...	91	22	113
17′- 0″	...	...	91	26	117
17′- 6″	...	...	91	29	120
18′- 0″	...	...	91	32	123
18′- 6″	...	...	91	35	126
19′- 0″	...	...	91	38	129
20′- 0″	...	...	91	44	135
21′- 0″	...	...	91	51	142
22′- 0″	...	...	91	57	148
23′- 0″	...	...	91	63	154
24′- 0″	...	...	91	70	161
25′- 0″	...	...	91	76	167
26′- 0″	...	...	91	82	173
27′- 0″	...	...	91	88	179
28′- 0″	...	...	91	95	186
29′- 0″	...	...	91	101	192
30′- 0″	...	...	91	107	198
31′- 0″	...	...	91	114	205
32′- 0″	...	...	91	120	211
33′- 0″	...	...	91	126	217
34′- 0″	...	...	91	132	223
35′- 0″	...	...	91	139	230
36′- 0″	...	...	91	145	236
37′- 0″	...	...	91	151	242
38′- 0″	...	...	91	158	249
39′- 0″	...	...	91	164	255
40′- 0″	...	...	91	170	261
41′- 0″	...	...	91	176	267

*NOTE: For brickwork of inside diameters less than 6 feet, involving the use of 9 x 6-inch No. 3 Keys which have a very sharp taper, a better bricklaying fit can be obtained by the use of the 9 x 4½-inch Key-brick combinations shown on page 546.

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9″ LINING—ROTARY KILN BLOCKS*

9″ x 9″ x 4″

Diameter Inside Brickwork	Number Required Per Ring		
	48-66	54-72	Total
4′- 0″	23	..	23
4′- 1″	20	4	24
4′- 2″	15	9	24
4′- 3″	11	13	24
4′- 4″	8	17	25
4′- 5″	4	21	25
	54-72	60-78	
4′- 6″	26	..	26
4′- 7″	21	5	26
4′- 8″	17	9	26
4′- 9″	13	14	27
4′-10″	9	18	27
4′-11″	4	23	27
	60-78	66-84	
5′- 0″	28	..	28
5′- 1″	23	5	28
5′- 2″	18	10	28
5′- 3″	14	15	29
5′- 4″	9	20	29
5′- 5″	5	24	29
	66-84	72-90	
5′- 6″	30	..	30
5′- 7″	25	5	30
5′- 8″	20	10	30
5′- 9″	15	16	31
5′-10″	10	21	31
5′-11″	5	26	31
	72-90	78-96	
6′- 0″	32	..	32
6′- 1″	26	6	32
6′- 2″	21	12	33
6′- 3″	16	17	33
6′- 4″	11	22	33
6′- 5″	6	28	34
	78-96	84-102	
6′- 6″	34	..	34
6′- 7″	28	6	34
6′- 8″	23	12	35
6′- 9″	17	18	35
6′-10″	11	24	35
6′-11″	6	30	36

Diameter Inside Brickwork	Number Required Per Ring		
	84-102	90-108	Total
7′- 0″	36	..	36
7′- 1″	30	6	36
7′- 2″	24	13	37
7′- 3″	18	19	37
7′- 4″	12	25	37
7′- 5″	6	32	38
	90-108	96-114	
7′- 6″	38	..	38
7′- 7″	31	7	38
7′- 8″	25	14	39
7′- 9″	19	20	39
7′-10″	13	26	39
7′-11″	7	33	40
	96-114	102-120	
8′- 0″	40	..	40
8′- 1″	34	7	41
8′- 2″	27	14	41
8′- 3″	20	21	41
8′- 4″	14	28	42
8′- 5″	7	35	42
	102-120	108-126	
8′- 6″	42	..	42
8′- 7″	35	8	43
8′- 8″	28	15	43
8′- 9″	21	22	43
8′-10″	14	30	44
8′-11″	7	37	44
	108-126	114-132	
9′- 0″	44	..	44
9′- 1″	37	8	45
9′- 2″	29	16	45
9′- 3″	22	23	45
9′- 4″	15	31	46
9′- 5″	7	39	46
	114-132	117-135	
9′- 6″	46	..	46
9′- 7″	31	16	47
9′- 8″	15	32	47
	117-135	120-138	
9′- 9″	48	..	48
9′-10″	32	16	48
9′-11″	16	32	48

Diameter Inside Brickwork	Number Required Per Ring		
	120-138	123-141	Total
10′- 0″	49	..	49
10′- 1″	32	17	49
10′- 2″	16	33	49
	123-141	126-144	
10′- 3″	50	..	50
10′- 4″	33	17	50
10′- 5″	16	34	50
	126-144	132-150	
10′- 6″	51	..	51
10′- 7″	42	9	51
10′- 8″	34	17	51
10′- 9″	25	27	52
10′-10″	17	35	52
10′-11″	8	44	52
	132-150	138-156	
11′- 0″	53	..	53
11′- 1″	44	9	53
11′- 2″	35	18	53
11′- 3″	26	28	54
11′- 4″	18	36	54
11′- 5″	9	46	55
	138-156	144-162	
11′- 6″	55	..	55
11′- 7″	45	10	55
11′- 8″	37	19	56
11′- 9″	27	29	56
11′-10″	18	38	56
11′-11″	9	48	57
	144-162	150-168	
12′- 0″	57	..	57
12′- 1″	47	10	57
12′- 2″	38	20	58
12′- 3″	28	30	58
12′- 4″	19	39	58
12′- 5″	10	49	59
	150-168	156-174	
12′- 6″	59	..	59
12′- 7″	49	10	59
12′- 8″	39	21	60
12′- 9″	29	31	60
12′-10″	20	40	60
12′-11″	10	51	61
	156-174	162-180	
13′- 0″	61	..	61
13′- 1″	51	10	61
13′- 2″	41	21	62
13′- 3″	30	32	62
13′- 4″	21	42	63
13′- 5″	10	53	63
13′- 6″	..	63	63

* NOTE: In orders, the complete names of the blocks desired should be given, as for example "48-66 RKB."

12″ LINING—3″ WEDGE BRICK

12″ x 4½″ x 3″, 12″ x 6″ x 3″, or 12″ x 9″ x 3″

Diameter Inside Brickwork	Number Required Per Ring					
	No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Straight	Total
4′- 0″	76	...	...	...	...	76
4′- 3″	72	7	...	...	...	79
4′- 6″	69	13	...	...	...	82
4′- 9″	66	19	...	...	...	85
5′- 0″	63	25	...	...	...	88
5′- 3″	60	32	...	...	...	92
5′- 6″	57	38	...	...	...	95
5′- 9″	54	44	...	...	...	98
6′- 0″	51	50	...	...	...	101
6′- 3″	47	57	...	...	...	104
6′- 6″	44	63	...	...	...	107
6′- 9″	41	69	...	...	...	110
7′- 0″	38	75	...	...	...	113
7′- 3″	35	82	...	...	...	117
7′- 6″	32	88	...	...	...	120
7′- 9″	29	94	...	...	...	123
8′- 0″	25	101	...	...	...	126
8′- 3″	22	107	...	...	...	129
8′- 6″	19	113	...	...	...	132
8′- 9″	16	119	...	...	...	135
9′- 0″	13	126	...	...	...	139
9′- 3″	10	132	...	...	...	142
9′- 6″	7	138	...	...	...	145
9′- 9″	3	145	...	...	...	148
10′- 0″	...	151	...	...	...	151
10′- 3″	...	148	6	...	...	154
10′- 6″	...	144	13	...	...	157
10′- 9″	...	142	19	...	...	161
11′- 0″	...	139	25	...	...	164
11′- 3″	...	135	32	...	...	167
11′- 6″	...	132	38	...	...	170
11′- 9″	...	129	44	...	...	173
12′- 0″	...	126	50	...	...	176
12′- 3″	...	122	57	...	...	179
12′- 6″	...	120	63	...	...	183
12′- 9″	...	117	69	...	...	186
13′- 0″	...	113	76	...	...	189
13′- 3″	...	110	82	...	...	192
13′- 6″	...	107	88	...	...	195
13′- 9″	...	104	94	...	...	198
14′- 0″	...	101	100	...	...	201
14′- 3″	...	98	107	...	...	205
14′- 6″	...	95	113	...	...	208
14′- 9″	...	91	120	...	...	211
15′- 0″	...	88	126	...	...	214
15′- 3″	...	85	132	...	...	217
15′- 6″	...	82	138	...	...	220
15′- 9″	...	79	144	...	...	223

Diameter Inside Brickwork	Number Required Per Ring					
	No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Straight	Total
16′- 0″	...	76	151	...	...	227
16′- 3″	...	73	157	...	...	230
16′- 6″	...	69	164	...	...	233
16′- 9″	...	66	170	...	...	236
17′- 0″	...	63	176	...	...	239
17′- 3″	...	60	182	...	...	242
17′- 6″	...	57	188	...	...	245
17′- 9″	...	54	195	...	...	249
18′- 0″	...	51	201	...	...	252
18′- 3″	...	47	208	...	...	255
18′- 6″	...	44	214	...	...	258
18′- 9″	...	41	220	...	...	261
19′- 0″	...	38	226	...	...	264
19′- 3″	...	35	232	...	...	267
19′- 6″	...	32	239	...	...	271
19′- 9″	...	29	245	...	...	274
20′- 0″	...	25	252	...	...	277
20′- 3″	...	22	258	...	...	280
20′- 6″	...	19	264	...	...	283
20′- 9″	...	16	270	...	...	286
21′- 0″	...	13	276	...	...	289
21′- 3″	...	10	283	...	...	293
21′- 6″	...	7	289	...	...	296
21′- 9″	...	3	296	...	...	299
22′- 0″	...	...	302	...	...	302
22′- 3″	...	...	299	6	...	305
22′- 6″	...	...	295	13	...	308
22′- 9″	...	...	292	19	...	311
23′- 0″	...	...	289	26	...	315
23′- 3″	...	...	286	32	...	318
23′- 6″	...	...	283	38	...	321
23′- 9″	...	...	280	44	...	324
24′- 0″	...	...	277	50	...	327
24′- 3″	...	...	273	57	...	330
24′- 6″	...	...	270	63	...	333
24′- 9″	...	...	267	70	...	337
25′- 0″	...	...	264	76	...	340
25′- 3″	...	...	261	82	...	343
25′- 6″	...	...	258	88	...	346
25′- 9″	...	...	255	94	...	349
26′- 0″	...	...	251	101	...	352
26′- 3″	...	...	248	107	...	355
26′- 6″	...	...	245	114	...	359
26′- 9″	...	...	242	120	...	362
27′- 0″	...	...	239	126	...	365
27′- 3″	...	...	236	132	...	368
27′- 6″	...	...	233	138	...	371
27′- 9″	...	...	229	145	...	374

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12″ LINING—3″ WEDGE BRICK

12″ x 4½″ x 3″, 12″ x 6″ x 3″, or 12″ x 9″ x 3″—CONTINUED

Diameter Inside Brickwork	Number Required Per Ring					
	No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Straight	Total
28′- 0″	...	...	226	151	...	377
28′- 3″	...	...	223	158	...	381
28′- 6″	...	...	220	164	...	384
28′- 9″	...	...	217	170	...	387
29′- 0″	...	...	214	176	...	390
29′- 3″	...	...	211	182	...	393
29′- 6″	...	...	207	189	...	396
29′- 9″	...	...	204	195	...	399
30′- 0″	...	...	202	201	...	403
30′- 3″	...	...	198	208	...	406
30′- 6″	...	...	195	214	...	409
30′- 9″	...	...	192	220	...	412
31′- 0″	...	...	189	226	...	415
31′- 3″	...	...	185	233	...	418
31′- 6″	...	...	182	239	...	421
31′- 9″	...	...	180	245	...	425
32′- 0″	...	...	176	252	...	428
32′- 3″	...	...	173	258	...	431
32′- 6″	...	...	170	264	...	434
32′- 9″	...	...	167	270	...	437
33′- 0″	...	...	163	277	...	440
33′- 3″	...	...	160	283	...	443
33′- 6″	...	...	158	289	...	447
33′- 9″	...	...	154	296	...	450
34′- 0″	...	...	151	302	...	453
34′- 3″	...	...	148	308	...	456
34′- 6″	...	...	145	314	...	459
34′- 9″	...	...	141	321	...	462
35′- 0″	...	...	138	327	...	465
35′- 3″	...	...	135	333	...	468
35′- 6″	...	...	132	340	...	472
35′- 9″	...	...	129	346	...	475
36′- 0″	...	...	126	352	...	478
36′- 3″	...	...	123	358	...	481
36′- 6″	...	...	119	365	...	484
36′- 9″	...	...	116	371	...	487
37′- 0″	...	...	113	377	...	490
37′- 3″	...	...	110	384	...	494
37′- 6″	...	...	107	390	...	497
37′- 9″	...	...	104	396	...	500
38′- 0″	...	...	101	402	...	503
38′- 3″	...	...	97	409	...	506
38′- 6″	...	...	94	415	...	509
38′- 9″	...	...	91	421	...	512
39′- 0″	...	...	88	428	...	516
39′- 3″	...	...	85	434	...	519
39′- 6″	...	...	82	440	...	522
39′- 9″	...	...	79	446	...	525

Diameter Inside Brickwork	Number Required Per Ring					
	No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Straight	Total
40′- 0″	...	...	76	452	...	528
40′- 3″	...	...	72	459	...	531
40′- 6″	...	...	69	465	...	534
40′- 9″	...	...	66	472	...	538
41′- 0″	...	...	63	478	...	541
41′- 3″	...	...	60	484	...	544
41′- 6″	...	...	57	490	...	547
41′- 9″	...	...	54	496	...	550
42′- 0″	...	...	50	503	...	553
42′- 3″	...	...	47	509	...	556
42′- 6″	...	...	44	516	...	560
42′- 9″	...	...	41	522	...	563
43′- 0″	...	...	38	528	...	566
43′- 3″	...	...	35	534	...	569
43′- 6″	...	...	32	540	...	572
43′- 9″	...	...	28	547	...	575
44′- 0″	...	...	25	553	...	578
44′- 3″	...	...	22	560	...	582
44′- 6″	...	...	19	566	...	585
44′- 9″	...	...	16	572	...	588
45′- 0″	...	...	13	578	...	591
45′- 3″	...	...	10	584	...	594
45′- 6″	...	...	6	591	...	597
45′- 9″	...	...	3	597	...	600
46′- 0″	...	...	...	604	...	604
46′- 3″	...	...	...	604	3	607
46′- 6″	...	...	...	604	6	610
46′- 9″	...	...	...	604	9	613
47′- 0″	...	...	...	604	12	616
47′- 3″	...	...	...	604	15	619
47′- 6″	...	...	...	604	18	622
47′- 9″	...	...	...	604	22	626
48′- 0″	...	...	...	604	25	629
48′- 3″	...	...	...	604	28	632
48′- 6″	...	...	...	604	31	635
48′- 9″	...	...	...	604	34	638
49′- 0″	...	...	...	604	37	641
49′- 6″	...	...	...	604	44	648
50′- 0″	...	...	...	604	50	654
50′- 6″	...	...	...	604	56	660
51′- 0″	...	...	...	604	62	666
51′- 6″	...	...	...	604	69	673
52′- 0″	...	...	...	604	75	679
52′- 6″	...	...	...	604	81	685
53′- 0″	...	...	...	604	88	692
53′- 6″	...	...	...	604	94	698
54′- 0″	...	...	...	604	100	704
54′- 6″	...	...	...	604	106	710

12″ LINING—3″ KEY BRICK

12″ x 6″ x 3″

Diameter Inside Brickwork	Number Required Per Ring			
	No. 2 Key	No. 1 Key	Straight	Total
10′- 0″	76	...	...	76
10′- 2″	75	2	...	77
10′- 4″	74	4	...	78
10′- 6″	72	7	...	79
10′- 8″	71	9	...	80
10′-10″	70	11	...	81
11′- 0″	69	13	...	82
11′- 2″	68	15	...	83
11′- 4″	67	17	...	84
11′- 6″	66	19	...	85
11′- 8″	65	21	...	86
11′-10″	64	23	...	87
12′- 0″	63	25	...	88
12′- 2″	62	27	...	89
12′- 4″	61	29	...	90
12′- 6″	60	32	...	92
12′- 8″	59	34	...	93
12′-10″	58	36	...	94
13′- 0″	57	38	...	95
13′- 2″	56	40	...	96
13′- 4″	55	42	...	97
13′- 6″	54	44	...	98
13′- 8″	53	46	...	99
13′-10″	52	48	...	100
14′- 0″	51	50	...	101
14′- 2″	49	53	...	102
14′- 4″	48	55	...	103
14′- 6″	47	57	...	104
14′- 8″	46	59	...	105
14′-10″	45	61	...	106
15′- 0″	44	63	...	107
15′- 2″	43	65	...	108
15′- 4″	42	67	...	109
15′- 6″	41	69	...	110
15′- 8″	40	71	...	111
15′-10″	39	73	...	112
16′- 0″	38	75	...	113
16′- 2″	37	78	...	115
16′- 4″	36	80	...	116
16′- 6″	35	82	...	117
16′- 8″	34	84	...	118
16′-10″	33	86	...	119
17′- 0″	32	88	...	120
17′- 2″	31	90	...	121
17′- 4″	30	92	...	122
17′- 6″	29	94	...	123
17′- 8″	27	97	...	124
17′-10″	26	99	...	125
18′- 0″	25	101	...	126
18′- 2″	24	103	...	127
18′- 4″	23	105	...	128
18′- 6″	22	107	...	129
18′- 8″	21	109	...	130
18′-10″	20	111	...	131

Diameter Inside Brickwork	Number Required Per Ring			
	No. 2 Key	No. 1 Key	Straight	Total
19′- 0″	19	113	...	132
19′- 2″	18	115	...	133
19′- 4″	17	117	...	134
19′- 6″	16	119	...	135
19′- 8″	15	122	...	137
19′-10″	14	124	...	138
20′- 0″	13	126	...	139
20′- 2″	12	128	...	140
20′- 4″	11	130	...	141
20′- 6″	10	132	...	142
20′- 8″	9	134	...	143
20′-10″	8	136	...	144
21′- 0″	7	138	...	145
21′- 2″	5	141	...	146
21′- 4″	4	143	...	147
21′- 6″	3	145	...	148
21′- 8″	2	147	...	149
21′-10″	1	149	...	150
22′- 0″	...	151	...	151
22′- 2″	...	151	1	152
22′- 4″	...	151	2	153
22′- 6″	...	151	3	154
23′- 0″	...	151	6	157
23′- 6″	...	151	10	161
24′- 0″	...	151	13	164
24′- 6″	...	151	16	167
25′- 0″	...	151	19	170
25′- 6″	...	151	22	173
26′- 0″	...	151	25	176
26′- 6″	...	151	28	179
27′- 0″	...	151	32	183
27′- 6″	...	151	35	186
28′- 0″	...	151	38	189
28′- 6″	...	151	41	192
29′- 0″	...	151	44	195
29′- 6″	...	151	47	198
30′- 0″	...	151	50	201
30′- 6″	...	151	54	205
31′- 0″	...	151	57	208
31′- 6″	...	151	60	211
32′- 0″	...	151	63	214
32′- 6″	...	151	66	217
33′- 0″	...	151	69	220
33′- 6″	...	151	72	223
34′- 0″	...	151	76	227
34′- 6″	...	151	79	230
35′- 0″	...	151	82	233
35′- 6″	...	151	85	236
36′- 0″	...	151	88	239
36′- 6″	...	151	91	242
37′- 0″	...	151	94	245
37′- 6″	...	151	98	249
38′- 0″	...	151	101	252
38′- 6″	...	151	104	255

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13½″ LINING—3″ WEDGE BRICK

13½″ x 4½″ x 3″, 13½″ x 6″ x 3″, or 13½″ x 9″ x 3″

Diameter Inside Brickwork	Number Required Per Ring					
	No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Straight	Total
4′- 6″	85	...	...	...	...	85
4′- 9″	82	6	...	...	...	88
5′- 0″	79	13	...	...	...	92
5′- 3″	76	19	...	...	...	95
5′- 6″	73	25	...	...	...	98
5′- 9″	69	32	...	...	...	101
6′- 0″	66	38	...	...	...	104
6′- 3″	63	44	...	...	...	107
6′- 6″	60	50	...	...	...	110
6′- 9″	57	56	...	...	...	113
7′- 0″	54	63	...	...	...	117
7′- 3″	51	69	...	...	...	120
7′- 6″	47	76	...	...	...	123
7′- 9″	44	82	...	...	...	126
8′- 0″	41	88	...	...	...	129
8′- 3″	38	94	...	...	...	132
8′- 6″	35	100	...	...	...	135
8′- 9″	32	107	...	...	...	139
9′- 0″	29	113	...	...	...	142
9′- 3″	25	120	...	...	...	145
9′- 6″	22	126	...	...	...	148
9′- 9″	19	132	...	...	...	151
10′- 0″	16	138	...	...	...	154
10′- 3″	13	144	...	...	...	157
10′- 6″	10	151	...	...	...	161
10′- 9″	7	157	...	...	...	164
11′- 0″	3	164	...	...	...	167
11′- 3″	...	170	...	...	...	170
11′- 6″	...	167	6	...	...	173
11′- 9″	...	163	13	...	...	176
12′- 0″	...	160	19	...	...	179
12′- 3″	...	157	26	...	...	183
12′- 6″	...	154	32	...	...	186
12′- 9″	...	151	38	...	...	189
13′- 0″	...	148	44	...	...	192
13′- 3″	...	145	50	...	...	195
13′- 6″	...	141	57	...	...	198
13′- 9″	...	138	63	...	...	201
14′- 0″	...	135	70	...	...	205
14′- 3″	...	132	76	...	...	208
14′- 6″	...	129	82	...	...	211
14′- 9″	...	126	88	...	...	214
15′- 0″	...	123	94	...	...	217
15′- 3″	...	119	101	...	...	220
15′- 6″	...	116	107	...	...	223
15′- 9″	...	113	114	...	...	227
16′- 0″	...	110	120	...	...	230
16′- 3″	...	107	126	...	...	233
16′- 6″	...	104	132	...	...	236
16′- 9″	...	101	138	...	...	239
17′- 0″	...	97	145	...	...	242
17′- 3″	...	94	151	...	...	245
17′- 6″	...	92	157	...	...	249
17′- 9″	...	88	164	...	...	252
18′- 0″	...	85	170	...	...	255
18′- 3″	...	82	176	...	...	258
18′- 6″	...	79	182	...	...	261
18′- 9″	...	75	189	...	...	264
19′- 0″	...	72	195	...	...	267
19′- 3″	...	70	201	...	...	271
19′- 6″	...	66	208	...	...	274
19′- 9″	...	63	214	...	...	277
20′- 0″	...	60	220	...	...	280
20′- 3″	...	57	226	...	...	283
20′- 6″	...	53	233	...	...	286
20′- 9″	...	50	239	...	...	289
21′- 0″	...	48	245	...	...	293
21′- 3″	...	44	252	...	...	296
21′- 6″	...	41	258	...	...	299
21′- 9″	...	38	264	...	...	302
22′- 0″	...	35	270	...	...	305
22′- 3″	...	31	277	...	...	308
22′- 6″	...	28	283	...	...	311
22′- 9″	...	26	289	...	...	315
23′- 0″	...	22	296	...	...	318
23′- 3″	...	19	302	...	...	321
23′- 6″	...	16	308	...	...	324
23′- 9″	...	13	314	...	...	327
24′- 0″	...	9	321	...	...	330
24′- 3″	...	6	327	...	...	333
24′- 6″	...	4	333	...	...	337
24′- 9″	...	...	340	...	...	340
25′- 0″	...	...	336	7	...	343
25′- 3″	...	...	333	13	...	346
25′- 6″	...	...	330	19	...	349
25′- 9″	...	...	327	25	...	352
26′- 0″	...	...	324	31	...	355
26′- 3″	...	...	321	38	...	359
26′- 6″	...	...	318	44	...	362
26′- 9″	...	...	314	51	...	365
27′- 0″	...	...	311	57	...	368
27′- 3″	...	...	308	63	...	371
27′- 6″	...	...	305	69	...	374
27′- 9″	...	...	302	75	...	377

13½″ LINING—3″ WEDGE BRICK

13½″ x 4½″ x 3″, 13½″ x 6″ x 3″, or 13½″ x 9″ x 3″—CONTINUED

Diameter Inside Brickwork	Number Required Per Ring					
	No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Straight	Total
28′- 0″	...	...	299	82	...	381
28′- 3″	...	...	296	88	...	384
28′- 6″	...	...	292	95	...	387
28′- 9″	...	...	289	101	...	390
29′- 0″	...	...	286	107	...	393
29′- 3″	...	...	283	113	...	396
29′- 6″	...	...	280	119	...	399
29′- 9″	...	...	277	126	...	403
30′- 0″	...	...	274	132	...	406
30′- 3″	...	...	270	139	...	409
30′- 6″	...	...	267	145	...	412
30′- 9″	...	...	264	151	...	415
31′- 0″	...	...	261	157	...	418
31′- 3″	...	...	258	163	...	421
31′- 6″	...	...	255	170	...	425
31′- 9″	...	...	252	176	...	428
32′- 0″	...	...	248	183	...	431
32′- 3″	...	...	245	189	...	434
32′- 6″	...	...	242	195	...	437
32′- 9″	...	...	239	201	...	440
33′- 0″	...	...	236	207	...	443
33′- 3″	...	...	233	214	...	447
33′- 6″	...	...	230	220	...	450
33′- 9″	...	...	227	226	...	453
34′- 0″	...	...	223	233	...	456
34′- 3″	...	...	220	239	...	459
34′- 6″	...	...	217	245	...	462
34′- 9″	...	...	214	251	...	465
35′- 0″	...	...	210	258	...	468
35′- 3″	...	...	208	264	...	472
35′- 6″	...	...	205	270	...	475
35′- 9″	...	...	201	277	...	478
36′- 0″	...	...	198	283	...	481
36′- 3″	...	...	195	289	...	484
36′- 6″	...	...	192	295	...	487
36′- 9″	...	...	188	302	...	490
37′- 0″	...	...	186	308	...	494
37′- 3″	...	...	183	314	...	497
37′- 6″	...	...	179	321	...	500
37′- 9″	...	...	176	327	...	503
38′- 0″	...	...	173	333	...	505
38′- 3″	...	...	170	339	...	509
38′- 6″	...	...	166	346	...	512
38′- 9″	...	...	164	352	...	516
39′- 0″	...	...	161	358	...	519
39′- 3″	...	...	157	365	...	522
39′- 6″	...	...	154	371	...	525
39′- 9″	...	...	151	377	...	528
40′- 0″	...	...	148	383	...	531
40′- 3″	...	...	144	390	...	534
40′- 6″	...	...	142	396	...	538
40′- 9″	...	...	139	402	...	541
41′- 0″	...	...	135	409	...	544
41′- 3″	...	...	132	415	...	547
41′- 6″	...	...	129	421	...	550
41′- 9″	...	...	126	427	...	553
42′- 0″	...	...	122	434	...	556
42′- 3″	..	...	120	440	...	560
42′- 6″	...	...	117	446	...	563
42′- 9″	...	...	113	453	...	566
43′- 0″	...	...	110	459	...	569
43′- 3″	...	...	107	465	...	572
43′- 6″	...	...	104	471	...	575
43′- 9″	...	...	101	477	...	578
44′- 0″	...	...	98	484	...	582
44′- 3″	...	...	95	490	...	585
44′- 6″	...	...	91	497	...	588
44′- 9″	...	...	88	503	...	591
45′- 0″	...	...	85	509	...	594
45′- 3″	...	...	82	515	...	597
45′- 6″	...	...	79	521	...	600
45′- 9″	...	...	76	528	...	604
46′- 0″	...	...	73	534	...	607
46′- 3″	...	...	69	541	...	610
46′- 6″	...	...	66	547	...	613
46′- 9″	...	...	63	553	...	616
47′- 0″	...	...	60	559	...	619
47′- 3″	...	...	57	565	...	622
47′- 6″	...	...	54	572	...	626
47′- 9″	...	...	51	578	...	629
48′- 0″	...	...	47	585	...	632
48′- 3″	...	...	44	591	...	635
48′- 6″	...	...	41	597	...	638
48′- 9″	...	...	38	603	...	641
49′- 0″	...	...	35	609	...	644
49′- 3″	...	...	32	616	...	648
49′- 6″	...	...	29	622	...	651
49′- 9″	...	...	25	629	...	654
50′- 0″	...	...	22	635	...	657
50′- 3″	...	...	19	641	...	660
50′- 6″	...	...	16	647	...	663
50′- 9″	...	...	13	653	...	666
51′- 0″	...	...	10	660	...	670
51′- 3″	...	...	7	666	...	673
51′- 6″	...	...	3	673	...	676
51′- 9″	...	...	...	679	...	679

