PLAINTIFF'S EXHIBIT
UC-5310

GUIDE TO PHENOLIC MOLDING MATERIALS

A Collection of Articles Contributed by the Technical Staff, Thermosetting and Specialty Molding Materials, Union Carbide Corporation, Bound Brook, New Jersey

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1968-1969 MODERN PLASTICS ENCYCLOPEDIA

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McGraw Hill, Inc.
330 West 42 St., New York, N.Y. 10036

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CHEMICALS AND PLASTICS
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PART I

phenolic resins

By George J. Kuzmak/Union Carbide Corp.*

The development of phenolic resin molding materials by Dr. Leo H. Baekeland in 1909 launched the modern plastics industry. These thermosetting phenol formaldehyde materials permitted production of standardized, interchangeable parts capable of being mass produced. Through the years, phenolics have been the largest volume-produced thermosets and have come to be known as the "workhorse" plastics. Today, material and fabrication innovations have heightened interest in phenolic molding compounds.

This pioneer plastic was immediately recognized for its dimensional stability and insulating properties. The insulating support of a field coil in a line of new instruments, for which every form of molding material previously known had been found inadequate, became the first commercial phenolic application, in 1910. Others followed rapidly in the electrical, automotive, and communication fields. For nearly six decades, phenolics have been providing a better balance of properties and cost for many uses than any other available material.

Chemistry

The term "phenolic resins" includes a wide variety of products made by reacting phenol with an aldehyde. The commercial phenols are phenol, cresols, xylenols, p-t-butylphenol, p-phenylphenol, bisphenols, and resorcinol. The most important aldehydes are formaldehyde and furfural. Most important among the commercial phenolic resins is the one based on phenol and formaldehyde.

Phenolic resins are formed as a result of the four main reactions shown in Fig. 1. Relative rates of these reactions can be influenced by the catalyst used, especially pH dependent, on which basis reactions can be classified according to 1) basic catalysts yielding one-step resins, and 2) acidic catalysts yielding two-step resins. The characteristics of the materials formed can be varied widely by formulation.

The one-step or resol type phenolic resins, as manufactured, can completely polymerize upon heating. The one-step molding compounds have limited shelf life because they may continue to react in the storage container, especially in hot weather. Two-step or novalak resins require additional aldehyde or crosslinking agents such as hexamethylenetetramine ("hexa") to cure when heated. Molding compounds prepared from two-step resins have longer shelf life.

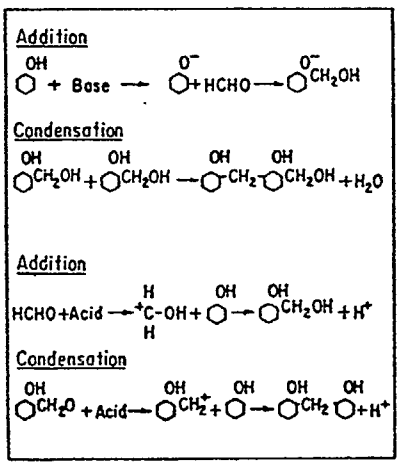


FIG. 1: Principal reactions in phenolic resin manufacture.

Properties

Molded phenolics have a high modulus of elasticity, excellent dimensional stability, strength, and rigidity. Their resistance to heat, chemicals, and moisture is exceptional, and they retain their mechanical properties over a wide temperature and humidity range.

The excellent water resistance of some of the phenolic compounds makes them preferred materials for wet-dry applications. They are widely used as washing machine agitators.

Because of their heat resistance, phenolics are commonly used for appliance parts. In addition, low heat conductivity permits their use for coffee pot and toaster handles, since heat transfer from the metallic appliance to the hand is minimized.

The effect of filler on the heat resistance of phenolics is shown in Fig. 2. For practical purposes, phenolic resin molded without filler would have no strength under heat. In general purpose compounds, substitution of wood-flour for some of the resin improves strength. Greater improvement is effected by loading with asbestos or other mineral fillers which also improve moisture resistance by the same order of magnitude. Mineral fillers offer maximum heat resistance.

High heat resistant phenolic materials, designated type 23 by ASTM Specification D-700, are available which can withstand 500° F. Figure 3 shows the effect of exposure time at this temperature for several phenolic compounds. It should be noted that the type 23 compound can stand 500° F. for weeks before significantly losing flexural strength.

Materials that have been developed to withstand increasingly higher temperatures also show improved resistance to water, with consequent improvement in electrical properties. For

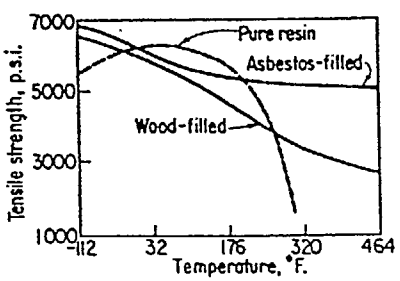


FIG. 2: Influence of fillers on phenolic heat resistance.

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example, the type 23 phenolic molding compound also has much better insulation resistance in humidity.

Several recently developed heat resistant phenolic materials have received provisional approval from Underwriters' Laboratory. These are stated to withstand 302° F., 320° F., and 338° F. indefinitely. Parts molded from the materials can be used at these temperatures without significant property changes. End use approval is still necessary. However, the use of approved basic material reduces exhaustive testing by Underwriters.