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13½″ LINING—2½″ or 3″ KEY BRICK

13½″ x 6″ x 2½″ or 13½″ x 6″ x 3″

Diameter Inside Brickwork*	Number Required Per Ring				
	No. 3 Key	No. 2 Key	No. 1 Key	Straight	Total
2′- 3″	29	...	...	...	29
2′- 4″	28	1	...	...	29
2′- 6″	26	4	...	...	30
2′- 8″	25	6	...	...	31
2′-10″	24	8	...	...	32
3′- 0″	23	10	...	...	33
3′- 2″	21	13	...	...	34
3′- 4″	20	15	...	...	35
3′- 6″	19	18	...	...	37
3′- 8″	18	20	...	...	38
3′-10″	17	22	...	...	39
4′- 0″	16	24	...	...	40
4′- 2″	14	27	...	...	41
4′- 4″	13	29	...	...	42
4′- 6″	12	31	...	...	43
4′- 8″	11	33	...	...	44
4′-10″	9	36	...	...	45
5′- 0″	8	38	...	...	46
5′- 2″	7	40	...	...	47
5′- 4″	6	42	...	...	48
5′- 6″	4	45	...	...	49
5′- 8″	3	47	...	...	50
5′-10″	2	49	...	...	51
6′- 0″	...	52	...	...	52
6′- 2″	...	51	2	...	53
6′- 4″	...	49	5	...	54
6′- 6″	...	48	7	...	55
6′- 8″	...	46	10	...	56
6′-10″	...	44	13	...	57
7′- 0″	...	43	16	...	59
7′- 2″	...	41	19	...	60
7′- 4″	...	40	21	...	61
7′- 6″	...	38	24	...	62
7′- 8″	...	36	27	...	63
7′-10″	...	35	29	...	64
8′- 0″	...	33	32	...	65
8′- 2″	...	31	35	...	66
8′- 4″	...	30	37	...	67
8′- 6″	...	28	40	...	68
8′- 8″	...	26	43	...	69
8′-10″	...	24	46	...	70
9′- 0″	...	23	48	...	71
9′- 2″	...	21	51	...	72
9′- 4″	...	19	54	...	73
9′- 6″	...	18	56	...	74
9′- 8″	...	16	59	...	75
9′-10″	...	14	62	...	76
10′- 0″	...	13	64	...	77
10′- 2″	...	11	67	...	78
10′- 4″	...	9	70	...	79
10′- 6″	...	8	73	...	81
10′- 8″	...	6	76	...	82
10′-10″	...	5	78	...	83

Diameter Inside Brickwork	Number Required Per Ring				
	No. 3 Key	No. 2 Key	No. 1 Key	Straight	Total
11′- 0″	...	3	81	...	84
11′- 2″	...	1	84	...	85
11′- 3″	...	...	85	...	85
11′- 6″	...	...	85	2	87
12′- 0″	...	...	85	5	90
12′- 6″	...	...	85	8	93
13′- 0″	...	...	85	11	96
13′- 6″	...	...	85	14	99
14′- 0″	...	...	85	18	103
14′- 6″	...	...	85	21	106
15′- 0″	...	...	85	24	109
15′- 6″	...	...	85	27	112
16′- 0″	...	...	85	30	115
16′- 6″	...	...	85	33	118
17′- 0″	...	...	85	36	121
17′- 6″	...	...	85	39	124
18′- 0″	...	...	85	43	128
18′- 6″	...	...	85	46	131
19′- 0″	...	...	85	49	134
19′- 6″	...	...	85	52	137
20′- 0″	...	...	85	55	140
20′- 6″	...	...	85	58	143
21′- 0″	...	...	85	61	146
21′- 6″	...	...	85	65	150
22′- 0″	...	...	85	68	153
22′- 6″	...	...	85	71	156
23′- 0″	...	...	85	74	159
23′- 6″	...	...	85	77	162
24′- 0″	...	...	85	80	165
24′- 6″	...	...	85	83	168
25′- 0″	...	...	85	87	172
25′- 6″	...	...	85	90	175
26′- 0″	...	...	85	93	178
26′- 6″	...	...	85	96	181
27′- 0″	...	...	85	99	184
27′- 6″	...	...	85	102	187
28′- 0″	...	...	85	105	190
28′- 6″	...	...	85	109	194
29′- 0″	...	...	85	112	197
29′- 6″	...	...	85	115	200
30′- 0″	...	...	85	118	203
30′- 6″	...	...	85	121	206
31′- 0″	...	...	85	124	209
31′- 6″	...	...	85	127	212
32′- 0″	...	...	85	131	216
33′- 0″	...	...	85	137	222
34′- 0″	...	...	85	143	228
35′- 0″	...	...	85	149	234
36′- 0″	...	...	85	156	241
37′- 0″	...	...	85	162	247
38′- 0″	...	...	85	168	253
39′- 0″	...	...	85	175	260
40′- 0″	...	...	85	181	266

*NOTE: For brickwork of inside diameters less than 6 feet, involving the use of 13½ x 6-inch No. 3 Keys which have a very sharp taper, appreciable cutting may be necessary in some cases to secure the best bricklaying fit.

15″ LINING—3″ WEDGE BRICK

15″ x 6″ x 3″ or 15″ x 9″ x 3″

Diameter Inside Brickwork	Number Required Per Ring			
	No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	Total
5′- 0″	95	...	...	95
5′- 1″	94	2	...	96
5′- 3″	91	7	...	98
5′- 6″	88	13	...	101
5′- 9″	85	19	...	104
6′- 0″	82	25	...	107
6′- 3″	79	31	...	110
6′- 6″	75	38	...	113
6′- 9″	73	44	...	117
7′- 0″	69	51	...	120
7′- 3″	66	57	...	123
7′- 6″	63	63	...	126
7′- 9″	60	69	...	129
8′- 0″	57	75	...	132
8′- 3″	53	82	...	135
8′- 6″	51	88	...	139
8′- 9″	47	95	...	142
9′- 0″	44	101	...	145
9′- 3″	41	107	...	148
9′- 6″	38	113	...	151
9′- 9″	35	119	...	154
10′- 0″	31	126	...	157
10′- 3″	29	132	...	161
10′- 6″	25	139	...	164
10′- 9″	22	145	...	167
11′- 0″	19	151	...	170
11′- 3″	16	157	...	173
11′- 6″	13	163	...	176
11′- 9″	9	170	...	179
12′- 0″	7	176	...	183
12′- 3″	3	183	...	186
12′- 6″	...	189	...	189
12′- 9″	...	186	6	192
13′- 0″	...	182	13	195
13′- 3″	...	179	19	198
13′- 6″	...	176	25	201
13′- 9″	...	173	32	205
14′- 0″	...	170	38	208
14′- 3″	...	167	44	211
14′- 6″	...	164	50	214
14′- 9″	...	160	57	217
15′- 0″	...	157	63	220
15′- 3″	...	154	69	223
15′- 6″	...	151	76	227
15′- 9″	...	148	82	230
16′- 0″	...	145	88	233
16′- 3″	...	142	94	236
16′- 6″	...	138	101	239
16′- 9″	...	135	107	242

Diameter Inside Brickwork	Number Required Per Ring			
	No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Total
17′- 0″	132	113	...	245
17′- 3″	129	120	...	249
17′- 6″	126	126	...	252
17′- 9″	123	132	...	255
18′- 0″	120	138	...	258
18′- 3″	116	145	...	261
18′- 6″	113	151	...	264
18′- 9″	110	157	...	267
19′- 0″	107	164	...	271
19′- 3″	104	170	...	274
19′- 6″	101	176	...	277
19′- 9″	98	182	...	280
20′- 0″	94	189	...	283
20′- 3″	91	195	...	286
20′- 6″	88	201	...	289
20′- 9″	85	208	...	293
21′- 0″	82	214	...	296
21′- 3″	79	220	...	299
21′- 6″	76	226	...	302
21′- 9″	72	233	...	305
22′- 0″	69	239	...	308
22′- 3″	66	245	...	311
22′- 6″	63	252	...	315
22′- 9″	60	258	...	318
23′- 0″	57	264	...	321
23′- 3″	54	270	...	324
23′- 6″	50	277	...	327
23′- 9″	47	283	...	330
24′- 0″	44	289	...	333
24′- 3″	41	296	...	337
24′- 6″	38	302	...	340
24′- 9″	35	308	...	343
25′- 0″	32	314	...	346
25′- 3″	28	321	...	349
25′- 6″	25	327	...	352
25′- 9″	22	333	...	355
26′- 0″	19	340	...	359
26′- 3″	16	346	...	362
26′- 6″	13	352	...	365
26′- 9″	10	358	...	368
27′- 0″	6	365	...	371
27′- 3″	3	371	...	374
27′- 6″	...	377	...	377
27′- 9″	...	374	7	381
28′- 0″	...	371	13	384
28′- 3″	...	368	19	387
28′- 6″	...	365	25	390
28′- 9″	...	361	32	393

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15″ LINING—3″ WEDGE BRICK

15″ x 6″ x 3″ or 15″ x 9″ x 3″—CONTINUED

Diameter Inside Brickwork	Number Required Per Ring		
	No. 1 Wedge	No. 1-X Wedge	Total
29′- 0″	358	38	396
29′- 3″	355	44	399
29′- 6″	352	51	403
29′- 9″	349	57	406
30′- 0″	346	63	409
30′- 3″	343	69	412
30′- 6″	339	76	415
30′- 9″	336	82	418
31′- 0″	333	88	421
31′- 3″	330	95	425
31′- 6″	327	101	428
31′- 9″	324	107	431
32′- 0″	321	113	434
32′- 3″	317	120	437
32′- 6″	314	126	440
32′- 9″	311	132	443
33′- 0″	308	139	447
33′- 3″	305	145	450
33′- 6″	302	151	453
33′- 9″	299	157	456
34′- 0″	295	164	459
34′- 3″	292	170	462
34′- 6″	289	176	465
34′- 9″	286	182	468
35′- 0″	283	189	472
35′- 3″	280	195	475
35′- 6″	277	201	478
35′- 9″	273	208	481
36′- 0″	270	214	484
36′- 3″	267	220	487
36′- 6″	264	226	490
36′- 9″	261	233	494
37′- 0″	258	239	497
37′- 3″	255	245	500
37′- 6″	252	251	503
37′- 9″	248	258	506
38′- 0″	245	264	509
38′- 3″	242	270	512
38′- 6″	239	277	516
38′- 9″	236	283	519
39′- 0″	233	289	522
39′- 3″	230	295	525
39′- 6″	226	302	528
39′- 9″	223	308	531
40′- 0″	220	314	534
40′- 3″	217	321	538
40′- 6″	214	327	541
40′- 9″	211	333	544
41′- 0″	208	339	547
41′- 3″	204	346	550
41′- 6″	201	352	553
41′- 9″	198	358	556
42′- 0″	195	365	560
42′- 3″	192	371	563
42′- 6″	189	377	566
42′- 9″	186	383	569

Diameter Inside Brickwork	Number Required Per Ring			
	No. 1 Wedge	No. 1-X Wedge	Straight	Total
43′- 0″	182	390	...	572
43′- 3″	179	396	...	575
43′- 6″	176	402	...	578
43′- 9″	173	409	...	582
44′- 0″	170	415	...	585
44′- 3″	167	421	...	588
44′- 6″	164	427	...	591
44′- 9″	160	434	...	594
45′- 0″	157	440	...	597
45′- 3″	154	446	...	600
45′- 6″	151	453	...	604
45′- 9″	148	459	...	607
46′- 0″	145	465	...	610
46′- 3″	142	471	...	613
46′- 6″	138	478	...	616
46′- 9″	135	484	...	619
47′- 0″	132	490	...	622
47′- 3″	129	497	...	626
47′- 6″	126	503	...	629
47′- 9″	123	509	...	632
48′- 0″	120	515	...	635
48′- 3″	116	522	...	638
48′- 6″	113	528	...	641
48′- 9″	110	534	...	644
49′- 0″	107	541	...	648
49′- 3″	104	547	...	651
49′- 6″	101	553	...	654
49′- 9″	98	559	...	657
50′- 0″	94	566	...	660
50′- 3″	91	572	...	663
50′- 6″	88	578	...	666
50′- 9″	85	585	...	670
51′- 0″	82	591	...	673
51′- 3″	79	597	...	676
51′- 6″	76	603	...	679
51′- 9″	72	610	...	682
52′- 0″	69	616	...	685
52′- 3″	66	622	...	688
52′- 6″	63	629	...	692
52′- 9″	60	635	...	695
53′- 0″	57	641	...	698
53′- 3″	54	647	...	701
53′- 6″	50	654	...	704
53′- 9″	47	660	...	707
54′- 0″	44	666	...	710
54′- 3″	41	673	...	714
54′- 6″	38	679	...	717
54′- 9″	35	685	...	720
55′- 0″	32	691	...	723
55′- 6″	25	704	...	729
56′- 0″	19	717	...	736
56′- 6″	13	729	...	742
57′- 0″	6	742	...	748
57′- 6″	...	754	...	754
58′- 0″	...	754	7	761
58′- 6″	...	754	13	767

18″ LINING—3″ WEDGE BRICK

18″ x 6″ x 3″ or 18″ x 9″ x 3″

Diameter Inside Brickwork	Number Required Per Ring			
	No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	Total
6′- 0″	113	...	...	113
6′- 1″	112	3	...	115
6′- 2″	111	5	...	116
6′- 3″	110	7	...	117
6′- 6″	107	13	...	120
6′- 9″	104	19	...	123
7′- 0″	101	25	...	126
7′- 3″	97	32	...	129
7′- 6″	94	38	...	132
7′- 9″	91	44	...	135
8′- 0″	88	51	...	139
8′- 3″	85	57	...	142
8′- 6″	82	63	...	145
8′- 9″	79	69	...	148
9′- 0″	76	75	...	151
9′- 3″	72	82	...	154
9′- 6″	69	88	...	157
9′- 9″	66	95	...	161
10′- 0″	63	101	...	164
10′- 3″	60	107	...	167
10′- 6″	57	113	...	170
10′- 9″	54	119	...	173
11′- 0″	50	126	...	176
11′- 3″	47	132	...	179
11′- 6″	44	139	...	183
11′- 9″	41	145	...	186
12′- 0″	38	151	...	189
12′- 3″	35	157	...	192
12′- 6″	32	163	...	195
12′- 9″	28	170	...	198
13′- 0″	25	176	...	201
13′- 3″	22	183	...	205
13′- 6″	19	189	...	208
13′- 9″	16	195	...	211
14′- 0″	13	201	...	214
14′- 3″	10	207	...	217
14′- 6″	6	214	...	220
14′- 9″	3	220	...	223
15′- 0″	...	227	...	227
15′- 3″	...	223	7	230
15′- 6″	...	220	13	233
15′- 9″	...	217	19	236
16′- 0″	...	214	25	239
16′- 3″	...	211	31	242
16′- 6″	...	207	38	245
16′- 9″	...	205	44	249
17′- 0″	...	201	51	252
17′- 3″	...	198	57	255
17′- 6″	...	195	63	258
17′- 9″	...	192	69	261

Diameter Inside Brickwork	Number Required Per Ring			
	No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Total
18′- 0″	189	75	...	264
18′- 3″	185	82	...	267
18′- 6″	183	88	...	271
18′- 9″	179	95	...	274
19′- 0″	176	101	...	277
19′- 3″	173	107	...	280
19′- 6″	170	113	...	283
19′- 9″	167	119	...	286
20′- 0″	163	126	...	289
20′- 3″	161	132	...	293
20′- 6″	157	139	...	296
20′- 9″	154	145	...	299
21′- 0″	151	151	...	302
21′- 3″	148	157	...	305
21′- 6″	145	163	...	308
21′- 9″	141	170	...	311
22′- 0″	139	176	...	315
22′- 3″	135	183	...	318
22′- 6″	132	189	...	321
22′- 9″	129	195	...	324
23′- 0″	126	201	...	327
23′- 3″	123	207	...	330
23′- 6″	119	214	...	333
23′- 9″	117	220	...	337
24′- 0″	113	227	...	340
24′- 3″	110	233	...	343
24′- 6″	107	239	...	346
24′- 9″	104	245	...	349
25′- 0″	101	251	...	352
25′- 3″	97	258	...	355
25′- 6″	95	264	...	359
25′- 9″	91	271	...	362
26′- 0″	88	277	...	365
26′- 3″	85	283	...	368
26′- 6″	82	289	...	371
26′- 9″	79	295	...	374
27′- 0″	75	302	...	377
27′- 3″	73	308	...	381
27′- 6″	69	315	...	384
27′- 9″	66	321	...	387
28′- 0″	63	327	...	390
28′- 3″	60	333	...	393
28′- 6″	57	339	...	396
28′- 9″	53	346	...	399
29′- 0″	51	352	...	403
29′- 3″	47	359	...	406
29′- 6″	44	365	...	409
29′- 9″	41	371	...	412

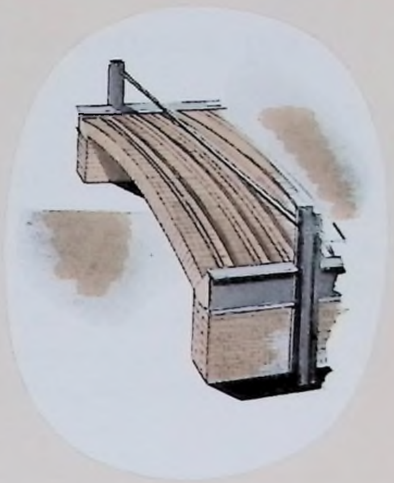
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18″ LINING—3″ WEDGE BRICK

18″ x 6″ x 3″ or 18″ x 9″ x 3″—CONTINUED

Diameter Inside Brickwork	Number Required Per Ring			
	No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Total
30′- 0″	38	377	...	415
30′- 3″	35	383	...	418
30′- 6″	31	390	...	421
30′- 9″	29	396	...	425
31′- 0″	26	402	...	428
31′- 3″	22	409	...	431
31′- 6″	19	415	...	434
31′- 9″	16	421	...	437
32′- 0″	13	427	...	440
32′- 3″	9	434	...	443
32′- 6″	7	440	...	447
32′- 9″	4	446	...	450
33′- 0″	...	453	...	453
33′- 3″	...	449	7	456
33′- 6″	...	446	13	459
33′- 9″	...	443	19	462
34′- 0″	...	440	25	465
34′- 3″	...	437	31	468
34′- 6″	...	434	38	472
34′- 9″	...	431	44	475
35′- 0″	...	427	51	478
35′- 3″	...	424	57	481
35′- 6″	...	421	63	484
35′- 9″	...	418	69	487
36′- 0″	...	415	75	490
36′- 3″	...	412	82	494
36′- 6″	...	409	88	497
36′- 9″	...	406	94	500
37′- 0″	...	402	101	503
37′- 3″	...	399	107	506
37′- 6″	...	396	113	509
37′- 9″	...	393	119	512
38′- 0″	...	390	126	516
38′- 3″	...	387	132	519
38′- 6″	...	384	138	522
38′- 9″	...	380	145	525
39′- 0″	...	377	151	528
39′- 3″	...	374	157	531
39′- 6″	...	371	163	534
39′- 9″	...	368	170	538
40′- 0″	...	365	176	541
40′- 3″	...	362	182	544
40′- 6″	...	358	189	547
40′- 9″	...	355	195	550
41′- 0″	...	352	201	553
41′- 3″	...	349	207	556
41′- 6″	...	346	214	560
41′- 9″	...	343	220	563
42′- 0″	...	340	226	566
42′- 3″	...	336	233	569
42′- 6″	...	333	239	572
42′- 9″	...	330	245	575

Diameter Inside Brickwork	Number Required Per Ring			
	No. 1 Wedge	No. 1-X Wedge	Straight	Total
43′- 0″	327	251	...	578
43′- 3″	324	258	...	582
43′- 6″	321	264	...	585
43′- 9″	318	270	...	588
44′- 0″	314	277	...	591
44′- 3″	311	283	...	594
44′- 6″	308	289	...	597
44′- 9″	305	295	...	600
45′- 0″	302	302	...	604
45′- 3″	299	308	...	607
45′- 6″	296	314	...	610
45′- 9″	292	321	...	613
46′- 0″	289	327	...	616
46′- 6″	283	339	...	622
47′- 0″	277	352	...	629
47′- 6″	270	365	...	635
48′- 0″	264	377	...	641
48′- 6″	258	390	...	648
49′- 0″	252	402	...	654
49′- 6″	245	415	...	660
50′- 0″	239	427	...	666
50′- 6″	233	440	...	673
51′- 0″	226	453	...	679
51′- 6″	220	465	...	685
52′- 0″	214	478	...	692
52′- 6″	208	490	...	698
53′- 0″	201	503	...	704
53′- 6″	195	515	...	710
54′- 0″	189	528	...	717
54′- 6″	182	541	...	723
55′- 0″	176	553	...	729
55′- 6″	170	566	...	736
56′- 0″	164	578	...	742
56′- 6″	157	591	...	748
57′- 0″	151	603	...	754
57′- 6″	145	616	...	761
58′- 0″	138	629	...	767
58′- 6″	132	641	...	773
59′- 0″	126	654	...	780
59′- 6″	120	666	...	786
60′- 0″	113	679	...	792
61′- 0″	101	704	...	805
62′- 0″	88	729	...	817
63′- 0″	76	754	...	830
64′- 0″	63	779	...	842
65′- 0″	51	804	...	855
66′- 0″	38	829	...	867
67′- 0″	25	855	..	880
68′- 0″	13	880	...	893
69′- 0″	...	905	...	905
70′- 0″	...	905	13	918
71′- 0″	...	905	25	930



BRICK COMBINATIONS FOR ARCHES

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BRICK COMBINATIONS REQUIRED FOR ARCHES

In estimating the quantities of brick required for the construction of arches, the various tables on the following pages will be found useful. These tables give the combinations of brick sizes required for arches of given spans and rises.

In calculating the tables, fractional parts equal to or greater than one-tenth of a brick were counted as entire brick; no allowance was made for mortar or expansion joints or for size deviations of the brick. For these reasons, the number of brick required for an arch as given in the tables may be slightly in excess of the number actually required.

Generally, in laying an arch course of brick, it is necessary to cut one or two pieces, and in some instances several pieces, to complete the course.