Unfilled phenolic resin is a good electrical insulator, although it must be combined with filler to give body and strength to molded parts. Because phenolic molding materials are hygroscopic, readily picking up moisture, electrical insulating characteristics are lowered under humid conditions. However, compounds containing an appropriate filler maintain improved electrical resistance. Mica-filled, low loss phenolic material far surpasses the woodflour filled, general purpose type in resistivity, particularly under humid conditions. Phenolics are used in certain high temperature electrical and electronic applications, such as grid caps for TV tubes. Many phenolic compounds offer excellent arc resistance, dielectric strength, and other electrical properties.

Phenolics are flame resistant and some compounds are self-extinguishing. They also have the advantage of being non-dripping, in contrast to thermoplastics.

Color is a limitation with phenolics because the lighter colors tend to darken in sunlight. However, phenolic molding compounds are available in black, brown, and colors darker than pastels. Despite this limiting factor, a substantial volume of phenolic business exists in colored closures, color coded electrical switches, and wire connectors.

New equipment and compounds

Today, improved phenolic molding compounds are being developed and advances are being made in molding equipment. Custom-formulated compounds permitting shorter cure times are now available for use in screw injection molding. The equipment innovations hold promise of revolutionizing the molding of many thermoset parts. Injection molding, until recently thought suitable only with thermoplastics, has been successfully adapted to thermoset molding on a commercial basis. (See Injection Molding of Thermosets in the Machinery and Methods Section of this Encyclopedia.)

Molding compounds and applications

Molding compounds generally consist of 40–50% phenolic resin, 40–50% filler, an accelerator, pigments, dyes, plasticizers, lubricants, and—for two-step resins—a hardener such as "hexa". Filler lowers the cost of the

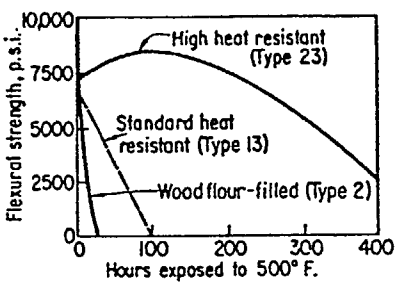


FIG. 3: Effect of 500° F. exposure time on strengths of phenolic molding compounds.

compound, alters its flow characteristics to reduce fluidity under molding pressure, and imparts special properties as required by the application. Because of their stability and physical and chemical compatibility with other materials, the phenolic resins are easily combined with powdered or fibrous fillers such as woodflour, cotton flock, pulp flock, coal, charcoal, asbestos, and metal.

The many phenolic molding compounds available are commonly classified in five categories identified as general purpose, heat resistant, impact resistant, electrical insulating, and special property types. More detailed classifications are available in the ASTM Tentative Specification for Phenolic Molding Compounds designated D700-63T.

General purpose compounds are usually woodflour filled compositions which permit the most popular balance of properties and price. They provide adequate electrical properties and mechanical strength for many insulation applications. Molded parts have a high gloss, smooth appearance, and a high heat distortion temperature. Numerous general purpose compositions, differing in cure speed, flow characteristics, granulation, odor level, and common electrical properties are available. At about 21½¢/lb., these compounds are the lowest priced phenolics and are cheaper than most other available thermosetting plastics. General purpose phenolic molding compounds are used for a wide range of applications, including appliance parts, closures, wiring devices, switchboards, and automotive parts.

Heat resistant phenolic compounds contain combinations of resin and mineral fillers. Compositions offering various levels of heat resistance are available at prices ranging from 21½¢/pound. Some compounds can withstand 500° F. for 200–300 hr. with little or no loss in strength or electrical properties. Typical applications for heat resistant phenolics are appliance, utensil, and oven parts, electrical switch gear, and resistors.

Impact resistant compounds are filled with cotton flock or other fibrous materials such as string, cloth clippings, or glass roving and offer high resistance to mechanical abuse or applied stress. Their Izod impact strengths range from about 0.4 to a high of 20 ft. lb/in. of notch. Price, which usually increases with impact strength, runs from 27¼¢/pound. Typical applications for impact resistant phenolics are vaporizer components, pump impellers, rocket components, and electrical switches.

Electrical insulating compounds offer special electrical characteristics superior to those of other phenolic molding types. They are formulated with mica or other mineral fillers to meet requirements such as lower dissipation factor and dielectric constant. Parts molded of these compounds maintain good electricals even after prolonged exposure to moisture. The electrical insulating phenolic compounds, priced from 32¢/lb., are used for tube bases, resistors, capacitors, and other electronic components.

Special property phenolic compounds, including chemical resistant types, are formulated for less common applications. Molding compositions are available that have improved resistance to organic solvents, acids, and alkalies for use in rayon fabricating equipment and other industrial parts in contact with chemical solutions. Self-lubricating phenolic molding compounds containing graphite or fluorocarbon fillers also are available for casters, rollers, guides, and other bearing applications.

Phenolic molding compounds are generally supplied in granular, nodular, or pelletized and macerated forms.

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Fiber-filled compounds are usually short rod-like nodules. Fabric-filled compounds are most often macerated in cut or shredded small sections. The granular form is the most common, and compounds are available in a variety of ASTM designated types.

Market growth

About a dozen years ago, the growth of phenolics was slowed down when some markets started switching from phenolics to new thermoplastics. However, thermosetting phenolic molding compounds continued to be the most important plastics materials for electrical parts. From 1954 to 1964, the consumption of phenolics in this market increased about 20% even though there was some replacement by molded thermoplastics.