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Description	2½″ Brick Sizes	3″ Brick Sizes
4½″ Arch Thickness	Page	Page
1½″ Rise per foot of span	561	561
1.608″ (1 19/32″) Rise per foot of span (60° central angle)	562	562
2″ Rise per foot of span	563	563
2.302″ (2 5/16″) Rise per foot of span	564	564
9″ Arch Thickness		
1½″ Rise per foot of span	565	566
1.608″ (1 19/32″) Rise per foot of span (60° central angle)	567	568
2″ Rise per foot of span	569	570
2.302″ (2 5/16″) Rise per foot of span	571	572
12″ Arch Thickness		
1.608″ (1 19/32″) Rise per foot of span (60° central angle)		573
13½″ Arch Thickness		
1.608″ (1 19/32″) Rise per foot of span (60° central angle)		574
15″ Arch Thickness		
1.608″ (1 19/32″) Rise per foot of span (60° central angle)		575
18″ Arch Thickness		
1.608″ (1 19/32″) Rise per foot of span (60° central angle)		576

4½″ ARCH THICKNESS—2½″ ARCH BRICK

9″ x 4½″ x 2½″ or 13½″ x 4½″ x 2½″

1½″ RISE PER FOOT OF SPAN

Span	Rise	Inside Radius	Number Required Per Course: No. 2 Arch	No. 1 Arch	Straight	Total
1′- 0″	1 ½″	1′- 0 ¾″	5	2	..	7
1′- 1″	1 5/8″	1′- 1 13/16″	5	3	..	8
1′- 2″	1 ¾″	1′- 2 7/8″	4	4	..	8
1′- 3″	1 7/8″	1′- 3 15/16″	4	4	..	8
1′- 4″	2″	1′- 5″	4	5	..	9
1′- 5″	2 1/8″	1′- 6 1/16″	3	6	..	9
1′- 6″	2 ¼″	1′- 7 1/8″	3	7	..	10
1′- 7″	2 3/8″	1′- 8 3/16″	2	8	..	10
1′- 8″	2 ½″	1′- 9 ¼″	2	8	..	10
1′- 9″	2 5/8″	1′-10 5/16″	1	10	..	11
1′-10″	2 ¾″	1′-11 3/8″	1	10	..	11
1′-11″	2 7/8″	2′- 0 7/16″	1	11	..	12
2′- 0″	3″	2′- 1 ½″	..	12	..	12
2′- 3″	3 3/8″	2′- 4 11/16″	..	12	1	13
2′- 6″	3 ¾″	2′- 7 7/8″	..	12	3	15
2′- 9″	4 1/8″	2′-11 1/16″	..	12	4	16
3′- 0″	4 ½″	3′- 2 ¼″	..	12	5	17
3′- 3″	4 5/8″	3′- 5 7/16″	..	12	6	18
3′- 6″	5 ¼″	3′- 8 5/8″	..	12	8	20
3′- 9″	5 5/8″	3′-11 13/16″	..	12	9	21
4′- 0″	6″	4′- 3″	..	12	10	22
4′- 3″	6 3/8″	4′- 6 3/16″	..	12	11	23
4′- 6″	6 ¾″	4′- 9 3/8″	..	12	13	25
4′- 9″	7 1/8″	5′- 0 9/16″	..	12	14	26
5′- 0″	7 ½″	5′- 3 ¾″	..	12	15	27
5′- 3″	7 7/8″	5′- 6 15/16″	..	12	16	28
5′- 6″	8 ¼″	5′-10 1/8″	..	12	18	30
5′- 9″	8 3/8″	6′- 1 5/16″	..	12	19	31
6′- 0″	9″	6′- 4 ½″	..	12	20	32
6′- 3″	9 3/8″	6′- 7 11/16″	..	12	21	33
6′- 6″	9 ¾″	6′-10 7/8″	..	12	23	35

4½″ ARCH THICKNESS—3″ ARCH BRICK

9″ x 4½″ x 3″ or 13½″ x 4½″ x 3″

1½″ RISE PER FOOT OF SPAN

Span	Rise	Inside Radius	Number Required Per Course: No. 3 Arch	No. 2 Arch	No. 1 Arch	Total
1′- 0″	1 ½″	1′- 0 ¾″	3	3	..	6
1′- 1″	1 5/8″	1′- 1 13/16″	3	3	..	6
1′- 2″	1 ¾″	1′- 2 7/8″	3	4	..	7
1′- 3″	1 7/8″	1′- 3 15/16″	2	5	..	7
1′- 4″	2″	1′- 5″	2	5	..	7
1′- 5″	2 1/8″	1′- 6 1/16″	2	6	..	8
1′- 6″	2 ¼″	1′- 7 1/8″	1	7	..	8
1′- 7″	2 3/8″	1′- 8 3/16″	1	7	..	8
1′- 8″	2 ½″	1′- 9 ¼″	1	8	..	9
1′- 9″	2 5/8″	1′-10 5/16″	..	9	..	9
1′-10″	2 ¾″	1′-11 3/8″	..	9	1	10
1′-11″	2 7/8″	2′- 0 7/16″	..	8	2	10
2′- 0″	3″	2′- 1 ½″	..	8	2	10
2′- 1″	3 1/8″	2′- 2 9/16″	..	8	3	11
2′- 2″	3 ¼″	2′- 3 5/8″	..	7	4	11
2′- 3″	3 3/8″	2′- 4 11/16″	..	7	4	11
2′- 4″	3 ½″	2′- 5 ¾″	..	7	5	12
2′- 5″	3 5/8″	2′- 6 13/16″	..	6	6	12
2′- 6″	3 ¾″	2′- 7 7/8″	..	6	6	12
2′- 7″	3 7/8″	2′- 8 15/16″	..	6	7	13
2′- 8″	4″	2′-10″	..	5	8	13
2′- 9″	4 1/8″	2′-11 1/16″	..	5	8	13
2′-10″	4 ¼″	3′- 0 1/8″	..	5	9	14
2′-11″	4 3/8″	3′- 1 3/16″	..	4	10	14
3′- 0″	4 ½″	3′- 2 ¼″	4	10	..	14
3′- 1″	4 5/8″	3′- 3 5/16″	4	11	..	15
3′- 2″	4 ¾″	3′- 4 3/8″	3	12	..	15
3′- 3″	4 7/8″	3′- 5 7/16″	3	12	..	15
3′- 4″	5″	3′- 6 ½″	3	13	..	16
3′- 5″	5 1/8″	3′- 7 9/16″	2	14	..	16
3′- 6″	5 ¼″	3′- 8 5/8″	2	14	..	16
3′- 7″	5 3/8″	3′- 9 11/16″	2	15	..	17
3′- 8″	5 ½″	3′-10 ¾″	1	16	..	17
3′- 9″	5 5/8″	3′-11 13/16″	..	17	..	17
3′-10″	5 ¾″	4′- 0 7/8″	..	18	..	18
3′-11″	5 7/8″	4′- 1 15/16″	..	18	..	18
4′- 0″	6″	4′- 3″	..	18	1	19
4′- 3″	6 3/8″	4′- 6 3/16″	..	18	2	20
4′- 6″	6 ¾″	4′- 9 3/8″	..	18	3	21
4′- 9″	7 1/8″	5′- 0 9/16″	..	18	4	22
5′- 0″	7 ½″	5′- 3 ¾″	..	18	5	23
5′- 3″	7 7/8″	5′- 6 15/16″	..	18	6	24
5′- 6″	8 ¼″	5′-10 1/8″	..	18	7	25
5′- 9″	8 3/8″	6′- 1 5/16″	..	18	8	26
6′- 0″	9″	6′- 4 ½″	..	18	9	27
6′- 6″	9 ¾″	6′-10 7/8″	..	18	11	29

For skewback illustration see page 508.

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4½″ ARCH THICKNESS—2½″ ARCH BRICK

9″ x 4½″ x 2½″ or 13½″ x 4½″ x 2½″

1.608″ (1-19/32″) RISE PER FOOT OF SPAN (60° CENTRAL ANGLE)

Span	Rise	Inside Radius	Number Required Per Course: No. 2 Arch	No. 1 Arch	Straight	Total
1′- 0″	1 19/32″	1′- 0″	6	1	..	7
1′- 1″	1 3/4″	1′- 1″	6	2	..	8
1′- 2″	1 3/8″	1′- 2″	5	3	..	8
1′- 3″	2″	1′- 3″	5	4	..	9
1′- 4″	2 5/32″	1′- 4″	4	5	..	9
1′- 5″	2 9/32″	1′- 5″	4	5	..	9
1′- 6″	2 13/32″	1′- 6″	3	7	..	10
1′- 7″	2 17/32″	1′- 7″	3	7	..	10
1′- 8″	2 11/16″	1′- 8″	3	8	..	11
1′- 9″	2 13/16″	1′- 9″	2	9	..	11
1′-10″	2 15/16″	1′-10″	2	10	..	12
1′-11″	3 3/32″	1′-11″	1	11	..	12
2′- 0″	3 7/32″	2′- 0″	1	11	..	12
2′- 1″	3 11/32″	2′- 1″	1	12	..	13
2′- 2″	3 15/32″	2′- 2″	..	13	..	13
2′- 3″	3 5/8″	2′- 3″	..	13	1	14
2′- 6″	4 1/32″	2′- 6″	..	13	2	15
2′- 9″	4 7/16″	2′- 9″	..	13	3	16
3′- 0″	4 13/16″	3′- 0″	..	13	4	17
3′- 3″	5 7/32″	3′- 3″	..	13	6	19
3′- 6″	5 5/8″	3′- 6″	..	13	7	20
3′- 9″	6 1/32″	3′- 9″	..	13	8	21
4′- 0″	6 7/16″	4′- 0″	..	13	9	22
4′- 3″	6 27/32″	4′- 3″	..	13	11	24
4′- 6″	7 1/4″	4′- 6″	..	13	12	25
4′- 9″	7 5/8″	4′- 9″	..	13	13	26
5′- 0″	8 1/32″	5′- 0″	..	13	14	27
5′- 3″	8 7/16″	5′- 3″	..	13	16	29
5′- 6″	8 27/32″	5′- 6″	..	13	17	30
5′- 9″	9 1/4″	5′- 9″	..	13	18	31
6′- 0″	9 21/32″	6′- 0″	..	13	19	32
6′- 3″	10 1/16″	6′- 3″	..	13	21	34
6′- 6″	10 7/16″	6′- 6″	..	13	22	35

4½″ ARCH THICKNESS—3″ ARCH BRICK

9″ x 4½″ x 3″ or 13½″ x 4½″ x 3″

1.608″ (1-19/32″) RISE PER FOOT OF SPAN (60° CENTRAL ANGLE)

Span	Rise	Inside Radius	Number Required Per Course: No. 3 Arch	No. 2 Arch	No. 1 Arch	Total
1′- 0″	1 19/32″	1′- 0″	4	2	..	6
1′- 1″	1 3/4″	1′- 1″	4	3	..	7
1′- 2″	1 7/8″	1′- 2″	3	4	..	7
1′- 3″	2″	1′- 3″	3	4	..	7
1′- 4″	2 5/32″	1′- 4″	3	5	..	8
1′- 5″	2 9/32″	1′- 5″	2	6	..	8
1′- 6″	2 13/32″	1′- 6″	2	6	..	8
1′- 7″	2 17/32″	1′- 7″	2	7	..	9
1′- 8″	2 11/16″	1′- 8″	1	8	..	9
1′- 9″	2 15/16″	1′- 9″	1	8	..	9
1′-10″	2 15/16″	1′-10″	1	9	..	10
1′-11″	3 3/32″	1′-11″	..	9	1	10
2′- 0″	3 7/32″	2′- 0″	..	9	1	10
2′- 1″	3 11/32″	2′- 1″	..	9	2	11
2′- 2″	3 15/32″	2′- 2″	..	8	3	11
2′- 3″	3 5/8″	2′- 3″	..	8	3	11
2′- 4″	3 3/4″	2′- 4″	..	8	4	12
2′- 5″	3 7/8″	2′- 5″	..	7	5	12
2′- 6″	4 1/32″	2′- 6″	..	7	5	12
2′- 7″	4 5/32″	2′- 7″	..	7	6	13
2′- 8″	4 9/32″	2′- 8″	..	6	7	13
2′- 9″	4 7/16″	2′- 9″	..	6	7	13
2′-10″	4 9/16″	2′-10″	..	6	8	14
2′-11″	4 11/16″	2′-11″	..	5	9	14
3′- 0″	4 13/16″	3′- 0″	5	10	..	15
3′- 1″	4 31/32″	3′- 1″	5	10	..	15
3′- 2″	5 3/32″	3′- 2″	4	11	..	15
3′- 3″	5 7/32″	3′- 3″	4	12	..	16
3′- 4″	5 11/32″	3′- 4″	4	12	..	16
3′- 5″	5 1/2″	3′- 5″	3	13	..	16
3′- 6″	5 5/8″	3′- 6″	3	14	..	17
3′- 7″	5 3/4″	3′- 7″	2	15	..	17
3′- 8″	5 29/32″	3′- 8″	2	15	..	17
3′- 9″	6 1/32″	3′- 9″	2	16	..	18
3′-10″	6 5/32″	3′-10″	1	17	..	18
3′-11″	6 9/32″	3′-11″	1	17	..	18
4′- 0″	6 7/16″	4′- 0″	1	18	..	19
4′- 1″	6 9/16″	4′- 1″	..	19	..	19
4′- 2″	6 11/16″	4′- 2″	..	19	..	19
4′- 3″	6 27/32″	4′- 3″	..	19	1	20
4′- 6″	7 1/4″	4′- 6″	..	19	2	21
5′- 0″	8 1/32″	5′- 0″	..	19	4	23
5′- 6″	8 27/32″	5′- 6″	..	19	6	25
6′- 0″	9 21/32″	6′- 0″	..	19	8	27
6′- 6″	10 7/16″	6′- 6″	..	19	10	29

For skewback illustration see page 509.

4½″ ARCH THICKNESS—2½″ ARCH BRICK

9″ x 4½″ x 2½″ or 13½″ x 4½″ x 2½″

2″ RISE PER FOOT OF SPAN

Span	Rise	Inside Radius	Number Required Per Course: No. 2 Arch	No. 1 Arch	Straight	Total
1′- 0″	2″	10″	8	..	..	8
1′- 1″	2 5/32″	10 27/32″	8	..	..	8
1′- 2″	2 11/32″	11 21/32″	7	2	..	9
1′- 3″	2 1/2″	1′- 0 1/2″	7	2	..	9
1′- 4″	2 21/32″	1′- 1 11/32″	7	3	..	10
1′- 5″	2 27/32″	1′- 2 5/32″	6	4	..	10
1′- 6″	3″	1′- 3″	5	5	..	10
1′- 7″	3 5/32″	1′- 3 27/32″	5	6	..	11
1′- 8″	3 11/32″	1′- 4 21/32″	5	6	..	11
1′- 9″	3 1/2″	1′- 5 1/2″	4	8	..	12
1′-10″	3 21/32″	1′- 6 11/32″	4	8	..	12
1′-11″	3 27/32″	1′- 7 5/32″	4	9	..	13
2′- 0″	4″	1′- 8″	3	10	..	13
2′- 1″	4 5/32″	1′- 8 27/32″	2	11	..	13
2′- 2″	4 11/32″	1′- 9 21/32″	2	12	..	14
2′- 3″	4 1/2″	1′-10 1/2″	2	12	..	14
2′- 4″	4 21/32″	1′-11 11/32″	1	14	..	15
2′- 5″	4 27/32″	2′- 0 5/32″	1	14	..	15
2′- 6″	5″	2′- 1″	1	15	..	16
2′- 9″	5 1/2″	2′- 3 1/2″	..	16	1	17
3′- 0″	6″	2′- 6″	..	16	2	18
3′- 3″	6 1/2″	2′- 8 1/2″	..	16	3	19
3′- 6″	7″	2′-11″	..	16	5	21
3′- 9″	7 1/2″	3′- 1 1/2″	..	16	6	22
4′- 0″	8″	3′- 4″	..	16	7	23
4′- 3″	8 1/2″	3′- 6 1/2″	..	16	9	25
4′- 6″	9″	3′- 9″	..	16	10	26
4′- 9″	9 1/2″	3′-11 1/2″	..	16	11	27
5′- 0″	10″	4′- 2″	..	16	12	28
5′- 3″	10 1/2″	4′- 4 1/2″	..	16	14	30
5′- 6″	11″	4′- 7″	..	16	15	31
5′- 9″	11 1/2″	4′- 9 1/2″	..	16	16	32
6′- 0″	1′- 0″	5′- 0″	..	16	18	34
6′- 3″	1′- 0 1/2″	5′- 2 1/2″	..	16	19	35
6′- 6″	1′- 1″	5′- 5″	..	16	20	36

4½″ ARCH THICKNESS—3″ ARCH BRICK

9″ x 4½″ x 3″ or 13½″ x 4½″ x 3″

2″ RISE PER FOOT OF SPAN

Span	Rise	Inside Radius	Number Required Per Course: No. 3 Arch	No. 2 Arch	No. 1 Arch	Total
1′- 0″	2″	10″	6	1	..	7
1′- 1″	2 5/32″	10 27/32″	5	2	..	7
1′- 2″	2 11/32″	11 21/32″	5	2	..	7
1′- 3″	2 1/2″	1′- 0 1/2″	5	3	..	8
1′- 4″	2 21/32″	1′- 1 11/32″	4	4	..	8
1′- 5″	2 27/32″	1′- 2 5/32″	4	4	..	8
1′- 6″	3″	1′- 3″	4	5	..	9
1′- 7″	3 5/32″	1′- 3 27/32″	3	6	..	9
1′- 8″	3 11/32″	1′- 4 21/32″	2	7	..	9
1′- 9″	3 1/2″	1′- 5 1/2″	2	8	..	10
1′-10″	3 21/32″	1′- 6 11/32″	2	8	..	10
1′-11″	3 27/32″	1′- 7 5/32″	2	9	..	11
2′- 0″	4″	1′- 8″	1	10	..	11
2′- 1″	4 5/32″	1′- 8 27/32″	1	10	..	11
2′- 2″	4 11/32″	1′- 9 21/32″	1	11	..	12
2′- 3″	4 1/2″	1′-10 1/2″	..	12	..	12
2′- 4″	4 21/32″	1′-11 11/32″	..	11	1	12
2′- 5″	4 27/32″	2′- 0 5/32″	..	11	2	13
2′- 6″	5″	2′- 1″	..	11	2	13
2′- 7″	5 5/32″	2′- 1 27/32″	..	10	3	13
2′- 8″	5 11/32″	2′- 2 21/32″	..	10	4	14
2′- 9″	5 1/2″	2′- 3 1/2″	10	4	..	14
2′-10″	5 21/32″	2′- 4 11/32″	9	5	..	14
2′-11″	5 27/32″	2′- 5 5/32″	9	6	..	15
3′- 0″	6″	2′- 6″	8	7	..	15
3′- 2″	6 11/32″	2′- 7 21/32″	8	8	..	16
3′- 4″	6 21/32″	2′- 9 11/32″	7	10	..	17
3′- 6″	7″	2′-11″	6	11	..	17
3′- 8″	7 11/32″	3′- 0 21/32″	6	12	..	18
3′-10″	7 21/32″	3′- 2 11/32″	5	14	..	19
4′- 0″	8″	3′- 4″	4	15	..	19
4′- 2″	8 11/32″	3′- 5 21/32″	3	17	..	20
4′- 4″	8 21/32″	3′- 7 11/32″	3	18	..	21
4′- 6″	9″	3′- 9″	2	20	..	22
4′- 8″	9 11/32″	3′-10 21/32″	1	21	..	22
4′-10″	9 21/32″	4′- 0 11/32″	1	22	..	23
4′-11″	9 27/32″	4′- 1 5/32″	..	23	..	23
5′- 0″	10″	4′- 2″	..	23	1	24
5′- 6″	11″	4′- 7″	..	23	3	26
6′- 0″	1′- 0″	5′- 0″	..	23	5	28
6′- 6″	1′- 1″	5′- 5″	..	23	7	30

For skewback illustration see page 508.

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4½″ ARCH THICKNESS—2½″ ARCH BRICK

9″ x 4½″ x 2½″ or 13½″ x 4½″ x 2½″

2.302″ (2-5/16″) RISE PER FOOT OF SPAN

Span	Rise	Inside Radius	Number Required Per Course: No. 3 Arch	No. 2 Arch	No. 1 Arch	Total
0′- 6″	1 5/32″	4 1/2″	4	2	..	6
0′- 7″	1 11/32″	5 7/32″	3	3	..	6
0′- 8″	1 17/32″	5 31/32″	3	4	..	7
0′- 9″	1 23/32″	6 29/32″	2	5	..	7
0′-10″	1 29/32″	7 15/32″	2	5	..	7
0′-11″	2 1/32″	8 7/32″	2	6	..	8
1′- 0″	2 5/32″	8 31/32″	1	7	..	8
1′- 1″	2 1/2″	9 23/32″	1	8	..	9
1′- 2″	2 11/32″	10 15/32″	..	9	..	9
1′- 3″	2 7/8″	11 7/32″	..	9	1	10
1′- 4″	3 1/32″	11 31/32″	..	8	2	10
1′- 5″	3 1/4″	1′- 0 23/32″	..	7	3	10
1′- 6″	3 15/32″	1′- 1 15/32″	..	7	4	11
1′- 7″	3 21/32″	1′- 2 3/16″	..	7	4	11
1′- 8″	3 27/32″	1′- 2 15/16″	..	6	6	12
1′- 9″	4 1/32″	1′- 3 11/16″	..	6	6	12
1′-10″	4 7/32″	1′- 4 7/16″	..	6	7	13
1′-11″	4 13/32″	1′- 5 3/16″	..	5	8	13
2′- 0″	4 19/32″	1′- 5 15/16″	..	5	9	14
2′- 1″	4 25/32″	1′- 6 11/16″	..	4	10	14
2′- 2″	5″	1′- 7 7/16″	..	4	10	14
2′- 3″	5 3/16″	1′- 8 3/16″	..	3	12	15

Span	Rise	Inside Radius	Number Required Per Course: No. 2 Arch	No. 1 Arch	Straight	Total
2′- 4″	5 3/8″	1′- 8 15/16″	3	12	..	15
2′- 5″	5 9/16	1′- 9 11/16″	3	13	..	16
2′- 6″	5 3/4″	1′-10 7/16″	2	14	..	16
2′- 7″	5 15/16″	1′-11 5/32″	2	15	..	17
2′- 8″	6 1/8″	1′-11 29/32″	1	16	..	17
2′- 9″	6 11/32″	2′- 0 21/32″	..	17	..	17
2′-10″	6 17/32″	2′- 1 13/32″	..	18	..	18
2′-11″	6 23/32″	2′- 2 5/32″	..	18	..	18
3′- 0″	6 29/32″	2′- 2 29/32″	..	18	1	19
3′- 1″	7 3/32″	2′- 3 21/32″	..	18	1	19
3′- 2″	7 9/32″	2′- 4 15/32″	..	18	2	20
3′- 3″	7 15/32″	2′- 5 5/32″	..	18	2	20
3′- 4″	7 11/16″	2′- 5 29/32″	..	18	3	21
3′- 5″	7 7/8″	2′- 6 21/32″	..	18	3	21
3′- 6″	8 1/16″	2′- 7 13/32″	..	18	3	21
4′- 0″	9 7/32″	2′-11 7/8″	..	18	6	24
4′- 6″	10 3/8″	3′- 4 3/8″	..	18	9	27
5′- 0″	11 1/2″	3′- 8 27/32″	..	18	11	29
5′- 6″	1′- 0 21/32″	4′- 1 11/32″	..	18	14	32
6′- 0″	1′- 1 13/16″	4′- 5 13/16″	..	18	17	35
6′- 6″	1′- 2 31/32″	4′-10 5/16″	..	18	19	37

4½″ ARCH THICKNESS—3″ ARCH BRICK

9″ x 4½″ x 3″ or 13½″ x 4½″ x 3″

2.302″ (2-5/16″) RISE PER FOOT OF SPAN

Span	Rise	Inside Radius	Number Required Per Course: No. 3 Arch	No. 2 Arch	No. 1 Arch	Total
1′- 0″	2 5/16″	8 31/32″	7	..	..	7
1′- 1″	2 1/2″	9 23/32″	6	1	..	7
1′- 2″	2 11/16″	10 15/32″	6	2	..	8
1′- 3″	2 7/8″	11 7/32″	6	2	..	8
1′- 4″	3 1/16″	11 31/32″	5	3	..	8
1′- 5″	3 1/4″	1′- 0 23/32″	5	4	..	9
1′- 6″	3 15/32″	1′- 1 15/32″	5	4	..	9
1′- 7″	3 21/32″	1′- 2 3/16″	4	6	..	10
1′- 8″	3 27/32″	1′- 2 15/16″	4	6	..	10
1′- 9″	4 1/32″	1′- 3 11/16″	3	7	..	10
1′-10″	4 7/32″	1′- 4 7/16″	3	8	..	11
1′-11″	4 13/32″	1′- 5 3/16″	3	8	..	11
2′- 0″	4 19/32″	1′- 5 15/16″	2	9	..	11
2′- 1″	4 25/32″	1′- 6 11/16″	2	10	..	12
2′- 2″	5″	1′- 7 7/16″	2	10	..	12
2′- 3″	5 3/16″	1′- 8 3/16″	1	11	..	12
2′- 4″	5 3/8″	1′- 8 15/16″	1	12	..	13
2′- 6″	5 3/4″	1′-10 7/16″	..	14	..	14
2′- 8″	6 1/8″	1′-11 29/32″	..	13	1	14
2′-10″	6 17/32″	2′- 1 13/32″	..	12	3	15

Span	Rise	Inside Radius	Number Required Per Course: No. 2 Arch	No. 1 Arch	Straight	Total
3′- 0″	6 29/32″	2′- 2 29/32″	11	5	..	16
3′- 2″	7 9/32″	2′- 4 13/32″	10	6	..	16
3′- 4″	7 11/16″	2′- 5 29/32″	10	7	..	17
3′- 6″	8 1/16″	2′- 7 13/32″	9	9	..	18
3′- 8″	8 7/16″	2′- 8 7/8″	8	11	..	19
3′-10″	8 13/16″	2′-10 3/8″	7	12	..	19
4′- 0″	9 7/32″	2′-11 7/8″	7	13	..	20
4′- 2″	9 19/32″	3′- 1 3/8″	6	15	..	21
4′- 4″	9 31/32″	3′- 2 7/8″	6	16	..	22
4′- 6″	10 3/8″	3′- 4 3/8″	5	17	..	22
4′- 8″	10 3/4″	3′- 5 27/32″	4	19	..	23
4′-10″	11 1/8″	3′- 7 11/32″	3	21	..	24
5′- 0″	11 1/2″	3′- 8 27/32″	3	22	..	25
5′- 2″	11 29/32″	3′-10 11/32″	2	23	..	25
5′- 4″	1′- 0 5/32″	3′-11 27/32″	1	25	..	26
5′- 6″	1′- 0 21/32″	4′- 1 11/32″	..	27	..	27
5′- 8″	1′- 1 1/16″	4′- 2 13/16″	..	27	..	27
5′-10″	1′- 1 7/16″	4′- 4 5/16″	..	27	1	28
6′- 0″	1′- 1 13/16″	4′- 5 13/16″	..	27	2	29
6′- 6″	1′- 2 31/32″	4′-10 5/16″	..	27	4	31

For skewback illustration see page 508.

9″ ARCH THICKNESS—2½″ WEDGE BRICK

9″ x 4½″ x 2½″, 9″ x 6¾″ x 2½″ or 9″ x 9″ x 2½″

1½″ RISE PER FOOT OF SPAN

Span	Rise	Inside Radius	Number Required Per Course: No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Total
1′- 6″	2 1/4″	1′- 7 1/8″	5	6	..	11
1′- 7″	2 3/8″	1′- 8 3/16″	5	7	..	12
1′- 7″	2 1/2″	1′- 9 1/4″	4	8	..	12
1′- 8″	2 5/8″	1′-10 5/16″	3	10	..	13
1′- 9″	2 3/4″	1′-11 3/8″	3	10	..	13
1′-10″	2 7/8″	2′- 0 7/16″	2	12	..	14
1′-11″						
2′- 0″	3″	2′- 1 1/2″	1	13	..	14
2′- 1″	3 1/8″	2′- 2 9/16″	..	14	..	14
2′- 1″	3 1/4″	2′- 3 5/8″	..	14	1	15
2′- 2″	3 3/8″	2′- 4 11/16″	..	14	1	15
2′- 3″	3 1/2″	2′- 5 3/4″	..	14	2	16
2′- 4″	3 5/8″	2′- 6 13/16″	..	13	3	16
2′- 6″	3 3/4″	2′- 7 7/8″	..	13	3	16
2′- 7″	3 7/8″	2′- 8 15/16″	..	13	4	17
2′- 8″	4″	2′-10″	..	12	5	17
2′- 9″	4 1/8″	2′-11 1/16″	..	12	6	18
2′-10″	4 1/4″	3′- 0 1/8″	..	12	6	18
2′-11″	4 3/8″	3′- 1 3/16″	..	12	7	19
3′- 0″	4 1/2″	3′- 2 1/4″	..	11	8	19
3′- 1″	4 5/8″	3′- 3 5/16″	..	11	8	19
3′- 2″	4 3/4″	3′- 4 3/8″	..	11	9	20
3′- 3″	4 7/8″	3′- 5 7/16″	..	10	10	20
3′- 4″	5″	3′- 6 1/2″	..	10	11	21
3′- 5″	5 1/8″	3′- 7 9/16″	..	10	11	21
3′- 6″	5 1/4″	3′- 8 5/8″	..	10	11	21
3′- 7″	5 3/8″	3′- 9 11/16″	..	10	12	22
3′- 8″	5 1/2″	3′-10 3/4″	..	9	13	22
3′- 9″	5 5/8″	3′-11 13/16″	..	9	14	23
3′-10″	5 3/4″	4′- 0 7/8″	..	9	14	23
3′-11″	5 7/8″	4′- 1 15/16″	..	9	15	24
4′- 0″	6″	4′- 3″	..	8	16	24
4′- 1″	6 1/8″	4′- 4 1/16″	..	8	16	24
4′- 2″	6 1/4″	4′- 5 1/8″	..	8	17	25
4′- 3″	6 3/8″	4′- 6 3/16″	..	7	18	25
4′- 4″	6 1/2″	4′- 7 1/4″	..	7	19	26
4′- 5″	6 5/8″	4′- 8 5/16″	..	7	19	26
4′- 6″	6 3/4″	4′- 9 3/8″	..	6	20	26
4′- 7″	6 7/8″	4′-10 7/16″	..	6	21	27
4′- 8″	7″	4′-11 1/2″	..	6	21	27
4′- 9″	7 1/8″	5′- 0 9/16″	..	6	22	28
4′-10″	7 1/4″	5′- 1 5/8″	..	5	23	28
4′-11″	7 3/8″	5′- 2 11/16″	..	5	23	28
5′- 0″	7 1/2″	5′- 3 3/4″	..	5	24	29
5′- 1″	7 5/8″	5′- 4 13/16″	..	4	25	29
5′- 2″	7 3/4″	5′- 5 7/8″	..	4	26	30
5′- 3″	7 7/8″	5′- 6 15/16″	..	4	26	30
5′- 4″	8″	5′- 8″	..	4	27	31
5′- 5″	8 1/8″	5′- 9 1/16″	..	3	28	31

Span	Rise	Inside Radius	Number Required Per Course: No. 1 Wedge	No. 1-X Wedge	Straight	Total
5′- 6″	8 1/4″	5′-10 1/8″	3	28	..	31
5′- 7″	8 3/8″	5′-11 3/16″	3	29	..	32
5′- 8″	8 1/2″	6′- 0 1/4″	2	30	..	32
5′- 9″	8 5/8″	6′- 1 5/16″	2	31	..	33
5′-10″	8 3/4″	6′- 2 3/8″	2	31	..	33
5′-11″	8 7/8″	6′- 3 7/16″	1	32	..	33
6′- 0″	9″	6′- 4 1/2″	1	33	..	34
6′- 1″	9 1/8″	6′- 5 9/16″	1	33	..	34
6′- 2″	9 1/4″	6′- 6 5/8″	1	34	..	35
6′- 3″	9 3/8″	6′- 7 11/16″	..	35	..	35
6′- 4″	9 1/2″	6′- 8 3/4″	..	36	..	36
6′- 5″	9 5/8″	6′- 9 13/16″	..	36	..	36
6′- 6″	9 3/4″	6′-10 7/8″	..	36	..	36
6′- 9″	10 1/8″	7′- 2 1/16″	..	36	2	38
7′- 0″	10 1/2″	7′- 5 1/4″	..	36	3	39
7′- 3″	10 7/8″	7′- 8 7/16″	..	36	4	40
7′- 6″	11 1/4″	7′-11 5/8″	..	36	5	41
7′- 9″	11 5/8″	8′- 2 13/16″	..	36	7	43
8′- 0″	1′- 0″	8′- 6″	..	36	8	44
8′- 3″	1′- 0 3/8″	8′- 9 3/16″	..	36	9	45
8′- 6″	1′- 0 3/4″	9′- 0 3/8″	..	36	10	46
8′- 9″	1′- 1 1/8″	9′- 3 9/16″	..	36	12	48
9′- 0″	1′- 1 1/2″	9′- 6 3/4″	..	36	13	49
9′- 3″	1′- 1 7/8″	9′- 9 15/16″	..	36	14	50
9′- 6″	1′- 2 1/4″	10′- 1 1/8″	..	36	15	51
9′- 9″	1′- 2 5/8″	10′- 4 5/16″	..	36	17	53
10′- 0″	1′- 3″	10′- 7 1/2″	..	36	18	54
10′- 3″	1′- 3 3/8″	10′-10 11/16″	..	36	19	55
10′- 6″	1′- 3 3/4″	11′- 1 7/8″	..	36	20	56
10′- 9″	1′- 4 1/8″	11′- 5 1/16″	..	36	22	58
11′- 0″	1′- 4 1/2″	11′- 8 1/4″	..	36	23	59
11′- 3″	1′- 4 7/8″	11′-11 7/16″	..	36	24	60
11′- 6″	1′- 5 1/4″	12′- 2 5/8″	..	36	25	61
11′- 9″	1′- 5 5/8″	12′- 5 13/16″	..	36	27	63
12′- 0″	1′- 6″	12′- 9″	..	36	28	64
12′- 3″	1′- 6 3/8″	13′- 0 3/16″	..	36	29	65
12′- 6″	1′- 6 3/4″	13′- 3 3/8″	..	36	30	66
12′- 9″	1′- 7 1/8″	13′- 6 9/16″	..	36	32	68
13′- 0″	1′- 7 1/2″	13′- 9 3/4″	..	36	33	69
13′- 3″	1′- 7 7/8″	14′- 0 15/16″	..	36	34	70
13′- 6″	1′- 8 1/4″	14′- 4 1/8″	..	36	35	71
13′- 9″	1′- 8 5/8″	14′- 7 5/16″	..	36	37	73
14′- 0″	1′- 9″	14′-10 1/2″	..	36	38	74
14′- 3″	1′- 9 3/8″	15′- 1 11/16″	..	36	39	75
14′- 6″	1′- 9 3/4″	15′- 4 7/8″	..	36	40	76
14′- 9″	1′-10 1/8″	15′- 8 1/16″	..	36	42	78
15′- 0″	1′-10 1/2″	15′-11 1/4″	..	36	43	79

For skewback illustration see page 508.

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Published by AsbestosClaims.Law
asbestosclaims.law/library/25270/286

9″ ARCH THICKNESS—3″ WEDGE BRICK

9″ x 4½″ x 3″, 9″ x 6¾″ x 3″ or 9″ x 9″ x 3″

1½″ RISE PER FOOT OF SPAN

This table can be used also for **13½″ x 9″ x 3″ arch brick** by substituting No. 1, 2, and 3 arch brick for the corresponding wedge brick.

Span	Rise	Inside Radius	Number Required Per Course: No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	Total
1′- 6″	2 ¼″	1′- 7 ⅛″	9	1	..	10
1′- 7″	2 ⅜″	1′- 8 3/16″	8	2	..	10
1′- 8″	2 ½″	1′- 9 ¼″	8	2	..	10
1′- 9″	2 5/8″	1′-10 5/16″	8	3	..	11
1′-10″	2 ¾″	1′-11 ⅜″	7	4	..	11
1′-11″	2 ⅞″	2′- 0 7/16″	7	4	..	11
2′- 0″	3″	2′- 1 ½″	7	5	..	12
2′- 1″	3 1/16″	2′- 2 9/16″	6	6	..	12
2′- 2″	3 ¼″	2′- 3 5/8″	6	6	..	12
2′- 3″	3 3/8″	2′- 4 11/16″	6	7	..	13
2′- 4″	3 ½″	2′- 5 ¾″	5	8	..	13
2′- 5″	3 5/8″	2′- 6 13/16″	5	8	..	13
2′- 6″	3 ¾″	2′- 7 7/8″	5	9	..	14
2′- 7″	3 ⅞″	2′- 8 15/16″	4	10	..	14
2′- 8″	4″	2′-10″	4	10	..	14
2′- 9″	4 1/16″	2′-11 1/16″	4	11	..	15
2′-10″	4 ¼″	3′- 0 1/8″	3	12	..	15
2′-11″	4 3/8″	3′- 1 3/16″	3	12	..	15
3′- 0″	4 ½″	3′- 2 ¼″	3	13	..	16
3′- 1″	4 5/8″	3′- 3 5/16″	2	14	..	16
3′- 2″	4 ¾″	3′- 4 3/8″	2	15	..	17
3′- 3″	4 3/8″	3′- 5 7/16″	1	16	..	17
3′- 4″	5″	3′- 6 ½″	1	16	..	17
3′- 5″	5 1/8″	3′- 7 9/16″	1	17	..	18
3′- 6″	5 ¼″	3′- 8 5/8″	..	18	..	18
3′- 7″	5 3/8″	3′- 9 11/16″	..	18	..	18
3′- 8″	5 ½″	3′-10 ¾″	..	17	2	19
3′- 9″	5 5/8″	3′-11 13/16″	..	17	2	19
3′-10″	5 ¾″	4′- 0 7/8″	..	16	3	19
3′-11″	5 ⅞″	4′- 1 15/16″	..	16	4	20
4′- 0″	6″	4′- 3″	..	16	4	20
4′- 1″	6 1/8″	4′- 4 1/16″	..	15	5	20
4′- 2″	6 ¼″	4′- 5 1/8″	..	15	6	21
4′- 3″	6 3/8″	4′- 6 3/16″	..	15	6	21
4′- 4″	6 ½″	4′- 7 ¼″	..	14	7	21
4′- 5″	6 5/8″	4′- 8 5/16″	..	14	8	22
4′- 6″	6 ¾″	4′- 9 3/8″	..	14	8	22
4′- 7″	6 ⅞″	4′-10 7/16″	..	13	9	22
4′- 8″	7″	4′-11 ½″	..	13	10	23
4′- 9″	7 1/8″	5′- 0 9/16″	..	13	10	23
4′-10″	7 ¼″	5′- 1 5/8″	..	12	11	23
4′-11″	7 3/8″	5′- 2 11/16″	..	12	12	24
5′- 0″	7 ½″	5′- 3 ¾″	..	12	12	24
5′- 1″	7 5/8″	5′- 4 13/16″	..	12	13	25
5′- 2″	7 ¾″	5′- 5 7/8″	..	11	14	25
5′- 3″	7 ⅞″	5′- 6 15/16″	..	11	14	25
5′- 4″	8″	5′- 8″	..	11	15	26
5′- 5″	8 1/8″	5′- 9 1/16″	..	10	16	26

Span	Rise	Inside Radius	Number Required Per Course: No. 2 Wedge	No. 1 Wedge	Straight	Total
5′- 6″	8 ¼″	5′-10 1/8″	10	16	..	26
5′- 7″	8 3/8″	5′-11 3/16″	9	18	..	27
5′- 8″	8 ½″	6′- 0 ¼″	9	18	..	27
5′- 9″	8 5/8″	6′- 1 5/16″	8	19	..	27
5′-10″	8 ¾″	6′- 2 3/8″	8	20	..	28
5′-11″	8 ⅞″	6′- 3 7/16″	8	20	..	28
6′- 0″	9″	6′- 4 ½″	7	21	..	28
6′- 1″	9 1/8″	6′- 5 9/16″	7	22	..	29
6′- 2″	9 ¼″	6′- 6 5/8″	7	22	..	29
6′- 3″	9 3/8″	6′- 7 11/16″	6	23	..	29
6′- 4″	9 ½″	6′- 8 ¾″	6	24	..	30
6′- 5″	9 5/8″	6′- 9 13/16″	6	24	..	30
6′- 6″	9 ¾″	6′-10 7/8″	5	25	..	30
6′- 7″	9 ⅞″	6 -11 15/16″	5	26	..	31
6′- 8″	10″	7′- 1″	5	26	..	31
6′- 9″	10 1/8″	7′- 2 1/16″	4	27	..	31
6′ 10″	10 ¼″	7′- 3 1/8″	4	28	..	32
6′-11″	10 3/8″	7′- 4 3/16″	4	28	..	32
7′- 0″	10 ½″	7′ 5 ¼″	3	29	..	32
7′- 1″	10 5/8″	7′- 6 5/16″	3	30	..	33
7′- 2″	10 ¾″	7′- 7 3/8″	3	30	..	33
7′- 3″	10 ⅞″	7′- 8 7/16″	3	31	..	34
7′- 4″	11″	7′- 9 ½″	2	32	..	34
7′- 5″	11 1/8″	7′-10 9/16″	2	32	..	34
7′- 6″	11 ¼″	7′-11 5/8″	2	33	..	35
7′- 7″	11 3/8″	8′- 0 11/16″	1	34	..	35
7′- 8″	11 ½″	8′- 1 ¾″	1	34	..	35
7′- 9″	11 5/8″	8′- 2 13/16″	..	36	..	36
7′-10″	11 ¾″	8′- 3 7/8″	..	36	..	36
7′-11″	11 ⅞″	8′- 4 15/16″	..	36	..	36
8′- 0″	1′- 0″	8′- 6″	..	36	1	37
8′- 6″	1′- 0 ¾″	9′- 0 3/8″	..	36	3	39
9′- 0″	1′- 1 ½″	9′- 6 ¾″	..	36	5	41
9′- 6″	1′- 2 ¼″	10′- 1 1/8″	..	36	7	43
10′- 0″	1′- 3″	10′- 7 ½″	..	36	9	45
10′- 6″	1′- 3 ¾″	11′- 1 7/8″	..	36	11	47
11′- 0″	1′- 4 ½″	11′- 8 ¼″	..	36	13	49
11′- 6″	1′- 5 ¼″	12′- 2 5/8″	..	36	15	51
12′- 0″	1′- 6″	12′- 9″	..	36	17	53
12′- 6″	1′- 6 ¾″	13′- 3 3/8″	..	36	19	55
13′- 0″	1′- 7 ½″	13′- 9 ¾″	..	36	21	57
13′- 6″	1′- 8 ¼″	14′- 4 1/8″	..	36	24	60
14′- 0″	1′- 9″	14′-10 ½″	..	36	26	62
14′- 6″	1′- 9 ¾″	15′- 4 7/8″	..	36	28	64
15′- 0″	1′-10 ½″	15′-11 ¼″	..	36	30	66

For skewback illustration see page 508.

9″ ARCH THICKNESS—2½″ WEDGE BRICK

9″ x 4½″ x 2½″, 9″ x 6¾″ x 2½″ or 9″ x 9″ x 2½″

1.608″ (1-19/32″) RISE PER FOOT OF SPAN (60° CENTRAL ANGLE)

Span	Rise	Inside Radius	Number Required Per Course: No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Total
1′- 6″	2 13/32″	1′- 6″	7	5	..	12
1′- 7″	2 17/32″	1′- 7″	6	6	..	12
1′- 8″	2 11/16″	1′- 8″	5	8	..	13
1′- 9″	2 13/16″	1′- 9″	4	9	..	13
1′-10″	2 15/16″	1′-10″	3	10	..	13
1′-11″	3 3/32″	1′-11″	3	11	..	14
2′- 0″	3 7/32″	2′- 0″	2	12	..	14
2′- 1″	3 11/32″	2′- 1″	2	13	..	15
2′- 2″	3 15/32″	2′- 2″	1	14	..	15
2′- 3″	3 5/8″	2′- 3″	..	15	..	15
2′- 4″	3 ¾″	2′- 4″	..	15	1	16
2′- 5″	3 7/8″	2′- 5″	..	15	1	16
2′- 6″	4 1/32″	2′- 6″	..	15	2	17
2′- 7″	4 5/32″	2′- 7″	..	14	3	17
2′- 8″	4 9/32″	2′- 8″	..	14	4	18
2′- 9″	4 7/16″	2′- 9″	..	14	4	18
2′-10″	4 9/16″	2′-10″	..	13	5	18
2′-11″	4 11/16″	2′-11″	..	13	6	19
3′- 0″	4 13/16″	3′- 0″	..	13	6	19
3′- 1″	4 31/32″	3′- 1″	..	13	7	20
3′- 2″	5 3/32″	3′- 2″	..	12	8	20
3′- 3″	5 7/32″	3′- 3″	..	12	9	21
3′- 4″	5 11/32″	3′- 4″	..	12	9	21
3′- 5″	5 ½″	3′- 5″	..	11	10	21
3′- 6″	5 5/8″	3′- 6″	..	11	11	22
3′- 7″	5 ¾″	3′- 7″	..	11	11	22
3′- 8″	5 29/32″	3′- 8″	..	11	12	23
3′- 9″	6 1/32″	3′- 9″	..	10	13	23
3′-10″	6 5/32″	3′-10″	..	10	13	23
3′-11″	6 9/32″	3′-11″	..	10	14	24
4′- 0″	6 7/16″	4′- 0″	..	9	15	24
4′- 1″	6 9/16″	4′- 1″	..	9	16	25
4′- 2″	6 11/16″	4′- 2″	..	9	16	25
4′- 3″	6 27/32″	4′- 3″	..	9	17	26
4′- 4″	6 31/32″	4′- 4″	..	8	18	26
4′- 5″	7 3/32″	4′- 5″	..	8	18	26
4′- 6″	7 ¼″	4′- 6″	..	8	19	27
4′- 7″	7 3/8″	4′- 7″	..	7	20	27
4′- 8″	7 ½″	4′- 8″	..	7	21	28
4′- 9″	7 5/8″	4′- 9″	..	7	21	28
4′-10″	7 25/32″	4′-10″	..	6	22	28
4′-11″	7 29/32″	4′-11″	..	6	23	29
5′- 0″	8 1/32″	5′- 0″	..	6	23	29
5′- 1″	8 3/16″	5′- 1″	..	6	24	30
5′- 2″	8 5/16″	5′- 2″	..	5	25	30
5′- 3″	8 7/16″	5′- 3″	..	5	26	31
5′- 4″	8 9/16″	5′- 4″	..	5	26	31
5′- 5″	8 23/32″	5′- 5″	..	4	27	31

Span	Rise	Inside Radius	Number Required Per Course: No. 1 Wedge	No. 1-X Wedge	Straight	Total
5′- 6″	8 27/32″	5′- 6″	4	28	..	32
5′- 7″	8 31/32″	5′- 7″	4	28	..	32
5′- 8″	9 1/8″	5′- 8″	4	29	..	33
5′- 9″	9 ¼″	5′- 9″	4	29	..	33
5′-10″	9 3/8″	5′-10″	3	30	..	33
5′-11″	9 ½″	5′-11″	3	31	..	34
6′- 0″	9 21/32″	6′- 0″	3	31	..	34
6′- 1″	9 25/32″	6′- 1″	3	32	..	35
6′- 2″	9 29/32″	6′- 2″	2	33	..	35
6′- 3″	10 1/16″	6′- 3″	2	34	..	36
6′- 4″	10 3/16″	6′- 4″	2	34	..	36
6′- 5″	10 5/16″	6′- 5″	1	35	..	36
6′- 6″	10 7/16″	6′- 6″	1	36	..	37
6′- 7″	10 19/32″	6′- 7″	1	36	..	37
6′- 8″	10 23/32″	6′- 8″	1	37	..	38
6′- 9″	10 27/32″	6′- 9″	..	38	..	38
7′- 0″	11 1/32″	7′- 0″	..	38	1	39
7′- 3″	11 21/32″	7′- 3″	..	38	3	41
7′- 6″	1′- 0 1/16″	7′- 6″	..	38	4	42
7′- 9″	1′- 0 15/32″	7′- 9″	..	38	5	43
8′- 0″	1′- 0 7/8″	8′- 0″	..	38	6	44
8′- 3″	1′- 1 1/4″	8′- 3″	..	38	8	46
8′- 6″	1′- 1 21/32″	8′- 6″	..	38	9	47
8′- 9″	1′- 2 1/16″	8′- 9″	..	38	10	48
9′- 0″	1′- 2 15/32″	9′- 0″	..	38	11	49
9′- 3″	1′- 2 7/8″	9′- 3″	..	38	13	51
9′- 6″	1′- 3 9/32″	9′- 6″	..	38	14	52
9′- 9″	1′- 3 11/16″	9′- 9″	..	38	15	53
10′- 0″	1′- 4 1/16″	10′- 0″	..	38	16	54
10′- 3″	1′- 4 15/32″	10′- 3″	..	38	18	56
10′- 6″	1′- 4 7/8″	10′- 6″	..	38	19	57
10′- 9″	1′- 5 9/32″	10′- 9″	..	38	20	58
11′- 0″	1′- 5 11/16″	11′- 0″	..	38	21	59
11′- 3″	1′- 6 1/32″	11′- 3″	..	38	23	61
11′- 6″	1′- 6 1/2″	11′- 6″	..	38	24	62
11′- 9″	1′- 6 7/8″	11′- 9″	..	38	25	63
12′- 0″	1′- 7 9/32″	12′- 0″	..	38	26	64
12′- 3″	1′- 7 11/16″	12′- 3″	..	38	28	66
12′- 6″	1′- 8 3/32″	12′- 6″	..	38	29	67
12′- 9″	1′- 8 1/2″	12′- 9″	..	38	30	68
13′- 0″	1′- 8 29/32″	13′- 0″	..	38	32	70
13′- 6″	1′- 9 11/16″	13′- 6″	..	38	34	72
14′- 0″	1′-10 1/2″	14′- 0″	..	38	37	75
14′- 6″	1′-11 5/16″	14′- 6″	..	38	39	77
15′- 0″	2′- 0 1/8″	15′- 0″	..	38	42	80

For skewback illustration see page 509.

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9″ ARCH THICKNESS—3″ WEDGE BRICK

9″ x 4½″ x 3″, 9″ x 6¾″ x 3″ or 9″ x 9″ x 3″

1.608″ (1-19/32″) RISE PER FOOT OF SPAN (60° CENTRAL ANGLE)

This table can be used also for **13½″ x 9″ x 3″ arch brick** by substituting No. 1, 2, and 3 arch brick for the corresponding wedge brick.

Span	Rise	Inside Radius	Number Required Per Course: No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	Total
1′- 6″	2 13/32″	1′- 6″	10	..	..	10
1′- 7″	2 17/32″	1′- 7″	9	1	..	10
1′- 8″	2 11/16″	1′- 8″	9	2	..	11
1′- 9″	2 13/16″	1′- 9″	9	2	..	11
1′-10″	2 15/16″	1′-10″	8	3	..	11
1′-11″	3 3/32″	1′-11″	8	4	..	12
2′- 0″	3 7/32″	2′- 0″	8	4	..	12
2′- 1″	3 11/32″	2′- 1″	7	5	..	12
2′- 2″	3 15/32″	2′- 2″	7	6	..	13
2′- 3″	3 5/8″	2′- 3″	7	6	..	13
2′- 4″	3 3/4″	2′- 4″	6	7	..	13
2′- 5″	3 1/8″	2′- 5″	6	8	..	14
2′- 6″	4 1/32″	2′- 6″	5	9	..	14
2′- 7″	4 5/32″	2′- 7″	5	9	..	14
2′- 8″	4 9/32″	2′- 8″	5	10	..	15
2′- 9″	4 7/16″	2′- 9″	4	11	..	15
2′-10″	4 9/16″	2′-10″	4	11	..	15
2′-11″	4 11/16″	2′-11″	4	12	..	16
3′- 0″	4 13/16″	3′- 0″	3	13	..	16
3′- 1″	4 31/32″	3′- 1″	3	13	..	16
3′- 2″	5 3/32″	3′- 2″	3	14	..	17
3′- 3″	5 7/32″	3′- 3″	2	15	..	17
3′- 4″	5 11/32″	3′- 4″	2	16	..	18
3′- 5″	5 1/2″	3′- 5″	2	16	..	18
3′- 6″	5 5/8″	3′- 6″	1	17	..	18
3′- 7″	5 3/4″	3′- 7″	1	18	..	19
3′- 8″	5 29/32″	3′- 8″	1	18	..	19
3′- 9″	6 1/32″	3′- 9″	..	19	..	19
3′-10″	6 5/32″	3′-10″	..	19	1	20
3′-11″	6 9/32″	3′-11″	..	18	2	20
4′- 0″	6 7/16″	4′- 0″	..	18	2	20
4′- 1″	6 9/16″	4′- 1″	..	18	3	21
4′- 2″	6 11/16″	4′- 2″	..	17	4	21
4′- 3″	6 27/32″	4′- 3″	..	17	4	21
4′- 4″	6 31/32″	4′- 4″	..	17	5	22
4′- 5″	7 3/32″	4′- 5″	..	16	6	22
4′- 6″	7 1/4″	4′- 6″	..	16	6	22
4′- 7″	7 3/8″	4′- 7″	..	16	7	23
4′- 8″	7 1/2″	4′- 8″	..	15	8	23
4′- 9″	7 5/8″	4′- 9″	..	15	8	23
4′-10″	7 25/32″	4′-10″	..	15	9	24
4′-11″	7 29/32″	4′-11″	..	14	10	24
5′- 0″	8 1/32″	5′- 0″	..	14	10	24
5′- 1″	8 3/16″	5′- 1″	..	14	11	25
5′- 2″	8 5/16″	5′- 2″	..	13	12	25
5′- 3″	8 7/16″	5′- 3″	..	13	13	26
5′- 4″	8 9/16″	5′- 4″	..	12	14	26
5′- 5″	8 23/32″	5′- 5″	..	12	14	26

Span	Rise	Inside Radius	Number Required Per Course: No. 2 Wedge	No. 1 Wedge	Straight	Total
5′- 6″	8 27/32″	5′- 6″	12	15	..	27
5′- 7″	8 31/32″	5′- 7″	11	16	..	27
5′- 8″	9 1/8″	5′- 8″	11	16	..	27
5′- 9″	9 1/4″	5′- 9″	11	17	..	28
5′-10″	9 3/8″	5′-10″	10	18	..	28
5′-11″	9 1/2″	5′-11″	10	18	..	28
6′- 0″	9 21/32″	6′- 0″	10	19	..	29
6′- 1″	9 25/32″	6′- 1″	9	20	..	29
6′- 2″	9 29/32″	6′- 2″	9	20	..	29
6′- 3″	10 1/16″	6′- 3″	9	21	..	30
6′- 4″	10 3/16″	6′- 4″	8	22	..	30
6′- 5″	10 5/16″	6′- 5″	8	22	..	30
6′- 6″	10 7/16″	6′- 6″	8	23	..	31
6′- 7″	10 19/32″	6′- 7″	7	24	..	31
6′- 8″	10 23/32″	6′- 8″	7	24	..	31
6′- 9″	10 27/32″	6′- 9″	7	25	..	32
6′-10″	11″	6′-10″	6	26	..	32
6′-11″	11 1/8″	6′-11″	6	27	..	33
7′- 0″	11 1/4″	7′- 0″	6	27	..	33
7′- 1″	11 3/8″	7′- 1″	5	28	..	33
7′- 2″	11 17/32″	7′- 2″	5	29	..	34
7′- 3″	11 21/32″	7′- 3″	4	30	..	34
7′- 4″	11 25/32″	7′- 4″	4	30	..	34
7′- 5″	11 15/16″	7′- 5″	4	31	..	35
7′- 6″	1′- 0 1/16″	7′- 6″	3	32	..	35
7′- 7″	1′- 0 3/16″	7′- 7″	3	32	..	35
7′- 8″	1′- 0 5/16″	7′- 8″	3	33	..	36
7′- 9″	1′- 0 15/32″	7′- 9″	2	34	..	36
7′-10″	1′- 0 19/32″	7′-10″	2	34	..	36
7′-11″	1′- 0 23/32″	7′-11″	2	35	..	37
8′- 0″	1′- 0 7/8″	8′- 0″	1	36	..	37
8′- 1″	1′- 1″	8′- 1″	1	36	..	37
8′- 2″	1′- 1 1/8″	8′- 2″	1	37	..	38
8′- 3″	1′- 1 1/4″	8′- 3″	..	38	..	38
8′- 6″	1′- 1 21/32″	8′- 6″	..	38	1	39
9′- 0″	1′- 2 15/32″	9′- 0″	..	38	3	41
9′- 6″	1′- 3 9/32″	9′- 6″	..	38	5	43
10′- 0″	1′- 4 1/16″	10′- 0″	..	38	7	45
10′- 6″	1′- 4 7/8″	10′- 6″	..	38	10	48
11′- 0″	1′- 5 11/16″	11′- 0″	..	38	12	50
11′- 6″	1′- 6 1/2″	11′- 6″	..	38	14	52
12′- 0″	1′- 7 9/32″	12′- 0″	..	38	16	54
12′- 6″	1′- 8 3/32″	12′- 6″	..	38	18	56
13′- 0″	1′- 8 29/32″	13′- 0″	..	38	20	58
13′- 6″	1′- 9 11/16″	13′- 6″	..	38	22	60
14′- 0″	1′-10 1/2″	14′- 0″	..	38	24	62
14′- 6″	1′-11 5/16″	14′- 6″	..	38	26	64
15′- 0″	2′- 0 1/8″	15′- 0″	..	38	28	66

For skewback illustration see page 509.