The last few years have seen a general resurgence of interest in phenolics; development of new markets and the regaining of others previously lost. Domestic sales of phenolic molding materials in the United States totaled about 270 million lb. in 1966, a 7% increase over 1965 which was also a record-breaking year. Although sales in 1967 were back down to the 1965 level due to the general business recession, growth should continue.

Long used in automotive ignition systems, phenolics today are finding many applications in high performance automotive transmissions. At least two automobile companies are molding such phenolic parts.

Properties that have projected phenolics into this market are excellent dimensional and heat stability, strength, light weight, and resistance to hydraulic fluids. Moreover, phenolics can now be compression, transfer or injection molded. Phenolic is now used in a stator retainer in automatic transmissions. This retainer is exposed to hot hydraulic fluid, must take the thrust attempting to push the torque converter out of place, and withstand wear as parts move past each other. In service tests, life of the phenolic exceeded that of metal parts formerly used. Space rings are other transmission parts utilizing phenolics.

Screw injection molding is expected to contribute to the steady, continued growth in consumption of phenolic compounds, which offer good balance between properties and cost.—End

PART II

Designing with phenolics

By F. W. Ducca*

Phenolic molding compounds, properly used, offer durability usually attributable to metals—and save weight. They can also provide the added advantages of electrical insulation, and heat and corrosion resistance.

When designing parts to be fabricated from phenolic materials, careful consideration of mechanical strength is advisable. Phenolics do not have as high tensile or compressive strength as steel; however, they can withstand much greater loads than wood or such thermoplastic materials as polyethylene. For parts to be molded of phenolic, the lower modulus of elasticity, as compared to metals, must be taken into account and a relatively greater volume of material used. Nevertheless, by proper redesign, phenolics can, in many instances, satisfactorily replace metals. Their lower specific gravities make them attractive alternates.

Phenolic materials are hard and scratch resistant and, therefore, useful for applications where abrasion is involved. Phenolics are also low in thermal conductivity, making them good heat insulators (in contrast to metals). While the heat distortion of phenolics is normally considered to be about 325° F., there are some specialized phenolic compounds which will withstand temperatures up to 500° F. for weeks before loss of strength, serious distortion, or warpage occurs. Phenolics are used for many electronic components requiring good insulation combined with structural properties. Phenolic materials, because of their lower specific gravities are cheaper than metals on a cost/unit volume basis. Finishing operations are minimal with phenolic molded parts.

Molded phenolics offer rigidity, dimensional stability, and creep resistance; phenolics are significantly more creep resistant than are virtually all thermoplastics.

Phenolics show good weathering and aging characteristics. Molded parts have been exposed to typical United States weather conditions for prolonged periods of time without serious effect on their properties. Heat-resistant phenolics exposed for 2½ yr. under extremes of weather ranging from arctic to tropic, exhibited very slight changes in tensile strength.

Phenolic materials have excellent chemical resistance, and are used in many household appliances, e.g. as washing machine agitators and vapor-izer components. The chemical, salt water, and saline atmosphere resistance of phenolics have made them especially useful for applications requiring corrosion resistance.

High heat resistance is also an important reason for the use of phenolic in appliance parts. In addition, low heat conductivity permits their use for appliance handles, since heat transfer from the metallic appliance to the hand is minimized. The thermal conductivity of phenolics is 6 in contrast to 1200 for steel. Phenolics are self-extinguishing after having been exposed to flame, and are dripless—additional advantages over wood and thermoplastics.

Materials that have been developed to withstand increasingly higher temperatures also show improved resistance to water, with consequent improvement in electrical properties. For example, ASTM type 23 phenolic molding compound which can withstand 500° F. for several weeks before deteriorating in strength also has much better electrical resistance in a humid environment.

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Adhesives for phenolics †

Because thermosetting materials are not readily affected by most solvents as are many thermoplastics, other means of bonding must be employed. The condition and smoothness of the surface add to the difficulty in bonding parts together. While it is desirable that the parts match perfectly, some misalignment may be compensated for through use of a gap-filling cement.

The surface can be properly prepared by wiping with a solvent to remove any oily film, and then roughening the surface by lightly sanding. In some cases, however, it may be necessary to do some machining to remove surface contamination and provide a suitable surface for bonding.

The type adhesive or cement used should be chosen to meet the service requirements of the article to be joined. Epoxy resins have been found to bond well to phenolic parts.

Since most adhesive bonds improve with curing time, heating or baking will shorten the time required. Excessive temperature should be avoided as it may cause bubbles, excess loss of adhesive, or degradation of the adhesive or part itself. Whenever possible, parts being bonded should be clamped or held together under pressure until full cure is obtained.

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PART III

thermoset molding

By Edward W. Vaill/Union Carbide Corp.*

Compression and transfer

When thermosetting plastics are molded under heat and pressure, an irreversible chemical reaction takes place. Known as polymerization, it results in a change in molecular structure that converts it to a solid, infusible, insoluble state.

Thermosetting molding materials are usually supplied in a partially cured state and may be processed by compression or transfer (plunger) molding. (They may also be injection molded; see the article starting on p. 14.) Compression molding consists of placing the compound in an open heated mold cavity, closing the mold with a top force or plug section and applying pressure ranging from 2000 to 8000 p.s.i., according to the geometry of the mold. Since the mold temperature ranges from 280 to 380° F., the material absorbs heat and polymerizes, or cures to the finished state.

Transfer or plunger molding involves use of a plunger and heated pot separate from the mold cavity; the material is loaded into the pot and, when hot, is transferred under pressure from the pot through runners into a closed mold cavity.