9″ ARCH THICKNESS—2½″ WEDGE BRICK

9″ x 4½″ x 2½″, 9″ x 6¾″ x 2½″ or 9″ x 9″ x 2½″

2″ RISE PER FOOT OF SPAN

Span	Rise	Inside Radius	Number Required Per Course: No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Total
1′- 6″	3″	1′- 3″	11	2	..	13
1′- 7″	3 5/32″	1′- 3 27/32″	10	3	..	13
1′- 8″	3 11/32″	1′- 4 21/32″	9	5	..	14
1′- 9″	3 1/2″	1′- 5 1/2″	8	6	..	14
1′-10″	3 21/32″	1′- 6 11/32″	7	7	..	14
1′-11″	3 27/32″	1′- 7 5/32″	7	8	..	15
2′- 0″	4″	1′- 8″	6	9	..	15
2′- 1″	4 5/32″	1′- 8 27/32″	6	10	..	16
2′- 2″	4 11/32″	1′- 9 21/32″	5	11	..	16
2′- 3″	4 1/2″	1′-10 1/2″	4	13	..	17
2′- 4″	4 21/32″	1′-11 11/32″	3	14	..	17
2′- 5″	4 27/32″	2′- 0 5/32″	2	15	..	17
2′- 6″	5″	2′- 1″	2	16	..	18
2′- 7″	5 5/32″	2′- 1 27/32″	1	17	..	18
2′- 8″	5 11/32″	2′- 2 21/32″	1	18	..	19
2′- 9″	5 1/2″	2′- 3 1/2″	..	18	1	19
2′-10″	5 21/32″	2′- 4 11/32″	..	18	2	20
2′-11″	5 27/32″	2′- 5 5/32″	..	18	2	20
3′- 0″	6″	2′- 6″	..	17	3	20
3′- 1″	6 5/32″	2′- 6 27/32″	..	17	4	21
3′- 2″	6 11/32″	2′- 7 21/32″	..	17	4	21
3′- 3″	6 1/2″	2′- 8 1/2″	..	17	5	22
3′- 4″	6 21/32″	2′- 9 11/32″	..	16	6	22
3′- 5″	6 27/32″	2′-10 5/32″	..	16	7	23
3′- 6″	7″	2′-11″	..	16	7	23
3′- 7″	7 5/32″	2′-11 27/32″	..	15	8	23
3′- 8″	7 11/32″	3′- 0 21/32″	..	15	9	24
3′- 9″	7 1/2″	3′- 1 1/2″	..	15	9	24
3′-10″	7 21/32″	3′- 2 11/32″	..	15	10	25
3′-11″	7 27/32″	3′- 3 5/32″	..	14	11	25
4′- 0″	8″	3′- 4″	..	14	12	26
4′- 1″	8 5/32″	3′- 4 27/32″	..	14	12	26
4′- 2″	8 11/32″	3′- 5 21/32″	..	13	13	26
4′- 3″	8 1/2″	3′- 6 1/2″	..	13	14	27
4′- 4″	8 21/32″	3′- 7 11/32″	..	13	14	27
4′- 5″	8 27/32″	3′- 8 5/32″	..	13	15	28
4′- 6″	9″	3′- 9″	..	12	16	28
4′- 7″	9 5/32″	3′- 9 27/32″	..	12	17	29
4′- 8″	9 11/32″	3′-10 21/32″	..	12	17	29
4′- 9″	9 1/2″	3′-11 1/2″	..	11	18	29
4′-10″	9 21/32″	4′- 0 11/32″	..	11	19	30
4′-11″	9 27/32″	4′- 1 5/32″	..	11	19	30
5′- 0″	10″	4′- 2″	..	11	20	31
5′- 1″	10 5/32″	4′- 2 27/32″	..	10	21	31
5′- 2″	10 11/32″	4′- 3 21/32″	..	10	22	32
5′- 3″	10 1/2″	4′- 4 1/2″	..	10	22	32
5′- 4″	10 21/32″	4′- 5 11/32″	..	9	23	32
5′- 5″	10 27/32″	4′- 6 5/32″	..	9	24	33

Span	Rise	Inside Radius	Number Required Per Course: No. 1 Wedge	No. 1-X Wedge	Straight	Total
5′- 6″	11″	4′- 7″	9	24	..	33
5′- 7″	11 5/32″	4′- 7 27/32″	9	25	..	34
5′- 8″	11 11/32″	4′- 8 21/32″	8	26	..	34
5′- 9″	11 1/2″	4′- 9 1/2″	8	27	..	35
5′-10″	11 21/32″	4′-10 11/32″	8	27	..	35
5′-11″	11 27/32″	4′-11 5/32″	7	28	..	35
6′- 0″	1′- 0″	5′- 0″	7	29	..	36
6′- 1″	1′- 0 5/32″	5′- 0 27/32″	7	29	..	36
6′- 2″	1′- 0 11/32″	5′- 1 21/32″	7	30	..	37
6′- 3″	1′- 0 1/2″	5′- 2 1/2″	6	31	..	37
6′- 4″	1′- 0 21/32″	5′- 3 11/32″	6	32	..	38
6′- 5″	1′- 0 27/32″	5′- 4 5/32″	6	32	..	38
6′- 6″	1′- 1″	5′- 5″	5	33	..	38
6′- 7″	1′- 1 5/32″	5′- 5 27/32″	5	34	..	39
6′- 8″	1′- 1 11/32″	5′- 6 21/32″	5	34	..	39
6′- 9″	1′- 1 1/2″	5′- 7 1/2″	5	35	..	40
6′-10″	1′- 1 21/32″	5′- 8 11/32″	4	36	..	40
6′-11″	1′- 1 27/32″	5′- 9 5/32″	4	37	..	41
7′- 0″	1′- 2″	5′-10″	4	37	..	41
7′- 1″	1′- 2 5/32″	5′-10 27/32″	3	38	..	41
7′- 2″	1′- 2 11/32″	5′-11 21/32″	3	39	..	42
7′- 3″	1′- 2 1/2″	6′- 0 1/2″	3	39	..	42
7′- 4″	1′- 2 21/32″	6′- 1 11/32″	3	40	..	43
7′- 5″	1′- 2 27/32″	6′- 2 5/32″	2	41	..	43
7′- 6″	1′- 3″	6′- 3″	2	42	..	44
7′- 7″	1′- 3 5/32″	6′- 3 27/32″	2	42	..	44
7′- 8″	1′- 3 11/32″	6′- 4 21/32″	2	43	..	45
7′- 9″	1′- 3 1/2″	6′- 5 1/2″	1	44	..	45
7′-10″	1′- 3 21/32″	6′- 6 11/32″	1	44	..	45
7′-11″	1′- 3 27/32″	6′- 7 5/32″	1	45	..	46
8′- 0″	1′- 4″	6′- 8″	..	46	..	46
8′- 1″	1′- 4 5/32″	6′- 8 27/32″	..	47	..	47
8′- 2″	1′- 4 11/32″	6′- 9 21/32″	..	47	..	47
8′- 3″	1′- 4 1/2″	6′-10 1/2″	..	47	1	48
8′- 4″	1′- 4 21/32″	6′-11 11/32″	..	47	1	48
8′- 5″	1′- 4 27/32″	7′- 0 5/32″	..	47	1	48
8′- 6″	1′- 5″	7′- 1″	..	47	2	49
9′- 0″	1′- 6″	7′- 6″	..	47	4	51
9′- 6″	1′- 7″	7′-11″	..	47	7	54
10′- 0″	1′- 8″	8′- 4″	..	47	10	57
10′- 6″	1′- 9″	8′- 9″	..	47	12	59
11′- 0″	1′-10″	9′- 2″	..	47	15	62
11′- 6″	1′-11″	9′- 7″	..	47	17	64
12′- 0″	2′- 0″	10′- 0″	..	47	20	67
12′- 6″	2′- 1″	10′- 5″	..	47	22	69
13′- 0″	2′- 2″	10′-10″	..	47	25	72
13′- 6″	2′- 3″	11′- 3″	..	47	28	75
14′- 0″	2′- 4″	11′- 8″	..	47	30	77
14′- 6″	2′- 5″	12′- 1″	..	47	33	80
15′- 0″	2′- 6″	12′- 6″	..	47	35	82

For skewback illustration see page 508.

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Published by AsbestosClaims.Law
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9″ ARCH THICKNESS—3″ WEDGE BRICK

9″ x 4½″ x 3″, 9″ x 6¾″ x 3″ or 9″ x 9″ x 3″

2″ RISE PER FOOT OF SPAN

This table can be used also for **13½″ x 9″ x 3″ arch brick** by substituting No. 1, 2, and 3 arch brick for the corresponding wedge brick.

Span	Rise	Inside Radius	Number Required Per Course: No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	Total
1′-10″	3 21/32″	1′- 6 11/32″	12	..	..	12
1′-11″	3 27/32″	1′- 7 5/32″	11	1	..	12
2′- 0″	4″	1′- 8″	11	2	..	13
2′- 1″	4 5/32″	1′- 8 27/32″	10	3	..	13
2′- 2″	4 11/32″	1′- 9 21/32″	10	4	..	14
2′- 3″	4 ½″	1′-10 ½″	10	4	..	14
2′- 4″	4 21/32″	1′-11 11/32″	9	5	..	14
2′- 5″	4 27/32″	2′- 0 5/32″	9	6	..	15
2′- 6″	5″	2′- 1″	9	6	..	15
2′- 7″	5 5/32″	2′- 1 27/32″	8	7	..	15
2′- 8″	5 11/32″	2′- 2 21/32″	8	8	..	16
2′- 9″	5 ½″	2′- 3 ½″	8	8	..	16
2′-10″	5 21/32″	2′- 4 11/32″	7	9	..	16
2′-11″	5 27/32″	2′- 5 5/32″	7	10	..	17
3′- 0″	6″	2′- 6″	7	10	..	17
3′- 1″	6 5/32″	2′- 6 27/32″	6	11	..	17
3′- 2″	6 11/32″	2′- 7 21/32″	6	12	..	18
3′- 3″	6 ½″	2′- 8 ½″	5	13	..	18
3′- 4″	6 21/32″	2′- 9 11/32″	5	14	..	19
3′- 5″	6 27/32″	2′-10 5/32″	5	14	..	19
3′- 6″	7″	2′-11″	4	15	..	19
3′- 7″	7 5/32″	2′-11 27/32″	4	16	..	20
3′- 8″	7 11/32″	3′- 0 21/32″	4	16	..	20
3′- 9″	7 ½″	3′- 1 ½″	3	17	..	20
3′-10″	7 21/32″	3′- 2 11/32″	3	18	..	21
3′-11″	7 27/32″	3′- 3 5/32″	3	18	..	21
4′- 0″	8″	3′- 4″	2	19	..	21
4′- 1″	8 5/32″	3′- 4 27/32″	2	20	..	22
4′- 2″	8 11/32″	3′- 5 21/32″	2	20	..	22
4′- 3″	8 ½″	3′- 6 ½″	1	21	..	22
4′- 4″	8 21/32″	3′- 7 11/32″	1	22	..	23
4′- 5″	8 27/32″	3′- 8 5/32″	1	22	..	23
4′- 6″	9″	3′- 9″	..	24	..	24
4′- 7″	9 5/32″	3′- 9 27/32″	..	23	1	24
4′- 8″	9 11/32″	3′-10 21/32″	..	23	1	24
4′- 9″	9 ½″	3′-11 ½″	..	22	3	25
4′-10″	9 21/32″	4′- 0 11/32″	..	22	3	25
4′-11″	9 27/32″	4′- 1 5/32″	..	21	4	25
5′- 0″	10″	4′- 2″	..	21	5	26
5′- 1″	10 5/32″	4′- 2 27/32″	..	21	5	26
5′- 2″	10 11/32″	4′- 3 21/32″	..	20	6	26
5′- 3″	10 ½″	4′- 4 ½″	..	20	7	27
5′- 4″	10 21/32″	4′- 5 11/32″	..	20	7	27
5′- 5″	10 27/32″	4′- 6 5/32″	..	19	8	27
5′- 6″	11″	4′- 7″	..	19	9	28
5′- 7″	11 5/32″	4′- 7 27/32″	..	19	9	28
5′- 8″	11 11/32″	4′- 8 21/32″	..	19	10	29
5′- 9″	11 ½″	4′- 9 ½″	..	18	11	29
5′-10″	11 21/32″	4′-10 11/32″	..	18	11	29
5′-11″	11 27/32″	4′-11 5/32″	..	17	13	30

Span	Rise	Inside Radius	Number Required Per Course: No. 2 Wedge	No. 1 Wedge	Straight	Total
6′- 0″	1′- 0″	5′- 0″	17	13	..	30
6′- 1″	1′- 0 5/32″	5′- 0 27/32″	16	14	..	30
6′- 2″	1′- 0 11/32″	5′- 1 21/32″	16	15	..	31
6′- 3″	1′- 0 ½″	5′- 2 ½″	16	15	..	31
6′- 4″	1′- 0 21/32″	5′- 3 11/32″	15	16	..	31
6′- 5″	1′- 0 27/32″	5′- 4 5/32″	15	17	..	32
6′- 6″	1′- 1″	5′- 5″	15	17	..	32
6′- 7″	1′- 1 5/32″	5′- 5 27/32″	15	18	..	33
6′- 8″	1′- 1 11/32″	5′- 6 21/32″	14	19	..	33
6′- 9″	1′- 1 ½″	5′- 7 ½″	14	19	..	33
6′-10″	1′- 1 21/32″	5′- 8 11/32″	14	20	..	34
6′-11″	1′- 1 27/32″	5′- 9 5/32″	13	21	..	34
7′- 0″	1′- 2″	5′-10″	13	21	..	34
7′- 1″	1′- 2 5/32″	5′-10 27/32″	12	23	..	35
7′- 2″	1′- 2 11/32″	5′-11 21/32″	12	23	..	35
7′- 3″	1′- 2 ½″	6′- 0 ½″	11	24	..	35
7′- 4″	1′- 2 21/32″	6′- 1 11/32″	11	25	..	36
7′- 5″	1′- 2 27/32″	6′- 2 5/32″	11	25	..	36
7′- 6″	1′- 3″	6′- 3″	10	26	..	36
7′- 7″	1′- 3 5/32″	6′- 3 27/32″	10	27	..	37
7′- 8″	1′- 3 11/32″	6′- 4 21/32″	10	27	..	37
7′- 9″	1′- 3 ½″	6′- 5 ½″	10	28	..	38
7′-10″	1′- 3 21/32″	6′- 6 11/32″	9	29	..	38
7′-11″	1′- 3 27/32″	6′- 7 5/32″	9	29	..	38
8′- 0″	1′- 4″	6′- 8″	9	30	..	39
8′- 1″	1′- 4 5/32″	6′- 8 27/32″	8	31	..	39
8′- 2″	1′- 4 11/32″	6′- 9 21/32″	8	31	..	39
8′- 3″	1′- 4 ½″	6′-10 ½″	7	33	..	40
8′- 4″	1′- 4 21/32″	6′-11 11/32″	7	33	..	40
8′- 5″	1′- 4 27/32″	7′- 0 5/32″	6	34	..	40
8′- 6″	1′- 5″	7′- 1″	6	35	..	41
8′- 7″	1′- 5 5/32″	7′- 1 27/32″	6	35	..	41
8′- 8″	1′- 5 11/32″	7′- 2 21/32″	5	36	..	41
8′- 9″	1′- 5 ½″	7′- 3 ½″	5	37	..	42
8′-10″	1′- 5 21/32″	7′- 4 11/32″	5	37	..	42
8′-11″	1′- 5 27/32″	7′- 5 5/32″	5	38	..	43
9′- 0″	1′- 6″	7′- 6″	4	39	..	43
9′- 2″	1′- 6 11/32″	7′- 7 21/32″	4	40	..	44
9′- 4″	1′- 6 21/32″	7′- 9 11/32″	3	41	..	44
9′- 6″	1′- 7″	7′-11″	2	43	..	45
9′- 8″	1′- 7 11/32″	8′- 0 21/32″	1	45	..	46
9′-10″	1′- 7 21/32″	8′- 2 11/32″	..	46	..	46
10′- 0″	1′- 8″	8′- 4″	..	47	..	47
10′- 6″	1′- 9″	8′- 9″	..	47	2	49
11′- 0″	1′-10″	9′- 2″	..	47	4	51
12′- 0″	2′- 0″	10′- 0″	..	47	9	56
13′- 0″	2′- 2″	10′-10″	..	47	13	60
14′- 0″	2′- 4″	11′- 8″	..	47	17	64
15′- 0″	2′- 6″	12′- 6″	..	47	22	69

For skewback illustration see page 508.

9″ ARCH THICKNESS—2½″ WEDGE BRICK

9″ x 4½″ x 2½″, 9″ x 6¾″ x 2½″ or 9″ x 9″ x 2½″

2.302″ (2-5/16″) RISE PER FOOT OF SPAN

Span	Rise	Inside Radius	Number Required Per Course: No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Total
1′- 6″	3 15/32″	1′- 1 15/32″	14	..	..	14
1′- 7″	3 21/32″	1′- 2 3/16″	13	1	..	14
1′- 8″	3 27/32″	1′- 2 15/16″	12	2	..	14
1′- 9″	4 1/32″	1′- 3 11/16″	11	4	..	15
1′-10″	4 7/32″	1′- 4 7/16″	10	5	..	15
1′-11″	4 13/32″	1′- 5 3/16″	10	6	..	16
2′- 0″	4 19/32″	1′- 5 15/16″	9	7	..	16
2′- 1″	4 25/32″	1′- 6 11/16″	9	8	..	17
2′- 2″	5″	1′- 7 7/16″	8	9	..	17
2′- 3″	5 3/16″	1′- 8 3/16″	7	11	..	18
2′- 4″	5 3/8″	1′- 8 15/16″	6	12	..	18
2′- 5″	5 9/16″	1′- 9 11/16″	5	13	..	18
2′- 6″	5 ¾″	1′-10 7/16″	5	14	..	19
2′- 7″	5 15/16″	1′-11 5/32″	4	15	..	19
2′- 8″	6 1/8″	2′- 0 21/32″	3	17	..	20
2′- 9″	6 11/32″	2′- 1 13/32″	2	18	..	20
2′-10″	6 17/32″	2′- 2 5/32″	2	19	..	21
2′-11″	6 23/32″	2′- 2 29/32″	1	20	..	21
3′- 0″	6 29/32″	2′- 3 21/32″	..	21	..	21
3′- 1″	7 3/32″	2′- 4 13/32″	..	21	1	22
3′- 2″	7 9/32″	2′- 5 5/32″	..	21	1	22
3′- 3″	7 15/32″	2′- 5 29/32″	..	21	2	23
3′- 4″	7 11/16″	2′- 6 21/32″	..	20	3	23
3′- 5″	7 7/8″	2′- 7 13/32″	..	20	4	24
3′- 6″	8 1/16″	2′- 8 3/8″	..	20	4	24
3′- 7″	8 ¼″	2′- 8 7/8″	..	20	5	25
3′- 8″	8 7/16″	2′- 9 5/8″	..	19	6	25
3′- 9″	8 5/8″	2′-10 3/8″	..	19	6	25
3′-10″	8 13/16″	2′-11 1/8″	..	18	8	26
3′-11″	9 1/32″	2′-11 7/8″	..	18	8	26
4′- 0″	9 7/32″	3′- 0 5/8″	..	18	9	27
4′- 1″	9 13/32″	3′- 1 3/8″	..	17	10	27
4′- 2″	9 19/32″	3′- 2 1/8″	..	17	11	28
4′- 3″	9 25/32″	3′- 2 7/8″	..	16	12	28
4′- 4″	9 31/32″	3′- 3 5/8″	..	16	13	29
4′- 5″	10 5/32″	3′- 4 3/8″	..	16	13	29
4′- 6″	10 3/8″	3′- 5 3/32″	..	16	14	30
4′- 7″	10 9/16″	3′- 5 27/32″	..	15	15	30
4′- 8″	10 ¾″	3′- 6 19/32″	..	15	16	31
4′- 9″	10 15/16″	3′- 7 11/32″	..	15	17	32
4′-10″	11 1/8″	3′- 8 3/32″	..	14	18	32
4′-11″	11 5/16″	3′- 8 27/32″	..	14	18	32
5′- 0″	11 ½″	3′- 9 19/32″	..	14	19	33
5′- 1″	11 23/32″	3′-10 11/32″	..	13	20	33
5′- 2″	11 29/32″	3′-11 3/32″	..	13	21	34
5′- 3″	1′- 0 3/32″	3′-11 27/32″	..	13	21	34
5′- 4″	1′- 0 9/32″	4′- 0 19/32″	..	13	22	35
5′- 5″	1′- 0 15/32″	4′- 1 11/32″	..	12	23	35
5′- 6″	1′- 0 21/32″	4′- 2 3/16″	..	12	23	35
5′- 7″	1′- 0 27/32″	4′- 2 13/16″	..	12	24	36
5′- 8″	1′- 1 1/16″	4′- 3 9/16″	..	11	25	36
5′- 9″	1′- 1 ¼″	4′- 4 5/16″	..	11	26	37
5′-10″	1′- 1 7/16″	4′- 5 1/16″				
5′-11″	1′- 1 5/8″					

Span	Rise	Inside Radius	Number Required Per Course: No. 1 Wedge	No. 1-X Wedge	Straight	Total
6′- 0″	1′- 1 13/16″	4′- 5 13/16″	11	26	..	37
6′- 1″	1′- 2″	4′- 6 9/16″	11	27	..	38
6′- 2″	1′- 2 3/16″	4′- 7 5/16″	10	28	..	38
6′- 3″	1′- 2 3/8″	4′- 8 1/16″	10	29	..	39
6′- 4″	1′- 2 19/32″	4′- 8 13/16″	10	29	..	39
6′- 5″	1′- 2 25/32″	4′- 9 9/16″	9	30	..	39
6′- 6″	1′- 2 31/32″	4′-10 5/16″	9	31	..	40
6′- 7″	1′- 3 5/32″	4′-11 1/32″	9	31	..	40
6′- 8″	1′- 3 11/32″	4′-11 25/32″	9	32	..	41
6′- 9″	1′- 3 17/32″	5′- 0 17/32″	8	33	..	41
6′-10″	1′- 3 23/32″	5′- 1 9/32″	8	34	..	42
6′-11″	1′- 3 15/16″	5′- 2 1/32″	8	34	..	42
7′- 0″	1′- 4 1/16″	5′- 2 25/32″	7	35	..	42
7′- 1″	1′- 4 5/16″	5′- 3 17/32″	7	36	..	43
7′- 2″	1′- 4 ½″	5′- 4 9/32″	7	36	..	43
7′- 3″	1′- 4 11/16″	5′- 5 1/32″	7	37	..	44
7′- 4″	1′- 4 7/8″	5′- 5 25/32″	6	38	..	44
7′- 5″	1′- 5 1/16″	5′- 6 17/32″	6	39	..	45
7′- 6″	1′- 5 9/32″	5′- 7 9/32″	6	39	..	45
7′- 7″	1′- 5 15/32″	5′- 8 1/32″	5	41	..	46
7′- 8″	1′- 5 21/32″	5′- 8 ¾″	5	41	..	46
7′- 9″	1′- 5 27/32″	5′- 9 ½″	4	42	..	46
7′-10″	1′- 6 1/32″	5′-10 ¼″	4	43	..	47
7′-11″	1′- 6 7/32″	5′-11″	4	43	..	47
8′- 0″	1′- 6 13/32″	5′-11 ¾″	4	44	..	48
8′- 1″	1′- 6 9/8″	6′- 0 ½″	3	45	..	48
8′- 2″	1′- 6 13/16″	6′- 1 ¼″	3	46	..	49
8′- 3″	1′- 7″	6′- 2″	3	46	..	49
8′- 4″	1′- 7 3/16″	6′- 2 ¾″	2	47	..	49
8′- 5″	1′- 7 3/8″	6′- 3 ½″	2	48	..	50
8′- 6″	1′- 7 9/16″	6′- 4 ¼″	2	48	..	50
8′- 7″	1′- 7 ¾″	6′- 5″	2	49	..	51
8′- 8″	1′- 7 31/32″	6′- 5 23/32″	1	50	..	51
8′- 9″	1′- 8 5/32″	6′- 6 15/32″	1	51	..	52
8′-10″	1′- 8 11/32″	6′- 7 7/32″	1	51	..	52
8′-11″	1′- 8 17/32″	6′- 7 31/32″	1	52	..	53
9′- 0″	1′- 8 23/32″	6′- 8 23/32″	..	53	..	53
9′- 6″	1′- 9 7/8″	7′- 1 7/32″	..	53	3	56
10′- 0″	1′-11 1/32″	7′- 5 11/16″	..	53	5	58
10′- 6″	2′- 0 3/16″	7′-10 3/16″	..	53	8	61
11′- 0″	2′- 1 5/16″	8′- 2 21/32″	..	53	11	64
11′- 6″	2′- 2 15/32″	8′- 7 5/32″	..	53	13	66
12′- 0″	2′- 3 7/8″	8′-11 5/8″	..	53	16	69
12′- 6″	2′- 4 23/32″	9′- 4 1/8″	..	53	18	71
13′- 0″	2′- 5 13/16″	9′- 8 19/32″	..	53	21	74
13′- 6″	2′- 7 3/32″	10′- 1 3/32″	..	53	24	77
14′- 0″	2′- 8 ¼″	10′- 5 9/16″	..	53	26	79
14′- 6″	2′- 9 3/8″	10′-10 1/16″	..	53	29	82
15′- 0″	2′-10 17/32″	11′- 2 17/32″	..	53	32	85

For skewback illustration see page 508.

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9″ ARCH THICKNESS—3″ WEDGE BRICK

9″ x 4½″ x 3″, 9″ x 6¾″ x 3″ or 9″ x 9″ x 3″

2.302″ (2-5/16″) RISE PER FOOT OF SPAN

This table can be used also for **13½″ x 9″ x 3″ arch brick** by substituting No. 1, 2, and 3 arch brick for the corresponding wedge brick.

Span	Rise	Inside Radius	Number Required Per Course: No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	Total
2′- 0″	4 19/32″	1′- 5 15/16″	14	..	..	14
2′- 1″	4 25/32″	1′- 6 11/16″	13	1	..	14
2′- 2″	5″	1′- 7 7/16″	13	1	..	14
2′- 3″	5 3/16″	1′- 8 3/16″	12	3	..	15
2′- 4″	5 3/8″	1′- 8 15/16″	12	3	..	15
2′- 5″	5 9/16″	1′- 9 11/16″	11	4	..	15
2′- 6″	5 3/4″	1′-10 7/16″	11	5	..	16
2′- 7″	5 15/16″	1′-11 5/32″	11	5	..	16
2′- 8″	6 1/8″	1′-11 29/32″	10	6	..	16
2′- 9″	6 11/32″	2′- 0 21/32″	10	7	..	17
2′-10″	6 17/32″	2′- 1 13/32″	10	7	..	17
2′-11″	6 23/32″	2′- 2 5/32″	10	8	..	18
3′- 0″	6 29/32″	2′- 2 29/32″	9	9	..	18
3′- 1″	7 3/32″	2′- 3 21/32″	9	9	..	18
3′- 2″	7 9/32″	2′- 4 15/32″	8	11	..	19
3′- 3″	7 15/32″	2′- 5 5/32″	8	11	..	19
3′- 4″	7 11/16″	2′- 5 29/32″	7	12	..	19
3′- 5″	7 1/8″	2′- 6 21/32″	7	13	..	20
3′- 6″	8 1/16″	2′- 7 13/32″	7	13	..	20
3′- 7″	8 1/4″	2′- 8 1/8″	6	14	..	20
3′- 8″	8 7/16″	2′- 8 7/8″	6	15	..	21
3′- 9″	8 5/8″	2′- 9 5/8″	6	15	..	21
3′-10″	8 13/16″	2′-10 3/8″	6	16	..	22
3′-11″	9 1/32″	2′-11 1/8″	5	17	..	22
4′- 0″	9 7/32″	2′-11 7/8″	4	18	..	22
4′- 1″	9 13/32″	3′- 0 5/8″	4	19	..	23
4′- 2″	9 19/32″	3′- 1 3/8″	4	19	..	23
4′- 3″	9 25/32″	3′- 2 1/8″	3	20	..	23
4′- 4″	9 31/32″	3′- 2 7/8″	3	21	..	24
4′- 5″	10 5/32″	3′- 3 5/8″	3	21	..	24
4′- 6″	10 3/8″	3′- 4 3/8″	3	22	..	25
4′- 7″	10 9/16″	3′- 5 3/32″	2	23	..	25
4′- 8″	10 3/4″	3′- 5 27/32″	2	23	..	25
4′- 9″	10 15/16″	3′- 6 19/32″	2	24	..	26
4′-10″	11 1/8″	3′- 7 11/32″	1	25	..	26
4′-11″	11 5/16″	3′- 8 3/32″	..	26	..	26
5′- 0″	11 1/2″	3′- 8 27/32″	..	27	..	27
5′- 1″	11 23/32″	3′- 9 19/32″	..	26	1	27
5′- 2″	11 29/32″	3′-10 11/32″	..	26	1	27
5′- 3″	1′- 0 3/32″	3′-11 3/32″	..	26	2	28
5′- 4″	1′- 0 9/32″	3′-11 27/32″	..	25	3	28
5′- 5″	1′- 0 15/32″	4′- 0 19/32″	..	25	4	29
5′- 6″	1′- 0 21/32″	4′- 1 11/32″	..	25	4	29
5′- 7″	1′- 0 27/32″	4′- 2 1/16″	..	24	5	29
5′- 8″	1′- 1 1/16″	4′- 2 13/16″	..	24	6	30
5′- 9″	1′- 1 1/4″	4′- 3 9/16″	..	23	7	30
5′-10″	1′- 1 7/16″	4′- 4 5/16″	..	23	7	30
5′-11″	1′- 1 5/8″	4′- 5 1/16″	..	23	8	31

Span	Rise	Inside Radius	Number Required Per Course: No. 2 Wedge	No. 1 Wedge	Straight	Total
6′- 0″	1′- 1 13/16″	4′- 5 13/16″	22	9	..	31
6′- 1″	1′- 2″	4′- 6 9/16″	22	9	..	31
6′- 2″	1′- 2 3/16″	4′- 7 5/16″	22	10	..	32
6′- 3″	1′- 2 3/8″	4′- 8 1/16″	21	11	..	32
6′- 4″	1′- 2 19/32″	4′- 8 13/16″	21	12	..	33
6′- 5″	1′- 2 25/32″	4′- 9 9/16″	20	13	..	33
6′- 6″	1′- 2 31/32″	4′-10 5/16″	20	13	..	33
6′- 7″	1′- 3 5/32″	4′-11 1/32″	20	14	..	34
6′- 8″	1′- 3 11/32″	4′-11 25/32″	19	15	..	34
6′- 9″	1′- 3 17/32″	5′- 0 17/32″	19	15	..	34
6′-10″	1′- 3 23/32″	5′- 1 9/32″	19	16	..	35
6′-11″	1′- 3 15/16″	5′- 2 1/32″	18	17	..	35
7′- 0″	1′- 4 1/8″	5′- 2 25/32″	18	17	..	35
7′- 1″	1′- 4 5/16″	5′- 3 17/32″	18	18	..	36
7′- 2″	1′- 4 1/2″	5′- 4 9/32″	17	19	..	36
7′- 3″	1′- 4 11/16″	5′- 5 1/32″	17	20	..	37
7′- 4″	1′- 4 7/8″	5′- 5 25/32″	16	21	..	37
7′- 5″	1′- 5 1/16″	5′- 6 17/32″	16	21	..	37
7′- 6″	1′- 5 9/32″	5′- 7 9/32″	16	22	..	38
7′- 7″	1′- 5 15/32″	5′- 8 1/32″	15	23	..	38
7′- 8″	1′- 5 21/32″	5′- 8 3/4″	15	23	..	38
7′- 9″	1′- 5 27/32″	5′- 9 1/2″	15	24	..	39
7′-10″	1′- 6 1/32″	5′-10 1/4″	14	25	..	39
7′-11″	1′- 6 7/32″	5′-11″	14	25	..	39
8′- 0″	1′- 6 13/32″	5′-11 3/4″	14	26	..	40
8′- 2″	1′- 6 13/16″	6′- 1 1/4″	13	28	..	41
8′- 4″	1′- 7 3/16″	6′- 2 3/4″	12	29	..	41
8′- 6″	1′- 7 9/16″	6′- 4 1/4″	11	31	..	42
8′- 8″	1′- 7 31/32″	6′- 5 23/32″	11	32	..	43
8′-10″	1′- 8 11/32″	6′- 7 7/32″	10	34	..	44
9′- 0″	1′- 8 23/32″	6′- 8 23/32″	9	35	..	44
9′- 2″	1′- 9 3/32″	6′-10 7/32″	8	37	..	45
9′- 4″	1′- 9 1/2″	6′-11 23/32″	8	38	..	46
9′- 6″	1′- 9 7/8″	7′- 1 7/32″	7	39	..	46
9′- 8″	1′-10 1/4″	7′- 2 11/16″	6	41	..	47
9′-10″	1′-10 5/8″	7′- 4 3/16″	6	42	..	48
10′- 0″	1′-11 1/32″	7′- 5 11/16″	5	44	..	49
10′- 2″	1′-11 13/32″	7′- 7 3/16″	4	45	..	49
10′- 4″	1′-11 29/32″	7′- 8 11/16″	3	47	..	50
10′- 6″	2′- 0 5/16″	7′-10 3/16″	3	48	..	51
10′- 8″	2′- 0 9/16″	7′-11 21/32″	2	50	..	52
10′-10″	2′- 0 15/16″	8′- 1 5/32″	1	51	..	52
11′- 0″	2′- 1 5/16″	8′- 2 21/32″	..	53	..	53
11′- 6″	2′- 2 15/32″	8′- 7 5/32″	..	53	2	55
12′- 0″	2′- 3 5/8″	8′-11 5/8″	..	53	4	57
13′- 0″	2′- 5 15/16″	9′- 8 19/32″	..	53	9	62
14′- 0″	2′- 8 1/4″	10′- 5 9/16″	..	53	13	66
15′- 0″	2′-10 17/32″	11′- 2 17/32″	..	53	18	71

For skewback illustration see page 508.

12″ ARCH THICKNESS—3″ WEDGE BRICK

12″ x 4½″ x 3″, 12″ x 6″ x 3″ or 12″ x 9″ x 3″

1.608″ (1-19/32″) RISE PER FOOT OF SPAN (60° CENTRAL ANGLE)

Span	Rise	Inside Radius	Number Required Per Course: No 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Total
6′- 0″	9 21/32″	6′- 0″	21	9	..	30
6′- 3″	10 1/16″	6′- 3″	20	11	..	31
6′- 6″	10 7/16″	6′- 6″	19	13	..	32
6′- 9″	10 27/32″	6′- 9″	18	15	..	33
7′- 0″	11 1/4″	7′- 0″	17	17	..	34
7′- 3″	11 21/32″	7′- 3″	16	19	..	35
7′- 6″	1′- 0 1/16″	7′- 6″	15	21	..	36
7′- 9″	1′- 0 15/32″	7′- 9″	14	23	..	37
8′- 0″	1′- 0 7/8″	8′- 0″	13	25	..	38
8′- 3″	1′- 1 1/4″	8′- 3″	12	27	..	39
8′- 6″	1′- 1 21/32″	8′- 6″	11	29	..	40
8′- 9″	1′- 2 1/16″	8′- 9″	10	31	..	41
9′- 0″	1′- 2 15/32″	9′- 0″	8	34	..	42
9′- 3″	1′- 2 7/8″	9′- 3″	7	36	..	43
9′- 6″	1′- 3 9/32″	9′- 6″	6	38	..	44
9′- 9″	1′- 3 11/16″	9′- 9″	5	40	..	45
10′- 0″	1′- 4 1/16″	10′- 0″	4	42	..	46
10′- 3″	1′- 4 15/32″	10′- 3″	4	44	..	48
10′- 6″	1′- 4 7/8″	10′- 6″	3	46	..	49
10′- 9″	1′- 5 9/32″	10′- 9″	1	49	..	50
11′- 0″	1′- 5 11/16″	11′- 0″	..	51	..	51
11′- 3″	1′- 6 3/32″	11′- 3″	..	50	2	52
11′- 6″	1′- 6 1/4″	11′- 6″	..	48	5	53
11′- 9″	1′- 6 3/8″	11′- 9″	..	47	7	54
12′- 0″	1′- 7 9/32″	12′- 0″	..	46	9	55
12′- 3″	1′- 7 11/16″	12′- 3″	..	45	11	56
12′- 6″	1′- 8 3/32″	12′- 6″	..	44	13	57
12′- 9″	1′- 8 1/2″	12′- 9″	..	43	15	58
13′- 0″	1′- 8 29/32″	13′- 0″	..	42	17	59
13′- 3″	1′- 9 5/16″	13′- 3″	..	41	19	60
13′- 6″	1′- 9 11/16″	13′- 6″	..	40	21	61
13′- 9″	1′-10 3/32″	13′- 9″	..	39	23	62
14′- 0″	1′-10 1/2″	14′- 0″	..	38	25	63
14′- 3″	1′-10 29/32″	14′- 3″	..	37	27	64
14′- 6″	1′-11 5/16″	14′- 6″	..	36	29	65
14′- 9″	1′-11 23/32″	14′- 9″	..	35	31	66
15′- 0″	2′- 0 1/8″	15′- 0″	..	34	33	67
15′- 3″	2′- 0 17/32″	15′- 3″	..	32	36	68
15′- 6″	2′- 0 29/32″	15′- 6″	..	32	38	70
15′- 9″	2′- 1 5/16″	15′- 9″	..	31	40	71

Span	Rise	Inside Radius	Number Required Per Course: No. 1 Wedge	No. 1-X Wedge	Straight	Total
16′- 0″	2′- 1 23/32″	16′- 0″	..	30	42	72
16′- 3″	2′- 2 1/8″	16′- 3″	..	29	44	73
16′- 6″	2′- 2 17/32″	16′- 6″	..	28	46	74
16′- 9″	2′- 2 15/16″	16′- 9″	..	27	48	75
17′- 0″	2′- 3 11/32″	17′- 0″	..	25	51	76
17′- 3″	2′- 3 29/32″	17′- 3″	..	24	53	77
17′- 6″	2′- 4 1/8″	17′- 6″	..	23	55	78
17′- 9″	2′- 4 17/32″	17′- 9″	..	22	57	79
18′- 0″	2′- 4 15/16″	18′- 0″	21	59	..	80
18′- 3″	2′- 5 11/32″	18′- 3″	20	61	..	81
18′- 6″	2′- 5 3/4″	18′- 6″	19	63	..	82
18′- 9″	2′- 6 5/32″	18′- 9″	18	65	..	83
19′- 0″	2′- 6 17/32″	19′- 0″	17	67	..	84
19′- 3″	2′- 6 15/16″	19′- 3″	16	69	..	85
19′- 6″	2′- 7 11/32″	19′- 6″	15	71	..	86
19′- 9″	2′- 7 3/4″	19′- 9″	14	73	..	87
20′- 0″	2′- 8 5/32″	20′- 0″	13	75	..	88
20′- 3″	2′- 8 9/16″	20′- 3″	12	77	..	89
20′- 6″	2′- 8 31/32″	20′- 6″	10	80	..	90
20′- 9″	2′- 9 11/32″	20′- 9″	10	82	..	92
21′- 0″	2′- 9 3/4″	21′- 0″	9	84	..	93
21′- 3″	2′-10 5/32″	21′- 3″	8	86	..	94
21′- 6″	2′-10 9/16″	21′- 6″	7	88	..	95
21′- 9″	2′-10 31/32″	21′- 9″	6	90	..	96
22′- 0″	2′-11 3/8″	22′- 0″	5	92	..	97
22′- 3″	2′-11 25/32″	22′- 3″	3	95	..	98
22′- 6″	3′- 0 3/16″	22′- 6″	2	97	..	99
22′- 9″	3′- 0 9/16″	22′- 9″	1	99	..	100
23′- 0″	3′- 0 31/32″	23′- 0″	..	101	..	101
23′- 3″	3′- 1 3/8″	23′- 3″	..	101	1	102
23′- 6″	3′- 1 25/32″	23′- 6″	..	101	2	103
23′- 9″	3′- 2 3/16″	23′- 9″	..	101	3	104
24′- 0″	3′- 2 19/32″	24′- 0″	..	101	4	105
24′- 3″	3′- 3″	24′- 3″	..	101	5	106
24′- 6″	3′- 3 3/8″	24′- 6″	..	101	6	107
24′- 9″	3′- 3 25/32″	24′- 9″	..	101	7	108
25′- 0″	3′- 4 3/16″	25′- 0″	..	101	8	109
25′- 3″	3′- 4 19/32″	25′- 3″	..	101	9	110
25′- 6″	3′- 5″	25′- 6″	..	101	10	111
25′- 9″	3′- 5 13/32″	25′- 9″	..	101	11	112

For skewback illustration see page 509.

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13½″ ARCH THICKNESS—3″ WEDGE BRICK

13½″ x 4½″ x 3″, 13½″ x 6″ x 3″ or 13½″ x 9″ x 3″

1.608″ (1-19/32″) RISE PER FOOT OF SPAN (60° CENTRAL ANGLE)

Span	Rise	Inside Radius	Number Required Per Course: No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Total
6′- 0″	9 21/32″	6′- 0″	27	3	..	30
6′- 3″	10 1/16″	6′- 3″	26	5	..	31
6′- 6″	10 7/16″	6′- 6″	25	7	..	32
6′- 9″	10 27/32″	6′- 9″	24	9	..	33
7′- 0″	11 1/4″	7′- 0″	22	12	..	34
7′- 3″	11 21/32″	7′- 3″	21	14	..	35
7′- 6″	1′- 0 1/16″	7′- 6″	21	16	..	37
7′- 9″	1′- 0 15/32″	7′- 9″	20	18	..	38
8′- 0″	1′- 0 7/8″	8′- 0″	19	20	..	39
8′- 3″	1′- 1 1/4″	8′- 3″	18	22	..	40
8′- 6″	1′- 1 21/32″	8′- 6″	17	24	..	41
8′- 9″	1′- 2 1/16″	8′- 9″	16	26	..	42
9′- 0″	1′- 2 15/32″	9′- 0″	14	29	..	43
9′- 3″	1′- 2 7/8″	9′- 3″	13	31	..	44
9′- 6″	1′- 3 9/32″	9′- 6″	12	33	..	45
9′- 9″	1′- 3 11/16″	9′- 9″	11	35	..	46
10′- 0″	1′- 4 1/16″	10′- 0″	10	37	..	47
10′- 3″	1′- 4 15/32″	10′- 3″	9	39	..	48
10′- 6″	1′- 4 7/8″	10′- 6″	8	41	..	49
10′- 9″	1′- 5 9/32″	10′- 9″	7	43	..	50
11′- 0″	1′- 5 11/16″	11′- 0″	6	45	..	51
11′- 3″	1′- 6 3/32″	11′- 3″	5	47	..	52
11′- 6″	1′- 6 1/2″	11′- 6″	4	49	..	53
11′- 9″	1′- 6 7/8″	11′- 9″	3	51	..	54
12′- 0″	1′- 7 9/32″	12′- 0″	2	53	..	55
12′- 3″	1′- 7 11/16″	12′- 3″	1	55	..	56
12′- 4½″	1′- 7 29/32″	12′- 4½″	..	57	..	57
12′- 6″	1′- 8 3/32″	12′- 6″	..	56	1	57
12′- 9″	1′- 8 1/2″	12′- 9″	..	55	4	59
13′- 0″	1′- 8 29/32″	13′- 0″	..	54	6	60
13′- 3″	1′- 9 5/16″	13′- 3″	..	53	8	61
13′- 6″	1′- 9 11/16″	13′- 6″	..	52	10	62
13′- 9″	1′-10 3/32″	13′- 9″	..	51	12	63
14′- 0″	1′-10 1/2″	14′- 0″	..	50	14	64
14′- 3″	1′-10 29/32″	14′- 3″	..	49	16	65
14′- 6″	1′-11 5/16″	14′- 6″	..	48	18	66
14′- 9″	1′-11 23/32″	14′- 9″	..	47	20	67
15′- 0″	2′- 0 1/8″	15′- 0″	..	46	22	68
15′- 3″	2′- 0 17/32″	15′- 3″	..	45	24	69
15′- 6″	2′- 0 29/32″	15′- 6″	..	44	26	70
15′- 9″	2′- 1 5/16″	15′- 9″	..	43	28	71
16′- 0″	2′- 1 23/32″	16′- 0″	..	41	31	72
16′- 3″	2′- 2 1/8″	16′- 3″	..	40	33	73
16′- 6″	2′- 2 17/32″	16′- 6″	..	39	35	74
16′- 9″	2′- 2 15/16″	16′- 9″	..	38	37	75

Span	Rise	Inside Radius	Number Required Per Course: No. 1 Wedge	No. 1-X Wedge	Straight	Total
17′- 0″	2′- 3 11/32″	17′- 0″	..	37	39	76
17′- 3″	2′- 3 23/32″	17′- 3″	..	36	41	77
17′- 6″	2′- 4 1/8″	17′- 6″	..	35	43	78
17′- 9″	2′- 4 17/32″	17′- 9″	..	34	45	79
18′- 0″	2′- 4 15/16″	18′- 0″	33	48	..	81
18′- 3″	2′- 5 11/32″	18′- 3″	32	50	..	82
18′- 6″	2′- 5 3/4″	18′- 6″	31	52	..	83
18′- 9″	2′- 6 5/32″	18′- 9″	30	54	..	84
19′- 0″	2′- 6 17/32″	19′- 0″	29	56	..	85
19′- 3″	2′- 6 15/16″	19′- 3″	28	58	..	86
19′- 6″	2′- 7 11/32″	19′- 6″	27	60	..	87
19′- 9″	2′- 7 3/4″	19′- 9″	26	62	..	88
20′- 0″	2′- 8 5/32″	20′- 0″	25	64	..	89
20′- 3″	2′- 8 9/16″	20′- 3″	24	66	..	90
20′- 6″	2′- 8 31/32″	20′- 6″	23	68	..	91
20′- 9″	2′- 9 11/32″	20′- 9″	22	70	..	92
21′- 0″	2′- 9 3/4″	21′- 0″	21	72	..	93
21′- 3″	2′-10 5/32″	21′- 3″	19	75	..	94
21′- 6″	2′-10 9/16″	21′- 6″	18	77	..	95
21′- 9″	2′-10 31/32″	21′- 9″	17	79	..	96
22′- 0″	2′-11 3/8″	22′- 0″	16	81	..	97
22′- 3″	2′-11 25/32″	22′- 3″	15	83	..	98
22′- 6″	3′- 0 3/16″	22′- 6″	14	85	..	99
22′- 9″	3′- 0 9/16″	22′- 9″	13	87	..	100
23′- 0″	3′- 0 31/32″	23′- 0″	12	89	..	101
23′- 3″	3′- 1 3/8″	23′- 3″	12	91	..	103
23′- 6″	3′- 1 25/32″	23′- 6″	10	94	..	104
23′- 9″	3′- 2 3/16″	23′- 9″	9	96	..	105
24′- 0″	3′- 2 19/32″	24′- 0″	8	98	..	106
24′- 3″	3′- 3″	24′- 3″	7	100	..	107
24′- 6″	3′- 3 3/8″	24′- 6″	6	102	..	108
24′- 9″	3′- 3 25/32″	24′- 9″	5	104	..	109
25′- 0″	3′- 4 3/16″	25′- 0″	4	106	..	110
25′- 6″	3′- 5″	25′- 6″	2	110	..	112
26′- 0″	3′- 5 13/16″	26′- 0″	..	113	1	114
26′- 6″	3′- 6 19/32″	26′- 6″	..	113	3	116
27′- 0″	3′- 7 13/32″	27′- 0″	..	113	5	118
27′- 6″	3′- 8 7/32″	27′- 0″	..	113	7	120
28′- 0″	3′- 9″	28′- 0″	..	113	9	122
28′- 6″	3′- 9 13/16″	28′- 6″	..	113	11	124
29′- 0″	3′-10 5/8″	29′- 0″	..	113	14	127
29′- 6″	3′-11 7/16″	29′- 6″	..	113	16	129
30′- 0″	4′- 0 7/32″	30′- 0″	..	113	18	131
30′- 6″	4′- 1 1/32″	30′- 6″	..	113	20	133

For skewback illustration see page 509.

15″ ARCH THICKNESS—3″ WEDGE BRICK

15″ x 6″ x 3″ or 15″ x 9″ x 3″

1.608″ (1-19/32″) RISE PER FOOT OF SPAN (60° CENTRAL ANGLE)

Span	Rise	Inside Radius	Number Required Per Course: No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Total
6′- 3″	10 1/16″	6′- 3″	32	..	..	32
6′- 6″	10 7/16″	6′- 6″	31	2	..	33
6′- 9″	10 27/32″	6′- 9″	30	4	..	34
7′- 0″	11 1/4″	7′- 0″	28	7	..	35
7′- 3″	11 21/32″	7′- 3″	27	9	..	36
7′- 6″	1′- 0 1/16″	7′- 6″	26	11	..	37
7′- 9″	1′- 0 15/32″	7′- 9″	25	13	..	38
8′- 0″	1′- 0 7/8″	8′- 0″	24	15	..	39
8′- 3″	1′- 1 1/4″	8′- 3″	23	17	..	40
8′- 6″	1′- 1 21/32″	8′- 6″	22	19	..	41
8′- 9″	1′- 2 1/16″	8′- 9″	21	21	..	42
9′- 0″	1′- 2 15/32″	9′- 0″	20	23	..	43
9′- 3″	1′- 2 7/8″	9′- 3″	19	25	..	44
9′- 6″	1′- 3 9/32″	9′- 6″	18	27	..	45
9′- 9″	1′- 3 11/16″	9′- 9″	17	29	..	46
10′- 0″	1′- 4 1/16″	10′- 0″	16	32	..	48
10′- 3″	1′- 4 15/32″	10′- 3″	15	34	..	49
10′- 6″	1′- 4 7/8″	10′- 6″	14	36	..	50
10′- 9″	1′- 5 9/32″	10′- 9″	13	38	..	51
11′- 0″	1′- 5 11/16″	11′- 0″	12	40	..	52
11′- 3″	1′- 6 3/32″	11′- 3″	11	42	..	53
11′- 6″	1′- 6 1/2″	11′- 6″	10	44	..	54
11′- 9″	1′- 6 7/8″	11′- 9″	9	46	..	55
12′- 0″	1′- 7 9/32″	12′- 0″	8	48	..	56
12′- 3″	1′- 7 11/16″	12′- 3″	7	50	..	57
12′- 6″	1′- 8 3/32″	12′- 6″	5	53	..	58
12′- 9″	1′- 8 1/2″	12′- 9″	4	55	..	59
13′- 0″	1′- 8 29/32″	13′- 0″	3	57	..	60
13′- 3″	1′- 9 5/16″	13′- 3″	2	59	..	61
13′- 6″	1′- 9 11/16″	13′- 6″	1	61	..	62
13′- 9″	1′-10 3/32″	13′- 9″	..	63	..	63
14′- 0″	1′-10 1/2″	14′- 0″	..	62	2	64
14′- 3″	1′-10 29/32″	14′- 3″	..	61	4	65
14′- 6″	1′-11 5/16″	14′- 6″	..	60	6	66
14′- 9″	1′-11 23/32″	14′- 9″	..	59	8	67
15′- 0″	2′- 0 1/8″	15′- 0″	..	58	10	68
15′- 3″	2′- 0 17/32″	15′- 3″	..	57	13	70
15′- 6″	2′- 0 29/32″	15′- 6″	..	56	15	71
15′- 9″	2′- 1 5/16″	15′- 9″	..	55	17	72
16′- 0″	2′- 1 23/32″	16′- 0″	..	54	19	73
16′- 3″	2′- 2 1/8″	16′- 3″	..	53	21	74
16′- 6″	2′- 2 17/32″	16′- 6″	..	52	23	75
16′- 9″	2′- 2 15/16″	16′- 9″	..	51	25	76
17′- 0″	2′- 3 11/32″	17′- 0″	..	49	28	77
17′- 3″	2′- 3 23/32″	17′- 3″	..	48	30	78
17′- 6″	2′- 4 1/8″	17′- 6″	..	47	32	79
17′- 9″	2′- 4 17/32″	17′- 9″	..	46	34	80