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Handling before molding

Most thermosetting compounds are supplied in particulate form ranging from fine powders to granular materials of mesh sizes from 6 to 16. Other forms include fluffy rag filled, impact type compositions, special nodular impact materials with a lower bulk factor, and pastes and gunks.

Since most thermosetting molding compounds are somewhat hygroscopic and can absorb moisture from the atmosphere, relative humidity in the storage area should not exceed 65 percent. Excessive moisture absorption may affect not only mold flow behavior, but the physical properties of the molding as well. Phenolic molding materials should be stored at temperatures between 65 and 75° F.; lower temperatures may affect the preform properties and cure speed. The material should be brought to room temperature before using. Temperatures higher than 85° F. should be avoided since a slight amount of polymerization may occur at such temperatures and affect the flow properties of the resin.

An economical method of loading material into press hoppers is with an air type conveyor. Feeding is controlled automatically by limit switches in the hoppers, and the material is charged into an auxiliary hopper at floor level. When preforms are used it is essential to maintain uniformity from charge to charge, and it may therefore be desirable for the molder to tumble and then blend the material before charging the hopper of the preform press.

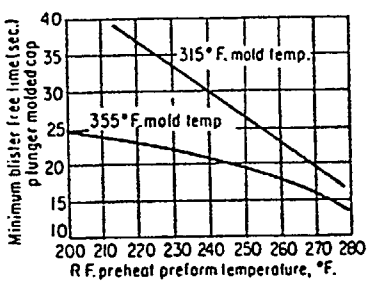
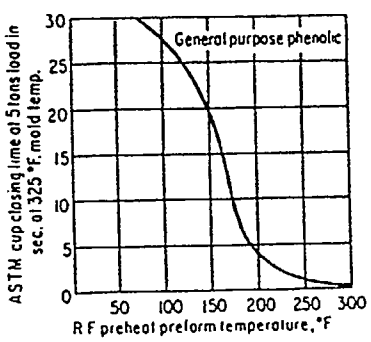


FIG. 1, above, and **FIG. 2,** below, chart the effects of R.F. preheat on cure time and on mold closing time.



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Preconditioning

Both predrying and preheating involve heating, but are different in application. Predrying drives off moisture and/or volatiles. Preheating is designed to deliver the molding material to the mold cavities at close to the required molding temperature, thus shortening the molding cycle by decreasing cure time. In many cases, drying and preheating can be done simultaneously. Preheating also promotes dimensional stability, reduces required molding pressure and may make possible larger molded parts in a given tonnage of compression molding press, since lower pressures may be used without undue risk.

The three primary methods for preheating thermosets are: 1) in a *circulating hot air oven*—steam, electricity, or burning gas may be used as a source of heat energy. The air should be circulated to avoid hot spots which result in non uniform heating; 2) *infra-red preheating*, which can be used to great advantage in automatic molding. Infrared lamps are mounted directly over the material in a special preheating hopper at the press. Constant hopper agitation prevents overheating of any part of the compound. This type of preheating can result in a 10% increase in productivity due to a shorter molding cycle; 3) *radio frequency or dielectric preheating*, the most effective and efficient method, especially for preforms. The heat is produced within the material in a matter of seconds. Loading board preheaters are designed to be used with multiple cavity compression molds on a semi-automatic basis.

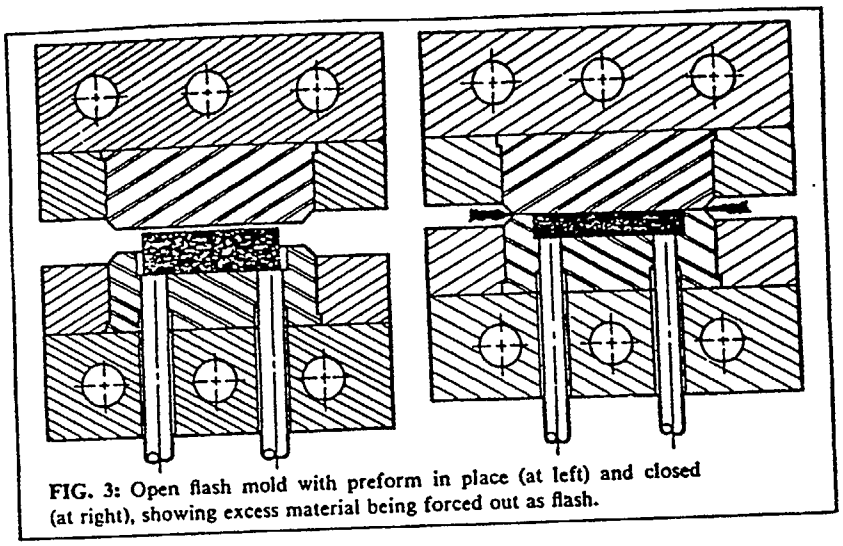


FIG. 3: Open flash mold with preform in place (at left) and closed (at right), showing excess material being forced out as flash.

Dielectric preheating can increase productivity by 20 to 60%, depending upon the geometry of the molded part and the material being used. Figures 1 and 2 illustrate the effects of dielectric preheating on cure and mold closing times.

Molded parts, whether produced by the compression or plunger methods, normally have higher density and less internal porosity when made from radio frequency preheated preforms than when the same parts are produced from cold powder or preforms. This promotes better physical properties, and also contributes to greater dimensional stability.

In radio frequency preheating, certain procedures should be followed to obtain maximum efficiency from the preheater. It is good practice to control preheat time automatically rather than leave the heating cycle to the discretion of the operator. The preheating time of the next mold charge should also run concurrently with the cure, so that there will be no loss of operating time over the complete cycle. The preforms should be uniformly hard, dense, and of uniform thickness, preferably rectangular and placed on their sides so that a constant dimension will be maintained between the preheater electrodes.

Table I: Minimum compression molding pressures, in p.s.i., for various molding depths, with and without H-F preheat*

Depth of molding, in.	*Conventional phenolic*		*Low-pressure phenolic*	
	H-F preheat	*No preheat*	*H-F preheat*	*No preheat*
0– ¾	1000 to 2000	3000	350	1000
¾–1½	1250 to 2500	3700	450	1250
2	1500 to 3000	4400	550	1500
3	1750 to 3500	5100	650	1750
4	2000 to 4000	5800	750	2000
5	2250 to 4500	1	850	1
6	2500 to 5000	1	950	1
7	2750 to 5500	1	1050	1
8	3000 to 6000	1	1150	1
9	3250 to 6500	1	1250	1
10	3500 to 7000	1	1350	1
12	4000 to 8000	1	1450	
14	4500 to 9000	1	1550	
16	5000 to 10000		1650	

* Source, Plastics Engineering Handbook, SPI, 3rd Edition

1—Add 700 p.s.i. for each additional inch of depth. But beyond 4 in. in depth it is desirable—and beyond 12 in. essential—to preheat.

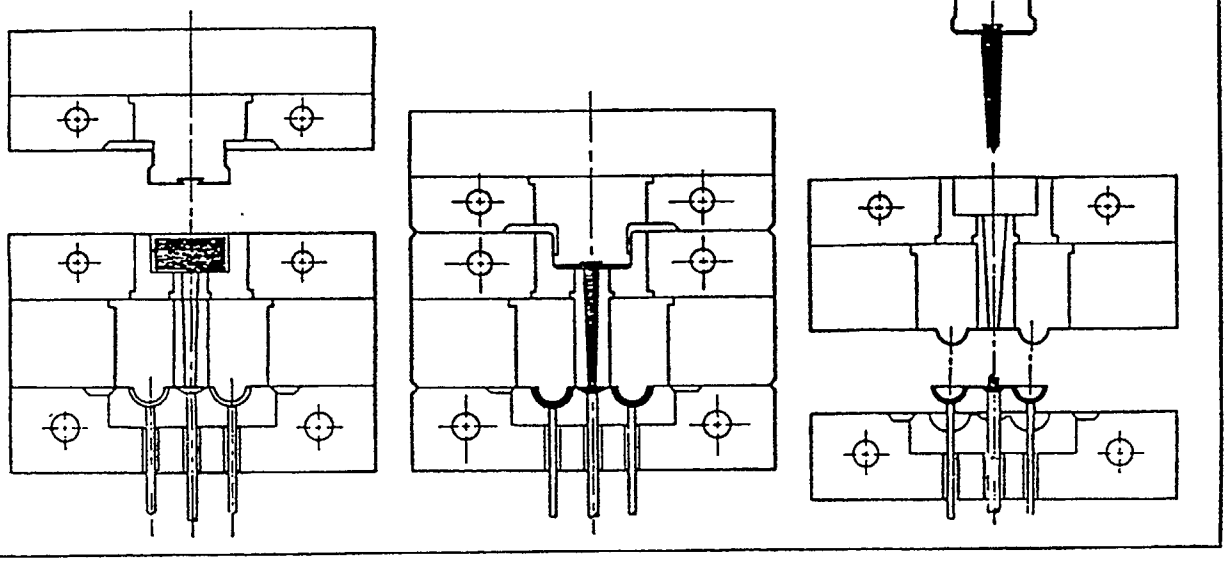
2—Add 250 p.s.i. for each additional inch of depth. But beyond 4 in. in depth it is desirable—and beyond 12 in. essential—to preheat.

Molding pressures

In the compression molding of general purpose phenolic, urea, and melamine materials without preheat, the minimum molding pressure is normally 3000 p.s.i. on the projected land area of the mold. (The projected land area of the mold is the total area obtained by multiplying the width by the length of each cavity, including land area, by the number of cavities in the mold.) For each inch of mold cavity depth over one, add 700 p.s.i. (Table I). This minimum pressure applies to the molding of cold powder or cold preforms. If preheated preforms of general purpose materials are used, the minimum molding pressure required

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FIG. 4a, below left: In the molding cycle of a transfer mold, the material is first placed in the transfer pot. It is then forced (FIG. 4b, below center) through an orifice into the closed mold. When the mold opens (FIG. 4c, below right), the cull and sprue are removed as a unit, and the part is lifted out of the cavity by ejector pins.



may be as low as 1000 p.s.i., with an additional 250 p.s.i. for each additional inch of depth over 1 inch. In many cases, particularly with improved impact and mineral-filled materials, higher molding pressures are desirable. These higher molding pressures permit stiffer plasticities to be used. Thus molded parts become more dense and cure times tend to be shortened in the overriding majority of molding operations.

In transfer or plunger molding, normal molding pressures range between 6000 and 12,000 p.s.i. on the plunger. It is very important that the total clamping force holding the mold halves together be at least 10% greater than the mold opening force developed by the material pressure built up within the mold.

Mold temperatures

Compression and transfer mold temperature range between 280 and 380° F. Actual mold temperature will be determined by the type of material being used, the geometry of the molded part, and whether the material is fed as a cold powder or as preheated preforms.