Span	Rise	Inside Radius	Number Required Per Course: No. 1 Wedge	No. 1-X Wedge	Straight	Total
18′- 0″	2′- 4 15/16″	18′- 0″	45	36	..	81
18′- 3″	2′- 5 11/32″	18′- 3″	44	38	..	82
18′- 6″	2′- 5 3/4″	18′- 6″	43	40	..	83
18′- 9″	2′- 6 5/32″	18′- 9″	42	42	..	84
19′- 0″	2′- 6 17/32″	19′- 0″	41	44	..	85
19′- 3″	2′- 6 15/16″	19′- 3″	40	46	..	86
19′- 6″	2′- 7 11/32″	19′- 6″	39	48	..	87
19′- 9″	2′- 7 3/4″	19′- 9″	38	50	..	88
20′- 0″	2′- 8 5/32″	20′- 0″	37	52	..	89
20′- 3″	2′- 8 9/16″	20′- 3″	36	54	..	90
20′- 6″	2′- 8 31/32″	20′- 6″	35	57	..	92
20′- 9″	2′- 9 11/32″	20′- 9″	34	59	..	93
21′- 0″	2′- 9 3/4″	21′- 0″	33	61	..	94
21′- 3″	2′-10 5/32″	21′- 3″	32	63	..	95
21′- 6″	2′-10 9/16″	21′- 6″	31	65	..	96
21′- 9″	2′-10 31/32″	21′- 9″	30	67	..	97
22′- 0″	2′-11 3/8″	22′- 0″	29	69	..	98
22′- 3″	2′-11 25/32″	22′- 3″	28	71	..	99
22′- 6″	3′- 0 3/16″	22′- 6″	26	74	..	100
22′- 9″	3′- 0 9/16″	22′- 9″	25	76	..	101
23′- 0″	3′- 0 31/32″	23′- 0″	24	78	..	102
23′- 3″	3′- 1 3/8″	23′- 3″	23	80	..	103
23′- 6″	3′- 1 25/32″	23′- 6″	22	82	..	104
23′- 9″	3′- 2 3/16″	23′- 9″	21	84	..	105
24′- 0″	3′- 2 19/32″	24′- 0″	20	86	..	106
24′- 3″	3′- 3″	24′- 3″	19	88	..	107
24′- 6″	3′- 3 3/8″	24′- 6″	18	90	..	108
24′- 9″	3′- 3 25/32″	24′- 9″	17	92	..	109
25′- 0″	3′- 4 3/16″	25′- 0″	16	94	..	110
25′- 3″	3′- 4 19/32″	25′- 3″	15	96	..	111
25′- 6″	3′- 5″	25′- 6″	14	98	..	112
25′- 9″	3′- 5 13/32″	25′- 9″	13	100	..	113
26′- 0″	3′- 5 13/16″	26′- 0″	12	103	..	115
26′- 3″	3′- 6 3/16″	26′- 3″	11	105	..	116
26′- 6″	3′- 6 19/32″	26′- 6″	10	107	..	117
26′- 9″	3′- 7″	26′- 9″	9	109	..	118
27′- 0″	3′- 7 13/32″	27′- 0″	8	111	..	119
27′- 3″	3′- 7 13/16″	27′- 3″	7	113	..	120
27′- 6″	3′- 8 7/32″	27′- 6″	6	115	..	121
27′- 9″	3′- 8 5/8″	27′- 9″	4	118	..	122
28′- 0″	3′- 9″	28′- 0″	3	120	..	123
28′- 3″	3′- 9 13/32″	28′- 3″	2	122	..	124
28′- 6″	3′- 9 13/16″	28′- 6″	1	124	..	125
28′- 9″	3′-10 7/32″	28′- 9″	..	126	..	126
29′- 0″	3′-10 5/8″	29′- 0″	..	126	1	127
29′- 6″	3′-11 7/16″	29′- 6″	..	126	3	129
30′- 0″	4′- 0 7/32″	30′- 0″	..	126	5	131
31′- 0″	4′- 1 27/32″	31′- 0″	..	126	9	135

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18″ ARCH THICKNESS—3″ WEDGE BRICK

18″ x 6″ x 3″ or 18″ x 9″ x 3″

1.608″ (1-19/32″) RISE PER FOOT OF SPAN (60° CENTRAL ANGLE)

Span	Rise	Inside Radius	Number Required Per Course			
			No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Total
8′- 0″	1′- 0 7/8″	8′- 0″	36	4	..	40
8′- 3″	1′- 1 1/4″	8′- 3″	35	6	..	41
8′- 6″	1′- 1 21/32″	8′- 6″	34	8	..	42
8′- 9″	1′- 2 1/16″	8′- 9″	32	11	..	43
9′- 0″	1′- 2 15/32″	9′- 0″	31	13	..	44
9′- 3″	1′- 2 7/8″	9′- 3″	30	15	..	45
9′- 6″	1′- 3 9/32″	9′- 6″	29	17	..	46
9′- 9″	1′- 3 11/16″	9′- 9″	29	19	..	48
10′- 0″	1′- 4 1/16″	10′- 0″	28	21	..	49
10′- 3″	1′- 4 15/32″	10′- 3″	27	23	..	50
10′- 6″	1′- 4 7/8″	10′- 6″	25	26	..	51
10′- 9″	1′- 5 9/32″	10′- 9″	24	28	..	52
11′- 0″	1′- 5 11/16″	11′- 0″	23	30	..	53
11′- 3″	1′- 6 3/32″	11′- 3″	22	32	..	54
11′- 6″	1′- 6 1/2″	11′- 6″	21	34	..	55
11′- 9″	1′- 6 7/8″	11′- 9″	20	36	..	56
12′- 0″	1′- 7 9/32″	12′- 0″	19	38	..	57
12′- 3″	1′- 7 11/16″	12′- 3″	18	40	..	58
12′- 6″	1′- 8 3/32″	12′- 6″	17	42	..	59
12′- 9″	1′- 8 1/2″	12′- 9″	16	44	..	60
13′- 0″	1′- 8 29/32″	13′- 0″	15	46	..	61
13′- 3″	1′- 9 5/16″	13′- 3″	14	48	..	62
13′- 6″	1′- 9 11/16″	13′- 6″	13	50	..	63
13′- 9″	1′-10 3/32″	13′- 9″	12	52	..	64
14′- 0″	1′-10 1/2″	14′- 0″	11	54	..	65
14′- 3″	1′-10 29/32″	14′- 3″	9	57	..	66
14′- 6″	1′-11 5/16″	14′- 6″	8	59	..	67
14′- 9″	1′-11 23/32″	14′- 9″	7	61	..	68
15′- 0″	2′- 0 1/8″	15′- 0″	7	63	..	70
15′- 3″	2′- 0 17/32″	15′- 3″	6	65	..	71
15′- 6″	2′- 0 29/32″	15′- 6″	5	67	..	72
15′- 9″	2′- 1 5/16″	15′- 9″	4	69	..	73
16′- 0″	2′- 1 23/32″	16′- 0″	2	72	..	74
16′- 3″	2′- 2 1/8″	16′- 3″	1	74	..	75
16′- 6″	2′- 2 17/32″	16′- 6″	..	76	..	76
16′- 9″	2′- 2 15/16″	16′- 9″	..	75	2	77
17′- 0″	2′- 3 11/32″	17′- 0″	..	74	4	78
17′- 3″	2′- 3 23/32″	17′- 3″	..	72	7	79
17′- 6″	2′- 4 1/8″	17′- 6″	..	71	9	80
17′- 9″	2′- 4 17/32″	17′- 9″	..	70	11	81
18′- 0″	2′- 4 15/16″	18′- 0″	..	69	13	82
18′- 3″	2′- 5 11/32″	18′- 3″	..	68	15	83
18′- 6″	2′- 5 3/4″	18′- 6″	..	67	17	84
18′- 9″	2′- 6 5/32″	18′- 9″	..	66	19	85
19′- 0″	2′- 6 17/32″	19′- 0″	..	65	21	86
19′- 3″	2′- 6 15/16″	19′- 3″	..	64	23	87
19′- 6″	2′- 7 11/32″	19′- 6″	..	63	25	88
19′- 9″	2′- 7 3/4″	19′- 9″	..	62	27	89
20′- 0″	2′- 8 5/32″	20′- 0″	..	61	29	90
20′- 3″	2′- 8 9/16″	20′- 3″	..	60	32	92
20′- 6″	2′- 8 31/32″	20′- 6″	..	59	34	93
20′- 9″	2′- 9 11/32″	20′- 9″	..	58	36	94
21′- 0″	2′- 9 3/4″	21′- 0″	..	57	38	95
21′- 3″	2′-10 5/32″	21′- 3″	..	56	40	96
21′- 6″	2′-10 9/16″	21′- 6″	..	55	42	97
21′- 9″	2′-10 31/32″	21′- 9″	..	54	44	98
22′- 0″	2′-11 3/8″	22′- 0″	..	53	46	99
22′- 3″	2′-11 25/32″	22′- 3″	..	52	48	100
22′- 6″	3′- 0 3/16″	22′- 6″	..	50	51	101
22′- 9″	3′- 0 9/16″	22′- 9″	..	49	53	102
23′- 0″	3′- 0 31/32″	23′- 0″	..	48	55	103
23′- 3″	3′- 1 3/8″	23′- 3″	..	47	57	104
23′- 6″	3′- 1 25/32″	23′- 6″	..	46	59	105
23′- 9″	3′- 2 3/16″	23′- 9″	..	45	61	106
24′- 0″	3′- 2 19/32″	24′- 0″	..	44	63	107
24′- 3″	3′- 3″	24′- 3″	..	43	65	108
24′- 6″	3′- 3 3/4″	24′- 6″	..	42	67	109
24′- 9″	3′- 3 25/32″	24′- 9″	..	41	69	110
25′- 0″	3′- 4 3/16″	25′- 0″	..	40	71	111
25′- 3″	3′- 4 19/32″	25′- 3″	..	39	73	112
25′- 6″	3′- 5″	25′- 6″	..	38	75	113
25′- 9″	3′- 5 13/32″	25′- 9″	..	37	78	115
26′- 0″	3′- 5 13/16″	26′- 0″	..	36	80	116
26′- 3″	3′- 6 3/16″	26′- 3″	..	35	82	117
26′- 6″	3′- 6 19/32″	26′- 6″	..	34	84	118
26′- 9″	3′- 7″	26′- 9″	..	33	86	119
27′- 0″	3′- 7 13/32″	27′- 0″	..	32	88	120
27′- 3″	3′- 7 13/16″	27′- 3″	..	31	90	121
27′- 6″	3′- 8 7/32″	27′- 6″	..	30	92	122
27′- 9″	3′- 8 5/8″	27′- 9″	..	29	94	123
28′- 0″	3′- 9″	28′- 0″	..	27	97	124
28′- 3″	3′- 9 13/32″	28′- 3″	..	26	99	125
28′- 6″	3′- 9 13/16″	28′- 6″	..	25	101	126
28′- 9″	3′-10 7/32″	28′- 9″	..	24	103	127
29′- 0″	3′-10 5/8″	29′- 0″	..	23	105	128
29′- 3″	3′-11 1/32″	29′- 3″	..	22	107	129
29′- 6″	3′-11 7/16″	29′- 6″	..	21	109	130
29′- 9″	3′-11 13/16″	29′- 9″	..	20	111	131
30′- 0″	4′- 0 7/32″	30′- 0″	..	19	113	132
30′- 3″	4′- 0 5/8″	30′- 3″	..	18	115	133
30′- 6″	4′- 1 1/32″	30′- 6″	..	17	117	134
30′- 9″	4′- 1 7/16″	30′- 9″	..	16	119	135
31′- 0″	4′- 1 27/32″	31′- 0″	..	15	122	137
31′- 3″	4′- 2 1/4″	31′- 3″	..	14	124	138
31′- 6″	4′- 2 21/32″	31′- 6″	..	13	126	139
31′- 9″	4′- 3 1/32″	31′- 9″	..	12	128	140
32′- 0″	4′- 3 7/16″	32′- 0″	..	11	130	141



GLOSSARY

HARBISON-WALKER REFRACTORIES COMPANY

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GLOSSARY

Abrasion of Refractories: Wearing away of the surfaces of refractory bodies in service by the scouring action of moving solids.

Absorption: As applied to ceramic products, the weight of water which can be absorbed by the ware, expressed as a percentage of the weight of the dry ware.

Acid-Proof Brick: Brick having low porosity and permeability, and high resistance to chemical attack or penetration by most commercial acids and some other corrosive chemicals.

Acid Refractories: Refractories such as silica brick, which contain a substantial proportion of free silica.

Aggregate: As applied to refractories, a ground mineral material, consisting of particles of various sizes, used with much finer sizes for making formed or monolithic bodies.

Air-Ramming*: A method of forming refractory shapes, furnace hearths, or other furnace parts by means of pneumatic hammers.

Air-Setting Refractories: Compositions of ground refractory materials which develop a strong bond upon drying. These refractories include mortars, plastic refractories, ramming mixes, and gunning mixes. They are marketed in both wet and dry condition. The dry compositions require tempering with water to develop the necessary consistency.

Alumina: Al_2O_3, the oxide of aluminum; melting point 3720°F. (2050°C.); in combination with H_2O (water), alumina forms the minerals diaspore, bauxite, and gibbsite; in combination with SiO_2 and H_2O, alumina forms kaolinite and other clay minerals.

Alumina-Silica Refractories: Refractories consisting essentially of alumina and silica, and including high-alumina, fireclay, and kaolin refractories.

Amorphous: Lacking crystalline structure or definite molecular arrangement; without definite external form.

Andalusite: A mineral having the theoretical composition $Al_2O_3 \cdot SiO_2$, corresponding to Al_2O_3 62.9%, SiO_2 37.1%. Specific gravity 3.1-3.2. Decomposes on heating, beginning at about 2460°F. (1350°C.) to form mullite ($3Al_2O_3 \cdot 2SiO_2$) and free silica.

Anneal: To remove internal stress by first heating and then cooling slowly.

Arc: As applied to circles, any portion of a circumference; as applied to electricity, the luminous bridge formed by the passage of a current across a gap between two conductors or terminals.

Arch, Flat: In furnace construction, a flat structure spanning an opening and supported by abutments at its extremities; the arch is formed of a number of special tapered brick, and the brick assembly is held in place by their keying action. Also called a jack arch. (See illustration on page 248.)

Arch, Sprung: In furnace construction, a bowed or curved structure which is supported by abutments at the sides or ends only, and which usually spans an opening or space between two walls.

Arch, Suspended: A furnace roof consisting of brick shapes suspended from overhead supporting members.

Arch Brick: A brick shape having six plane faces (two sides, two edges, and two ends), in which two faces (the sides) are inclined toward each other and one edge face is narrower than the other, as illustrated on page 478.

Asbestos: Commercially, any mineral which can be separated into flexible fibers.

Ash: The noncombustible residue which remains after burning a fuel or other combustible material.

Attrition: Wearing away by friction; abrasion.

Auger Machine: A machine for extruding ground clays in moist and stiffly plastic form, through a die by means of a revolving screw or auger.

Baddeleyite: A mineral composed of zirconia (ZrO_2). Specific gravity 5.8. Melting point 4890°F. (2700°C.).

Bagasse: The fibrous material remaining after the extraction of the juice from sugar cane.

Ball Clay: A highly plastic refractory bond clay of very fine grain, which has a wide range of vitrification and which burns to a light color; often high in carbonaceous matter.

Basic Refractories: Refractories which consist essentially of magnesia, lime, chrome ore, or forsterite, or mixtures of two or more of these.

Bauxite: (1) A high-alumina mineral, usually consisting of rounded concretionary grains embedded in a clay-like mass, and believed to consist essentially of alumina trihydrate ($Al_2O_3 \cdot 3H_2O$) and alumina hydrate ($Al_2O_3 \cdot H_2O$), in varying proportions. (2) Commercially, bauxite must contain at least 65 per cent alumina on a calcined basis.

Bauxitic Clay: A natural mixture of bauxite and clay, containing not less than 47 per cent nor more than 65 per cent alumina on a calcined basis.

Bentonite: A kind of clay derived from volcanic ash, and characterized by extreme fineness of grain. Its main constituent is the clay mineral montmorillonite. It is somewhat variable in composition and usually contains 5 to 10% of alkalies or alkaline earth oxides. One type has the capacity for absorption of large amounts of water, with enormous increase in volume.

Bessemer Process: A process for making steel by blowing air through molten pig iron, whereby most of the carbon and impurities are removed by oxidation; the process is carried out in a vessel known as a converter.

British Thermal Unit (Btu): The amount of heat required to raise the temperature of one pound of water one degree Fahrenheit at standard barometric pressure, and at a standard temperature.

Brucite: A mineral having the composition $MgO \cdot H_2O$, corresponding to MgO 69.0%, H_2O 31.0%. Specific gravity 2.38-2.40. A soft, waxy, translucent mineral which dissociates at moderate temperatures with the formation of MgO.

Bunker Oil: A heavy fuel oil formed by stabilization of the residual oil remaining after the cracking of crude petroleum.

Burn: The degree of heat treatment to which refractory brick are subjected in the firing process; also, the degree to which desired physical and chemical changes have been developed in the firing of a refractory material.

Burning (Firing) of Refractories*: The final heat treatment in a kiln to which refractory brick are subjected in the process of manufacture, for the purpose of developing bond and other necessary physical and chemical properties.

Calcination: A heat treatment to which many ceramic raw materials are subjected, preparatory to further processing or use, for the purpose of driving off volatile chemically combined components and effecting physical changes.

Calcite: A mineral having the composition $CaCO_3$, which corresponds to a composition of CaO 56.0%, CO_2 44.0%. Specific gravity 2.71 for pure calcite crystals. Calcite is the essential constituent of limestone, chalk, and marble, and a minor constituent of many other rocks.

Calorie (Small): The amount of heat required to raise the temperature of one gram of water one degree Centigrade at standard barometric pressure and standard temperature.

Calorie (Large): One thousand small calories.

Cap or Crown: The arched roof of a furnace, especially a glass-tank furnace.

Carbon Deposition: The deposition of amorphous carbon, resulting from the decomposition of carbon monoxide gas into carbon dioxide and carbon within a critical temperature range. When deposited within the pores of a refractory brick, the carbon may build up such pressure that it destroys the bond and causes the brick to disintegrate.

Carbon Refractory*: A manufactured refractory comprised substantially or entirely of carbon (including graphite).

Carbon—Ceramic Refractory*: A manufactured refractory comprised of carbon (including graphite) and one or more ceramic materials such as fire clay and silicon carbide.

Castable Refractory: A mixture of a heat-resistant aggregate and a heat-resistant hydraulic cement; for use, it is mixed with water and rammed or poured into place.

Catalyst: A substance which causes or accelerates a chemical change without being permanently affected by the reaction.

Cement: A finely divided substance which is workable when first prepared but which becomes hard and stone-like as a result of chemical reaction or crystallization; also, the compact groundmass which surrounds and binds together the larger fragments or particles in sedimentary rocks.

Ceramic Bond: In a ceramic body, the mechanical strength developed by a heat treatment which causes the cohesion of adjacent particles.

Ceramics: "Products made of inorganic materials by first shaping them and later hardening them by fire."—F. Singer. Originally, the term ceramics referred only to ware formed from clay and hardened by the action of heat, and to the art of making such ware. However, its significance has gradually been extended by usage, and it is now understood to include all refractory materials, cement, lime, plaster, pottery, glass, enamels, glazes, abrasives, electrical insulating products, and thermal insulating products made from clay or from other inorganic nonmetallic mineral substances.

Cermet: A product consisting of a mixture of ceramic material and finely divided metal; also referred to as ceramals.

Checkers: Brick used in furnace regenerators to recover heat from outgoing hot gases, and later to transmit the heat to cold air or gas entering the furnace; so-called because the brick are arranged in checkerboard patterns, with alternating brick units and open spaces.

Chemically-Bonded Brick: Brick manufactured by processes in which mechanical strength is imparted by chemical bonding agents instead of by firing.

Chord: As applied to circles, a straight line joining any two points on a circumference.

Chrome Brick*: A refractory brick manufactured substantially or entirely of chrome ore.

Chrome-Magnesite Brick: A refractory brick which may be either fired or chemically bonded, manufactured substantially of a mixture of chrome ore and dead-burned magnesite, in which the chrome ore predominates by weight.

Chrome Ore: A rock having as its essential constituent the mineral chromite or chrome spinel, which is a combination of FeO and MgO with Cr_2O_3, Al_2O_3, and usually a small proportion of Fe_2O_3. The composition, which is represented by the formula $(Fe, Mg)O \cdot (Cr, Al, Fe)_2O_3$, is extremely variable. Refractory grade chrome ore has only minor amounts of accessory minerals, and has physical properties that are suitable for the manufacture of refractory products.

Clay: A natural mineral aggregate, consisting essentially of hydrous aluminum silicates. See also Fire Clay.

Colloid: "A condition of the dispersion of a substance in a medium, the peculiar characters of the substance depending upon the size of the particles."—Friend.

Colloidal particles are so small that they are invisible under the microscope. Their diameters are believed to lie roughly between one-tenth and one-thousandth of a micron. Glue, starch, and gelatin are typical colloids, and many clays are colloidal at least in part.

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Conductivity: The property of conducting heat, electricity, or sound.

Congruent Melting: The change of a substance, when heated, from the solid form to a liquid of the same composition. The melting of ice is an example of congruent melting.

Convection: The transfer of heat by the circulation or movement of the heated parts of a liquid or gas.

Corbel: A supporting projection of the face of a wall; an arrangement of brick in a wall in which each course projects beyond the one immediately below it to form a support, shelf, or baffle.

Corrosion of Refractories: Deterioration or wearing away of refractory bodies largely at their surfaces through chemical action of external agencies.

Corundum: A natural or synthetic mineral theoretically consisting solely of alumina (Al_2O_3). Specific gravity 4.00-4.02. Melting point 3720°F. (2050°C.). Hardness 8.8.

Course: A horizontal layer or row of brick in a structure.

Cristobalite: A mineral form of silica; stable from 2678° F. (1470°C.) to the melting point, 3133°F. (1723°C.). Specific gravity is 2.32. Cristobalite is an important constituent of silica brick.

Crown: A furnace roof, especially one which is dome-shaped; the highest point of an arch.

Cryptocrystalline: A crystalline structure in which the individual crystals are so small that they cannot be made visible by means of the petrographic microscope. Various so-called amorphous minerals are actually cryptocrystalline.

Crystal: A chemically homogeneous solid body having a definite internal molecular structure and, if developed under favorable conditions, having a characteristic external form, bounded by plane surfaces.

Crystalline: Composed of crystals.

Dead-Burned Dolomite: A coarsely granular refractory material prepared by firing raw dolomite with or without additives, to a temperature above 2800°F., so as to form primarily lime and magnesia in a matrix that provides resistance to hydration and carbonation.

Dead-Burned Magnesite: A coarsely granular dense refractory material composed essentially of periclase (crystalline magnesium oxide); prepared by firing raw magnesite (or other substances convertible to magnesia) at temperatures sufficiently high to drive off practically all of the volatile materials, and to effect complete shrinkage of the resultant magnesia, thereby producing hard dense grains which are almost entirely inert to atmospheric hydration and carbonation, and free from excessive shrinkage when again subjected to a high temperature.

Deairing: Removal of air from firebrick mixes in an auger machine before extrusion, by means of a partial vacuum.

Density: The mass of a unit volume of a substance. It is usually expressed either in grams per cubic centimeter, or in pounds per cubic foot.

Devitrification: The change from a glassy to a crystalline condition.

Diaspore: A mineral having the theoretical composition $Al_2O_3 \cdot H_2O$, corresponding to 85% alumina and 15% water of combination. Specific gravity 3.45. Decomposes when heated to high temperatures and forms corundum (Al_2O_3).

Diaspore Clay: A rock consisting essentially of diaspore bonded by flint clay. Commercial diaspore clay of the purest grade usually contains between 70 and 80% alumina after calcination.

Diatomaceous Earth: A hydrous form of silica which is soft, light in weight, and consists mainly of microscopic shells of diatoms or other marine organisms. It is widely used for furnace insulation.

Dobie: A molded block of ground clay or other refractory material, usually crudely formed, and either raw or fired.

Dolomite: The mineral calcium-magnesium carbonate, having the theoretical composition $CaO \cdot MgO \cdot 2CO_2$ which corresponds to CaO 30.4%, MgO 21.9%, CO_2 47.7%. Specific gravity 2.85-2.95. The rock called dolomite consists mainly of the mineral of that name and may also contain a large amount of the mineral calcite ($CaO \cdot CO_2$).

Dry Pan: A pan-type rotating grinding machine, equipped with heavy steel rollers or mullers which do the grinding, and having slotted plates in the bottom through which the ground material passes out.

Dusting: Conversion of a refractory material either wholly or in part, into fine powder or dust. Dusting usually results from (1) chemical reactions such as hydration; or (2) from mineral inversion accompanied by large and abrupt change in volume, such as the inversion of beta to gamma dicalcium silicate upon cooling.

Dutch Oven: A combustion chamber built outside and connected with a furnace.

Electron Beam Furnace: A furnace in which metals are melted in a vacuum at very high temperatures by bombardment with electrons.

Emissivity, Thermal: The capacity of a material for radiating heat; commonly expressed as a fraction or percentage of the ideal "black body" radiation of heat which is the maximum theoretically possible.

Erosion of Refractories: Mechanical wearing away of the surfaces of refractory bodies in service by the washing action of moving liquids, such as molten slags or metals.

Eutectic Temperature: The lowest melting temperature in a series of mixtures of two or more components.

Exfoliate: To expand and separate into rudely parallel layers or sheets, under the action of heat.

Extrusion: A process in which plastic material is forced through a die by the application of pressure.

Fayalite: A mineral having the composition $2FeO \cdot SiO_2$, corresponding to FeO 70.6%, SiO_2 29.4%. Specific gravity 4.0-4.1. Melting point 2201°F. (1205°C.).

Feldspar: A group of aluminum silicate minerals. The most important feldspars are: (a) the potash group, of which orthoclase and microcline ($K_2O \cdot Al_2O_3 \cdot 6SiO_2$) are the most common, and (b) the soda-lime group, of which albite ($Na_2O \cdot Al_2O_3 \cdot 6SiO_2$) and anorthite ($CaO \cdot Al_2O_3 \cdot 2SiO_2$) form the end members of a continuous series of solid solutions. Specific gravity 2.55-2.76. Melting points 2050° to 2820°F. (1120° to 1550°C.).

Fillet: The concave curved junction of two surfaces which would otherwise meet at an angle. Fillets are used at reentrant angles in the design of brick shapes, to lessen the danger of cracking.

Firebrick: Refractory brick of any type.

Fire Clay: An earthy or stony mineral aggregate which has as the essential constituent hydrous silicates of aluminum with or without free silica, plastic when sufficiently pulverized and wetted, rigid when subsequently dried, and of sufficient purity and refractoriness for use in commercial refractory products.

Fireclay Brick: A refractory brick manufactured substantially or entirely from fire clay.

Flat Arch: An arch in which both outer and inner surfaces are horizontal planes. (See sketch on page 248.)

Flint: A hard fine-grained cryptocrystalline rock, composed essentially of silica.

Flint Clay: A hard or flint-like fire clay which has very low natural plasticity and which usually breaks with a smooth or shell-like fracture.

Flux: A substance or mixture which promotes fusion of a solid material by chemical action.

Fluxing: Fusion or melting of a substance as a result of chemical action.

Forsterite: A mineral having the composition $2MgO \cdot SiO_2$, corresponding to MgO 57.3%, SiO_2 42.7%. Specific gravity 3.21. Melting point approximately 3450°F. (1900°C.).

Friable: Easily reduced to a granular or powdery condition.

Furnace Chrome: A mortar material prepared from finely ground chrome ore, suitable for laying brick or for patching or daubing in furnaces.

Furnace Magnesite: A mortar material prepared from finely ground dead-burned magnesite, suitable for use as a joint material in laying magnesite brick, and for patching or daubing furnace masonry.

Fused-Cast Refractories: Refractories formed by electrical fusion followed by casting and annealing.

Fusion: A state of fluidity or flowing, in consequence of heat; the softening of a solid body, either through heat alone or through heat and the action of a flux, to such a degree that it will no longer support its own weight, but will slump or flow. Also the union or blending of materials, such as metals, upon melting, with the formation of alloys.