Mold temperatures may be maintained by the use of electric heater units, high pressure steam, oil heaters, or by using gas flames as commonly used on rotary automatic presses. Maintaining the mold temperature within ±5° F. is important in thermoset molding. Mold temperature significantly affects flow of the material, the physical properties of the molded part, cure time, and production rate, especially on large runs. Generally speaking, when cold powder charges are used the higher the mold temperature (up to about 380° F.), the faster the mold closing time. When radio frequency preheated preforms or powder are used, it may be necessary to use lower mold temperatures (325 to 350° F.), because the material is already at or near molding temperature and may cure or harden prematurely before the mold has completely filled and closed.

When high pressure steam (100 to 180 p.s.i.) is used for mold heating, the steam lines for the top plate of the mold and the cavity may be hooked up either in series or in parallel, depending upon the size of the mold. In small molds for shallow draft small parts, a series hookup is advisable. The steam channel circuitry in this type of mold is usually not very complex, and there is little chance for steam condensate to be trapped in the channels, and reduce the mold temperature around the channeled area. In a large mold with a complicated channeling system, a parallel steam line hookup is an advisable procedure so that steam enters both the top and cavity sections of the compression mold at the same time.

Mold cure time

Key to high molding productivity is the minimization of mold cure time. This may be done by combining high mold temperatures with high molding pressures, and using material which exhibits maximum plasticity.

Mold cure time may also be decreased by "breathing" the mold (opening the mold about ⅛-in. after it initially closes) to allow volatiles developed during the curing process to escape from the cavity rather than be trapped in the molded part. Degassing, or breathing, is a difficult process to control and should be used only as a last resort. If care is not taken, molded parts may exhibit dull areas, porosity, or weak sections because of lack of knitting of the material before and after mold opening.

Flash molds

The simplest and least expensive type of mold is the flash mold. In this, as with other types of compression molds, the material is fed directly into the heated mold cavity. The top of the mold, or force plug, is then advanced

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a trouble shooting check *for thermoset molders*

Defect: Blistering, heavy section

1. Increase cure.
2. Close mold slowly on low pressure, then apply high pressure to purge gas.
3. Vent mold if plunger molding.
4. Preheat to eliminate moisture. Increase preform temperature.
5. Breathe mold as soon as possible.
6. Increase pressure.
7. Use stiffer material.
8. Lower mold temperature.
9. Check mold temperature for uniformity.
10. Vent mold at dead ends with vent pins.

Defect: Porosity (not filled out in every section)

1. Try a range of plasticities for best grade.
2. Increase pressure.
3. Lower mold temperature.
4. Close mold faster if external porosity, apply high pressure sooner; close mold slower if internal porosity, apply low pressure longer.
5. Preheat material.
6. Adjust charge weight.
7. Try a higher density material to obtain greater "back pressure" in the mold.
8. Breathe mold earlier.
9. Use semi-positive molds to minimize porosity.

Defect: Mold sticking

1. Raise mold temperature.
2. Preheat to eliminate moisture.
3. Clean mold.
4. Use stiffer material.
5. Remove dents and undercuts in mold cavity and force.
6. Polish mold.
7. Increase cure.
8. Lower pressure; softer material if plunger molding.
9. Check knockout pin adjustment.
10. Be sure cavities have ¼° draft.

Defect: Dull surface

1. Adjust mold temperature—usually reduce temperature for better appearance.
2. Polish mold.
3. Chrome plate.
4. Close mold more slowly.

Defect: Orange peel (rough, pimply surface)

1. Close slowly on low pressure. Delay 2 sec. before applying high pressure.
2. Preheat (radio frequency).
3. Use stiffer material.
4. Use finer ground material.
5. Use large preforms and as few as possible.
6. Use lower mold temperature.

Defect: Pitted surface

1. Use stiffer material.
2. Preheat.

Defect: Clouded or segregated surface

1. Reduce molding temperature (for colors, 300 to 310° F.).
2. Preheat preforms.
3. Adjust plasticity.
4. Adjust pressure and closing speed.

Defect: Dimpled surface

1. Close slowly, longer on low pressure, no breathe, then high pressure.
2. Use stiffer material.
3. Lower mold temperature.
4. Increase charge weight.
5. Shape preforms more closely to piece.
6. Increase pressure.

Defect: Warped piece

1. Heat mold more uniformly.
2. Use stiffer material.
3. Preheat if soft plasticity.
4. Increase cure.
5. Use lower shrinkage material and/or material more rigid at discharge.
6. Redesign mold; use wider knockout pins.
7. Adjust temperature of force and cavity—lower temperature may reduce warpage.
8. Preheat for irregular shaped pieces.
9. Cool uniformly and use shrink fixtures.

Defect: Cracking after molding

1. Increase wall thickness around inserts.
2. Check knockout pins.
3. Correct size of shrink fixture.
4. Use more flexible material.
5. Increase radii and ribs.
6. Oven anneal 2 hr. at 200° F.

Defect: Poor electrical properties

1. Close slowly.
2. Preheat ½ hr. at 185° F.
3. Increase cure.
4. Reduce temperature.
5. Use stiffer grade.

Defect: Weak mechanically

1. Increase temperature.
2. Increase cure.
3. Increase pressure.
4. High frequency preheat.
5. Increase charge.
6. Afterbake to increase strength, if economical. Try 2 hr. at 250° F.

Defect: Pimpling

1. Breathe mold.
2. Use higher fines material.
3. Use softer material.
4. R. F. preheat.
5. Lower mold temperature.

Defect: Burned marks

1. Reduce preheat temperature.
2. Reduce mold temperature.
3. Plunger molding: open gates; be sure vents are clear; check plunger travel time to see if it is between five and 12 sec. (faster close will entrap gas; slower close causes burn marks).
4. Avoid or minimize breathing.

Defect: Thick flash

1. Reduce mold charge.
2. Reduce mold temperature.
3. Increase high pressure.
4. Close on low, apply high pressure sooner.
5. Eliminate breathe, follow (4).
6. Use softer grade material for more pressure.
7. Be sure of 0.002-in. between force and cavity.
8. Be sure overflow grooves are clean.
9. In plunger molds, reduce injection pressure and/or increase clamping pressure.

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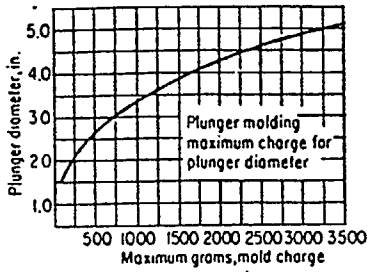
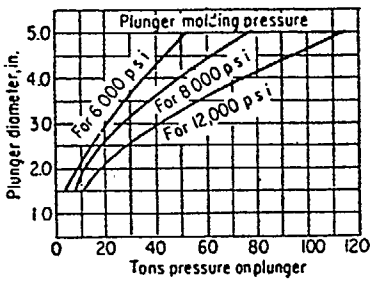


FIG. 5, above: Diameter of plunger for a given mold charge can be determined from the graph. **FIG. 6,** below: A graph for determining plunger pressure needed for producing given pressure on material.



into its matching cavity, and the mold is closed for the time required to cure or set the material. The mold temperature and pressure that are required to obtain a satisfactory molded piece must be predetermined for each type of thermosetting material that is used.

Figure 3 shows an open flash mold with a preform charge placed in its cavity. The weight of charge required must be more than enough to produce the molded piece. When the mold is closed, the excess material is forced out between the two halves of the mold in the form of flash, as shown in Fig. 3. This type of mold produces pieces having constant dimensions, and is suitable for multiple cavity molds. However, low pressure is developed on the piece, which may result in a less dense structure in the finished part then when other mold designs are used.

Transfer molding

The following factors are important in the design of a transfer mold:

In transfer molding, the material is fed into a pot (Fig. 4a) and then forced under heat and pressure through an orifice into a closed mold (Fig. 4b). This method is usually faster than compression molding, since cure time, particularly for thick sections, often is shorter because the hot material is injected into the closed cavity under high pressure. This results in molded parts with good dimensional control along their parting lines. Transfer molding is ideally suited for molding around inserts, or the molding of intricate shapes with thin and thick sections. From an economic point of view, however, mold cost is usually higher than in compression molding.

Because the material enters the cavity at a single point, an orientation of any fibrous filler is produced in a direction parallel to the flow. The shrinkage of the molded part parallel to the line of flow, and shrinkage at right angles to the line of flow, may thus be different and rather difficult to predict, depending upon molded part geometry and gate position.

When a transfer mold is opened (Fig. 4c), the residual disk of material left in the pot, known as the cull, and the sprue (or runner from the pot into the cavities) are removed as a unit. To remove the molded part from the bottom section of the mold, the center section then must be raised.

In transfer molding, the pressure in the pot is developed by the action of the main hydraulic ram of the press. The area of the pot should exceed the area of the cavities underneath it by at least 10% so that the wedging action of the material entering the cavities will not cause the mold to open and, subsequently, to flash.

Plunger molding

Plunger molding is similar to transfer molding except that an auxiliary hydraulic ram is used for exerting pressure on a plunger ram which, in turn, injects the material through a system of runners and gates into the closed cavities of the mold. The basic steps of this process are similar to those of the pot type—or transfer molding—method. When the plunger is withdrawn and the mold opened, the molded part may be removed from the cavity with the runners and cull still attached to it as a single unit. The overall molding cycle in plunger molding is usually shorter than for transfer molding, since there is no separate operation incurred in the removal of the sprue, runners, or cull. In plunger molding it is essential that radio frequency preheated preforms be used to take maximum advantage of the fast cures obtainable, as well as to reduce costs.

Very important in plunger molding is the diameter of the preform and the height of the total charge in relation to the diameter of the plunger and plunger well. Figure 5 will be helpful in determining the diameter of the plunger and chamber for molding general purpose phenolics.

In this regard, the following requirements are considered fundamental: 1) Sufficient space should be provided between the upper half of the mold and the head of the press so that the preheated preforms can be exactly and quickly loaded. 2) Diameter of a preform should be at least 10% less than the inside diameter of the pressure chamber to allow for swelling of the preform during the preheating operation. For more rapid loading, the preform must drop freely into the pressure chamber without sticking or hanging up. 3) Total height of the preform charge should not be more than 2½ times that of the preform diameter. 4) Mold charge should be sufficiently large so that the cull of material left at the bottom of the pressure chamber is not less than 1/16-in. thick. Lesser quantities are very apt to produce parts of low density due to lack of positive pressure caused by the material entering the cavities at the end of the stroke. 5) It is important that the plunger enter the pressure chamber at least ⅜-in before coming into contact with the charge of material. Otherwise, the material may flash up around the plunger.

The consequent amount of the flashing will depend upon clearance between the plunger and chamber wall. This loss of material will result in porous, or low density, molded parts. The greater the clearance, the greater the amount of flashing that will be experienced as the mold closes.