Fusion Point: The temperature at which melting takes place. Most refractory materials have no definite melting points, but soften gradually over a range of temperatures.

Ganister: A dense, high-silica rock (quartzite), suitable for the manufacture of silica brick. Confusion sometimes results from the use of this term, because it is also applied in some parts of the United States to crushed firebrick or to mixtures of either crushed firebrick or silica rock with clay, for use in tamped linings.

Gibbsite: The mineral $Al_2O_3 \cdot 3H_2O$. Theoretical composition: Al_2O_3 65.4%, H_2O 34.6%. Specific gravity 2.3-2.4.

Glass*: An inorganic product of fusion which has cooled to a rigid condition without crystallizing.

Grain Magnesite: Dead-burned magnesite in the form of granules, generally ranging in size from about ⅜ inch in diameter to very fine particles.

Grain Size: As applied to ground refractory materials, the relative proportions of particles of different sizes; usually determined by separation into a series of fractions by screening.

Grog: A granular product produced by crushing and grinding calcined or burned refractory material, usually of alumina-silica composition.

Ground Fire Clay: Fire clay or a mixture of fire clays that have been subjected to no mechanical treatment other than crushing and grinding.

Grout: A suspension of mortar material in water, of such consistency that when it is poured upon horizontal courses of brick masonry, it will flow into vertical open joints.

Gunning: The application of monolith-forming refractories by means of air-placement guns.

Halloysite: One of the clay minerals; a hydrated silicate of alumina similar in composition to kaolinite, but amorphous and containing more water; approximate composition $Al_2O3 \cdot 2SiO_2 \cdot 2H_2O + nH_2O$, corresponding to SiO_2 43.5%, Al_2O_3 36.9%, water 19.6%.

Header: A brick laid on flat with its longest dimension perpendicular to the face of a wall.

Heat-Setting Refractories: Compositions of ground refractory materials which require relatively high temperatures for the development of an adequate bond, commonly called the ceramic bond.

Hematite: The mineral Fe_2O_3 (red iron ore). Theoretical composition: iron 70%, oxygen 30%. Specific gravity 4.9-5.3.

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High-Alumina Refractories: Alumina-silica refractories containing 45% or more alumina. The materials used in their production include diaspore, bauxite, gibbsite, kyanite, sillimanite, andalusite, and fused alumina (artificial corundum).

High-Duty Fireclay Brick: Fireclay brick which have a P.C.E. not lower than Cone 31½ or above 32½-33.

Hydrate, (verb): To combine chemically with water.

Hydraulic-Setting Refractories: Compositions of ground refractory materials in which some of the components react chemically with water to form a strong hydraulic bond. These refractories are commonly known as castables.

Illite: A mica-like mineral of small particle size containing less alkali and more water of composition than muscovite mica.

Impact Pressing: A process for forming refractory shapes, in which the ground particles of refractory material are packed closely together by rapid vibration.

Incongruent Melting: Dissociation of a compound upon heating, with the formation of another compound and a liquid of different composition from the original compound.

Ingot Mold: A mold in which ingots are cast.

Insulating Firebrick: A firebrick having a low thermal conductivity and suitable for use in the insulation of industrial furnaces.

Inversion: A change in crystal form without change in chemical composition; as for example, the change from low-quartz to high-quartz, or the change from quartz to cristobalite.

Isomorphous Mixture: A type of solid solution, in which mineral compounds of analogous chemical composition and closely related crystal habit crystallize together in various proportions.

Jack Arch: See "Arch, Flat."

Jamb: (1) A vertical structural member forming the side of an opening in a furnace wall. (2) A type of brick shapes, as illustrated on page 479, intended for use in the sides of wall openings.

Kaldo Process (Stora): An oxygen process for making steel.

Kaliophilite: A mineral having the composition $K_2O \cdot Al_2O_3 \cdot 2SiO_2$, corresponding to K_2O 29.8%, Al_2O_3 32.2%, SiO_2 38.0%.

Kaolin: A white-burning clay having kaolinite as its chief constituent. Specific gravity 2.4-2.6. The P.C.E. of most commercial kaolins ranges from Cone 33 to Cone 35.

Kaolinite: A mineral consisting theoretically of $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$, corresponding to 39.5% alumina, 46.5% silica, and 14.0% combined water. Kaolinite is the principal constituent of most kaolins and fire clays. Specific gravity 2.59. The P.C.E. of pure kaolinite is Cone 35.

Key: In furnace construction, the uppermost or the closing brick of a curved arch.

Key Brick: A brick shape having six plane faces (two sides, two edges, and two ends), in which two faces (the edges) are inclined toward each other and one of the end faces is narrower than the other, as illustrated on page 478.

K-factor: The thermal conductivity of a material, expressed in standard units.

Kyanite: Also spelled cyanite. A mineral having the theoretical formula $Al_2O_3 \cdot SiO_2$, and the chemical composition Al_2O_3 62.9%, SiO_2 37.1%. Specific gravity 3.56-3.67. Decomposition begins at about 2415°F. (1325°C.) with the formation of mullite and free silica.

Ladle: A refractory-lined vessel used for the temporary storage or transfer of molten metals.

L-D Process: A process for making steel by blowing oxygen upon or through molten pig iron, whereby most of the carbon and impurities are removed by oxidation.

Limestone: A sedimentary rock composed essentially of the mineral calcite ($CaCO_3$) or of calcite mixed with dolomite ($CaCO_3 \cdot MgCO_3$). Specific gravity 2.6-2.8.

Limonite: A mineral consisting of hydrated ferric oxide; the essential component of "brown ore." Approximate composition Fe_2O_3 85%, H_2O 15%. Specific gravity 3.6-4.0.

Lintel: A horizontal supporting member spanning a wall opening.

Loss on Ignition: As applied to chemical analyses, the loss in weight which results from heating a sample of material to a high temperature, after preliminary drying at a temperature just above the boiling point of water. The loss in weight upon drying is called "free moisture"; that which occurs above the boiling point, "loss on ignition."

Low-Duty Fireclay Brick: Fireclay brick which have a P.C.E. not lower than Cone 15, nor higher than 28-29.

Magnesioferrite: One of the spinel group of minerals; theoretical composition $MgO \cdot Fe_2O_3$, which corresponds to MgO 20.15%, Fe_2O_3 79.85%. Rarely found in nature; usually constitutes the brown coloring material in magnesite brick. Specific gravity 4.57-4.65.

Magnesite: A mineral consisting of magnesium carbonate $MgCO_3$, and theoretically containing 47.8% magnesia and 52.2% carbon dioxide; a rock containing the mineral magnesite as its essential consituent. See also "magnesite, caustic," and "dead-burned magnesite."

Magnesite Brick: A refractory brick manufactured substantially or entirely of dead-burned magnesite which consists essentially of magnesia in crystalline form (periclase).

Magnesite, Caustic: The product obtained by calcining magnesite, or other substances convertible to magnesia upon heating, at a temperature generally not exceeding 2200°F. The product is readily reactive to water and to atmospheric moisture and carbon dioxide.

Magnesite-Chrome Brick: A refractory brick, which may be either fired or chemically bonded, manufactured substantially of a mixture of dead-burned magnesite (magnesia) and refractory chrome ore, in which the magnesite predominates by weight.

Magnesium Hydroxide: The compound of magnesium oxide and chemically combined water, $MgO \cdot H_2O$; composition MgO 69.0%, H_2O 31.0%. Naturally occurring magnesium hydroxide is known as brucite.

Magnetite: Fe_3O_4 (magnetic iron ore). Composition: iron 72.4%, oxygen 27.6%; specific gravity 5.17-5.18; strongly magnetic. Melting point about 2901°F. (1594°C.).

Medium-Duty Fireclay Brick: A fireclay brick with a P.C.E. value not lower than 29 nor higher than 31-31½.

Melting Point: The temperature at which crystalline and liquid phases having the same composition coexist in equilibrium. Metals and most pure crystalline materials have sharp melting points, i.e., they change abruptly from solid to liquid at definite temperatures. However, most refractory materials have no true melting points, but melt progressively over a relatively wide range of temperatures.

Metalkase Brick: Basic brick provided with thin steel casings.

Mica: A group of rock minerals having nearly perfect cleavage in one direction and consisting of thin elastic plates. The most common varieties are muscovite and biotite.

Micron: The one-thousandth part of a millimeter (0.001 mm.); a unit of measurement used in microscopy.

Mineral: A mineral species is a natural inorganic substance which is either definite in chemical composition and physical characteristics or which varies in these respects within definite natural limits. Most minerals have a definite crystalline structure; a few are amorphous.

Modulus of Elasticity (Physics): A measure of the elasticity of a solid body; the ratio of stress (force) to strain (deformation) within the elastic limit.

Modulus of Rupture: A measure of the transverse or "cross-breaking" strength of a solid body.

Monolithic Lining: A furnace lining without joints, formed of material which is rammed, cast, gunned, or sintered into place.

Monticellite: A mineral having the theoretical composition $CaO \cdot MgO \cdot 2SiO_2$, corresponding to CaO 34.9%, MgO 25.6%, SiO_2 39.5%. Specific gravity 3.1-3.25; melts incongruently at 2730°F. (1499°C.) to form MgO and a liquid.

Montmorillonite: (1) A clay mineral having the theoretical composition $Al_2O_3 \cdot 4SiO_2 \cdot H_2O + nH_2O$; (2) a group of clay minerals, all hydrous silicates of aluminum, some of which contain certain variable percentages of magnesia, lime, iron oxide, and other components; a common constituent of bentonites.

Mortar (Refractory): A finely ground refractory material which becomes plastic when mixed with water, and is suitable for use in laying refractory brick.

Mullite: A mineral having the theoretical composition $3Al_2O_3 \cdot 2SiO_2$, corresponding to Al_2O_3 71.8%, SiO_2 28.2%. Specific gravity 3.15. An important constituent of fireclay and high-alumina brick. Melting point under equilibrium conditions approximately 3362°F. (1850°C.).

Mullite Refractories*: Refractory products consisting predominantly of mullite ($3Al_2O_3 \cdot 2SiO_2$) crystals formed either by conversion of one or more of the sillimanite group of minerals or by synthesis from appropriate materials employing either melting or sintering processes.

Muscovite: One of the mica group of minerals; composition approximately $K_2O \cdot 3Al_2O_3 \cdot 6SiO_2 \cdot 2H_2O$, corresponding to K_2O 11.8%, Al_2O_3 38.5%, SiO_2 45.2%, H_2O 4.5%.

Nephelite: A mineral having the theoretical composition $Na_2O \cdot Al_2O_3 \cdot 2SiO_2$. A common reaction product in furnaces wherein slags or vapors of high soda content come into contact with fireclay or high-alumina brick. Stable at 2278°F. (1248°C.) at which temperature it inverts to the mineral carnegieite, which has the same composition, but a different crystalline form. Natural nephelite contains a small amount of potash. Specific gravity 2.67.

Neutral Refractory: A refractory material which is neither acid nor basic, such as carbon.

Nine-Inch Equivalent: A brick volume equal to that of a standard 9″ x 4½″ x 2½″ straight brick; the unit of measurement of brick quantities in the refractories industry.

Nodule Clay: A rock containing aluminous or ferruginous nodules, or both, bonded by flint clay; called "burley" clay or "burley flint" clay in some districts.

Noselite: A silicate mineral; approximate composition, $2(Na_2O \cdot Al_2O_3 \cdot 2SiO_2) + Na_2O \cdot SO_3$, corresponding to Na_2O 26%, Al_2O_3 29%, SiO_2 34%, SO_3 11%.

Olivine: A series of minerals having the general formula $2RO \cdot SiO_2$, in which RO is MgO, CaO, FeO, and sometimes MnO. More specifically, chrysolite, a continuous mineral series consisting of forsterite ($2MgO \cdot SiO_2$) and fayalite ($2FeO \cdot SiO_2$) in varying proportions. Specific gravity 3.27-3.37, increasing with the amount of iron present.

Overfiring: A heat treatment which causes deformation or bloating of clay or clay ware.

Oxiduction: Alternate oxidation and reduction.

Oxygen Process: A process for making steel in which oxygen is blown upon or through molten pig iron, whereby most of the carbon and impurities are removed by oxidation.

Periclase: The mineral or crystalline form of magnesium oxide. Specific gravity 3.58. Melting point approximately 5070°F. (2800°C.).

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Perlite: A siliceous glassy rock composed of small spheroids, varying in size from small shot to peas; combined water content, 3 to 4%. When heated to a suitable temperature, perlite expands to form a lightweight glassy material with a cellular structure.

Permeability: The property of porous materials which permits the passage of gases and liquids under pressure. The permeability of a body is largely dependent upon the number, size and shape of the open connecting pores, and is measured by the rate of flow of a standard fluid under definite pressure.

Plasma Jet: Ionized gas produced by passing an inert gas through a high-intensity arc, causing temperatures up to tens of thousands degrees centigrade.

Plastic Chrome Ore: An air-setting ramming material having a base of refractory chrome ore and shipped in plastic form ready for use.

Plastic Fire Clay: A fire clay which has sufficient natural plasticity to bond together other materials which have little or no plasticity.

Plastic Refractory: A blend of ground refractory materials in plastic form, suitable for ramming into place to form monolithic linings.

Plasticity: That property of a material that enables it to be molded into desired forms, which are retained after the pressure of molding has been released.

Pores: As applied to refractories, the small voids between solid particles. Pores are described as "open" if permeable to fluids; "sealed" if impermeable.

Porosity of Refractories: The ratio of the volume of the pores or voids in a body to the total volume, usually expressed as a percentage. The "true porosity" is based upon the total pore-volume; the "apparent porosity" upon the open pore-volume only.

Power Pressing: The forming of refractory brick shapes, from ground refractory material containing an optimum amount of added water, by means of high pressure applied vertically in a power-driven press.

Pug Mill: A machine used for blending and tempering clays in a moist or stiffly plastic condition.

Pyrite: The most common sulfide mineral; composition FeS_2, corresponding to Fe 46.6%, S 53.4%. Specific gravity 4.9-5.2. Color, brass-yellow. Used mainly for making sulfuric acid and sulfates.

Pyrometric Cone: One of a series of pyramidal-shaped pieces consisting of mineral mixtures, and used for measuring time-temperature effect. A standard pyrometric cone is a three-sided truncated pyramid; and, approximately, is either 2⅜ inches high by ⅝-inch wide at base, or 1⅛ inches high by ⅜-inch wide at base. Each cone is of a definite mineral composition, and has a number stamped upon one face; and when heated under standard conditions, it bends at a definite temperature.

Pyrometric Cone Equivalent (P.C.E.)*: The number of that Standard Pyrometric Cone whose tip would touch the supporting plaque simultaneously with a cone of the refractory material being investigated, when tested in accordance with the Method of Test for Pyrometric Cone Equivalent (P.C.E.) of Refractory Materials (A.S.T.M. Designation C 24).

Pyrophyllite: A mineral consisting of hydrated silicate of aluminum, having the theoretical formula $Al_2O_3 \cdot 4SiO_2 \cdot H_2O$, corresponding to 28.3% alumina, 66.7% silica, 5.0% combined water.

Pyroplasticity: The physical state induced by soaking heat which permits a refractory body to be readily deformed under pressure or by its own weight.

Quartz: A common mineral, consisting of silica (SiO_2). Sandstones and quartzites are composed largely of quartz. Specific gravity 2.65.

Quartzite: A hard compact rock consisting predominantly of quartz. There are two types: (1) metaquartzite, a metamorphic rock usually derived from sandstone; and (2) orthoquartzite, a sedimentary rock consisting of grains of silica sand, cemented together by at least 10 per cent of precipitated silica.

Ramming Mixi A ground refractory material which is mixed with water and rammed into place for patching shapes or for forming monolithic furnace linings.

Recuperator: A system of thin-walled refractory ducts used for the purpose of transferring heat from a heated gas to colder air or gas.

Refractories: Nonmetallic materials suitable for use at high temperatures in furnace construction. While their primary function is resistance to high temperature, they are usually called upon to resist other destructive influences also, such as abrasion, pressure, chemical attack, and rapid changes in temperature.

Refractoriness: In ceramics, the property of resistance to melting, softening or deformation at high temperatures. For fireclay and some high-alumina materials the most commonly used index of refractoriness is that known as the Pyrometric Cone Equivalent.

Refractory, adj.: Chemically and physically stable at high temperatures.

Refractory Clay: An earthy or stony mineral aggregate which has as the essential constituent hydrous silicates of aluminum with or without free silica, plastic when sufficiently pulverized and wetted, rigid when subsequently dried, and of sufficient purity and refractoriness for use in commercial refractory products.

Regenerator: A refractory structure in which thermal energy from hot furnace gases is alternately absorbed by checker brick work and released to cold air or gas.

Regenerator Checkers: Brick used in furnace regenerators to recover heat from hot outgoing gases, and later to release this heat to cold air or gas entering the furnace; so called because of the checkerboard pattern in which the brick are arranged.

Rise of Arches: The vertical distance between the level of the spring lines and the highest point of the under surface of an arch.

Rock: A naturally occurring mineral aggregate consisting of one or more minerals. For example, quartzite rock is an aggregate consisting essentially of crystals of the mineral quartz; granite is an aggregate consisting essentially of crystals of feldspar and quartz.

Rowlock Course: A course of brick laid on edge with their longest dimensions perpendicular to the face of a wall.

Rutile: A mineral consisting of titanium dioxide (TiO_2). Specific gravity 4.18-4.25.

Screen Analysis: The size distribution of noncohering particles as determined by screening through a series of standard screens.

Secondary Expansion: The property exhibited by some fireclay and high-alumina refractories of developing permanent expansion at temperatures within their useful range; not the same as overfiring.

Semi-Silica Fireclay Brick: A fireclay brick containing not less than 72% silica.

Serpentine: A group of hydrous magnesium silicate minerals. Chrysotile and antigorite, $3MgO \cdot 2SiO_2 \cdot 2H_2O$, are the most common. Specific gravity 2.5-2.7. Also, a common rock consisting essentially of serpentine minerals.

Silica: SiO_2, the oxide of silicon. Quartz and chalcedony are common silica materials; quartzite, sandstone and sand are composed largely of free silica in the form of quartz.

Silica Brick: A fired refractory consisting essentially of silica, and usually made from quartzite bonded with about 1.8 to 3.5% of added lime.

Silica Fire Clay*: A refractory mortar consisting of a finely ground mixture of quartzite, silica brick, and fire clay of various proportions; often called silica cement.

Silicon Carbide: A compound of silicon and carbon; formula, SiC.

Silicon Carbide Refractories*: Refractory products consisting predominantly of silicon carbide.

Sillimanite: A mineral having the formula $Al_2O_3 \cdot SiO_2$; composition: Al_2O_3 62.9%, SiO_2 37.1%. Specific gravity 3.24. At about 2785°F. (1530°C.) it begins to dissociate into mullite and free silica.

Sintering: A heat treatment which causes adjacent particles of material to cohere, at a temperature below that of complete melting.

Skewback: The course of brick, having an inclined face, from which an arch is sprung.

Slag: A substance formed in any one of several ways by chemical action and fusion at furnace operating temperatures:

1. In smelting operations, through the combination of a flux, such as limestone, with the gangue or waste portion of the ore.
2. In the refining of metals, by substances such as lime added for the purpose of effecting or aiding the refining.
3. By chemical reaction between refractories and fluxing agents such as coal ash, or between two different types of refractories.

Slagging of Refractories*: Destructive chemical action between refractories and external agencies at high temperatures, resulting in the formation of a liquid.

Slurry: A suspension of finely pulverized solid material in water, of creamy consistency.

Soapstone: A soft magnesium silicate rock consisting mainly of talc.

Soldier Course: A course of brick set on end; little used in the case of refractories except in the bottoms of some types of furnaces.

Solid Solution: A homogeneous crystalline phase with a variable composition. The most common solid solutions involve two or more substances having the same crystalline structure. However, the term may also refer to the solution of small proportions of a material in a seemingly unrelated substance.

Spalling of Refractories: The loss of fragments (spalls) from the face of a refractory structure, through cracking and rupture, with exposure of inner portions of the original refractory mass.

Specific Gravity: The ratio between the weight of a unit volume of a substance and that of some other standard substance, under standard conditions of temperature and pressure. For solids and liquids, the specific gravity is based upon water as the standard.

The "true specific gravity" of a body is based on the volume of solid material, excluding all pores. The bulk or volume specific gravity is based upon the volume as a whole, i.e., the solid material with all included pores. The apparent specific gravity is based upon the volume of the solid material plus the volume of the sealed pores.

Specific Heat: The quantity of heat required to raise the temperature of a unit mass of a substance one degree.

Spinel: (1) The mineral composed of magnesium aluminate ($MgO \cdot Al_2O_3$); theoretical composition 28.2% MgO, 71.8% Al_2O_3; specific gravity 3.6; melting point 3875°F. (2135°C). (2) A group of minerals which crystallize in the cubic system, and which have the formula $RO \cdot R_2O_3$; the RO may consist of one or more of the bivalent oxides MgO, FeO, MnO, or ZnO, and the R_2O_3 of one or more of the trivalent oxides Al_2O_3, Cr_2O_3, or Fe_2O_3.

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Sprung Arch: An arch which is supported by abutments at the side or ends only.

Stretcher: A brick laid on flat with its length parallel to the face of the wall.

Superduty Fireclay Brick: Fireclay brick which have a P.C.E. not lower than Cone 33, and which meet certain other requirements as outlined in A.S.T.M. Designation: C 27-58T.

Suspended Arch: An arch in which the brick shapes are suspended from overhead supporting members.

Taconite: A compact ferruginous chert or slate in which the iron oxide is so finely disseminated that substantially all of the iron-bearing particles are smaller than 20 mesh. Typical analyses of the ore grade shows total Fe 32.0%.

Talc: A hydrous magnesium silicate mineral having the theoretical composition $3MgO{\cdot}4SiO_2{\cdot}H_2O$, corresponding to MgO 31.7%, SiO_2 63.5%, H_2O 4.8%. Specific gravity 2.7-2.8.

Thermal Conductivity: The property of matter by virtue of which heat energy is transmitted through particles in contact.

Thermal Expansion: The increase in linear dimensions and volume which occurs when materials are heated and which is counterbalanced by contraction of equal amount when the materials are cooled.

Thermal Shock: A sudden transient temperature change.

Tolerance: The permissible deviation in a dimension or property of a material from an established standard, or from an average value.

Tridymite: A mineral form of silica; stable from 1598°F. to 2678°F. (870°C. to 1470°C.). Specific gravity 2.26. An important constituent of silica brick.

Vacuum Pressing: A method of forming brick shapes by which they are subjected to a partial vacuum during pressing in a power press.

Vermiculite: A group of micaceous minerals, all hydrated silicates, varying widely in composition. When heated, vermiculite exfoliates and increases greatly in volume.

Vesicular: Having a cellular structure; applied to fire clays which have become bloated by overfiring.

Vibratory Pressing: A process for forming refractory shapes, in which the ground particles of refractory material are packed closely together by rapid impact-type vibrations of the top and bottom dies; also called impact pressing.

Vitrification: A process of permanent chemical and physical change at high temperatures in a ceramic body, such as fire clay, with the development of a substantial proportion of glass.

Warpage: The deviation of the surface of a refractory shape from that intended, caused by bending or bowing during manufacture.

Wedge Brick: A brick shape having six plane faces (two sides, two edges, and two ends), in which two faces (the sides) are inclined toward each other, and one end face is narrower than the other, as illustrated on page 478.

Wetting: The adherence of a film of liquid to the surface of a solid.

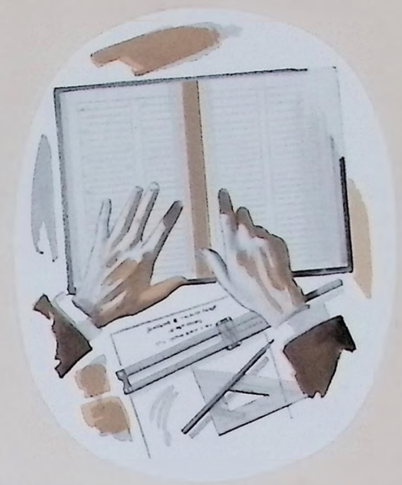
Wollastonite: A mineral having the theoretical formula $CaO{\cdot}SiO_2$, equivalent to CaO 48.3%, SiO_2 51.7%. Specific gravity 2.9. Inverts at 2192°F. (1200°C.) to pseudowollastonite. Melts incongruently at 2811°F. (1544°C.).

Young's Modulus: In mechanics, the ratio of tensile stress to elongation within the elastic limit; the modulus of elasticity.

Zircon: The mineral $ZrO{\cdot}SiO_2$. Composition: ZrO_2 67.1%, SiO_2 32.9%; specific gravity 4.7; begins to melt incongruently at 3045°F. (1685°C.) forming ZrO_2 solid solution plus liquid; completely melted at about 4800°F. (2650°C.).

Zirconia: Zirconium oxide, ZrO_2. Specific gravity 5.8. Melting point 4890°F. (2700°C.). Its chief source is the mineral baddeleyite.

* *A.S.T.M. Standard Definitions C 71-57; or A.S.T.M. "Tentative Definitions."*



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ERRATA
MODERN REFRACTORY PRACTICE
Fourth Edition

It is suggested that the following corrections be indicated on the appropriate pages in the book to avoid error in case of loss of Errata Sheet.

P. 514—For Frustum of a Cone, second formula from bottom, "Volume $= \frac{1}{3}\ \pi h\ (a + \sqrt{aA} + A)$" should read "Volume $= \frac{1}{3} h(a + \sqrt{aA} + A)$"

P. 573—Right-hand portion of table, the first eight lines of tabulation of brick combinations should read as follows:

Span	Rise	Inside Radius	Number Required Per Course			
			No. 1 Wedge	No. 1-X Wedge	Straight	Total
16′- 0″	2′- 1 23/32″	16′- 0″	30	42	..	72
16′- 3″	2′- 2 1/8″	16′- 3″	29	44	..	73
16′- 6″	2′- 2 17/32″	16′- 6″	28	46	..	74
16′- 9″	2′- 2 15/16″	16′- 9″	27	48	..	75
17′- 0″	2′- 3 11/32″	17′- 0″	25	51	..	76
17′- 3″	2′- 3 23/32″	17′- 3″	24	53	..	77
17′- 6″	2′- 4 1/8″	17′- 6″	23	55	..	78
17′- 9″	2′- 4 17/32″	17′- 9″	22	57	..	79

P. 574—Right-hand portion of table, the first four lines of tabulation of brick combinations should read as follows:

Span	Rise	Inside Radius	Number Required Per Course			
			No. 1 Wedge	No. 1-X Wedge	Straight	Total
17′- 0″	2′- 3 11/32″	17′- 0″	37	39	..	76
17′- 3″	2′- 3 23/32″	17′- 3″	36	41	..	77
17′- 6″	2′- 4 1/8″	17′- 6″	35	43	..	78
17′- 9″	2′- 4 17/32″	17′- 9″	34	45	..	79

P. 583—Left-hand column, for "Monticellite," the first part of the description should read "A mineral having the theoretical composition $CaO \cdot MgO \cdot SiO_2$, corresponding to CaO 35.9%, MgO 25.6%, SiO_2 38.5%."

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