The manner in which the data in Fig. 5 can be used to determine plunger diameter can be demonstrated by the following examples: 1)To determine what plunger diameter should be used for a ½-lb. or 227-gm. mold charge, read up the vertical line closest to 227 gm., to its intersection with the curved line. Then read across to the left to determine the optimum plunger diameter required for this charge. This indicates that a plunger and pressure chamber diameter of 2 in. should be adequate. Figure 6 then can be used to determine the hydraulic load,

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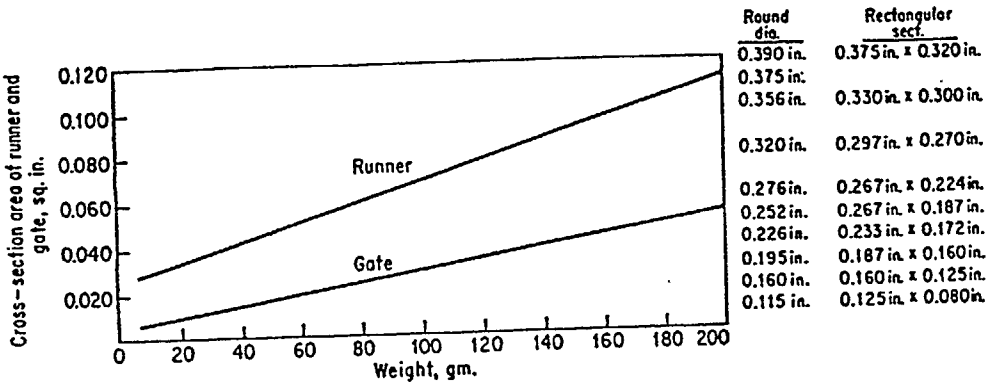


FIG. 7: Graph gives a rting point for determining the gate size needed for molding parts of given net weights.

in tons, required on the plunger to deliver 6000, 8000, or 12,000 p.s.i. on the material. In this particular example, a 12.6-ton capacity ram should be used for a plunger pressure of 8000 p.s.i. 2) Figure 5 may also be used to determine the maximum mold charge possible for a particular set of conditions, as outlined below.

Suppose you had a given plunger diameter measuring 3 in., and a series of cavities that totaled out to eight. You would read across the 3-in. diameter plunger line and, at the intersection with the curved line, would find 755 gms. Allowing 10% for cull and runners, this would leave 680 gms. r the eight cavities, or 85 gms. as the maximum possible weight for each molded part. Then, using Fig. 6, you can find the pressure required on the plunger for any of three pressures on the material.

Runner and gate design

Design of runners and gates for thermoset plunger and injection molds is important in achieving fast, uniform cavity fill without gas entrapment or precure. Trapped gas may cause blisters; precure may cause short or porous moldings. These and other problems confronting thermoset molders, and suggestions for their solution, are listed on the opposite page.

Figure 7 will serve as a guide for determining optimum cross sectional areas of runners and gates, utilizing the weights of molded parts and the weight of material to be transferred through runners and gates. Areas and weights are based on general purpose materials. Larger gates and runners are necessary for fiber-filled, improved impact materials. Consideration of geometry of gates and runners is most important.

For multiple cavity plunger molds in which one main runner feeds branch runners to the cavities, we can use the following nomenclature: *base runner* (from the sprue or cull), and *branch runner* (from the base runner to the cavity). Each runner should have a cross-section area consistent with the material that is being passed through it.

For multiple cavities fed by one base runner, calculate the cross-section area of the base runner that would have to accommodate total flow to all cavities. For example, assume that two cavities are fed from one base runner. The weight of each molded part is 50 gms., and total weight of the shot is 110 gms. (2 x 50 + 10% for branch runners).

From the runner line on Fig. 7, note that the base runner cross-sectional area should be 0.072 sq. in. This should hold true for base runners up to 3 in. long. For longer runners, the area should be proportionally larger to compensate for frictional losses during plastic flow.

Runner geometry

There are three basic types of runners used in thermoset plunger and injection molds: trapezoidal, half round, and full round.

Trapezoidal (Fig. 8): This is usually machined into only half of the die plate, and is the least expensive to mill but harder to polish. A minimum radius of 1/16-in. is essential at each corner to obtain best material flow and mold release. This design requires higher plunger pressures, and causes slower cavity fill than the half round or full round runner.

Half round (Fig. 9): This is machined into only half of the die plate. The runner is easy to polish and, because of the semicircular contour, the molded runner releases easily from the mold. This is probably the most popular type of runner found in current mold design, though it requires higher injection pressures and slower fill times than the full round runner.

Full round (Fig. 10): A semicircular runner groove is machined into each half of the die plate. It is important that the runner halves match closely to obtain the best material flow. It has been proved that a full round runner will result in faster cavity fill, with lower plunger pressure, than with either half round or rectangular runners. Full round runners are particularly recommended for transfer molding by the screw plunger and screw injection methods.

Gate design

Various gate designs may be used with transfer molds:

Rectangular gate: The main advantages in this type of gate design are cleaner breakoff of the gate at the edge of the molded part, and a gate that can be "fanned" out to obtain good as-molded surface finish, particularly on large, flat surfaces.

Half round gate: There is no particular advantage to this gate design, except ease in grinding and polishing the gate if it must be enlarged.

Full round gate: This gate design does not lend itself to edge gating on a flat piece at the mold parting line if the cavity is located in only half of the mold. However, it should be used wherever part design will permit.

Figure 11, p. 11, shows the half round runner combined with a straight rectangular gate on the side, or edge, of the molded article. Figure 12 shows

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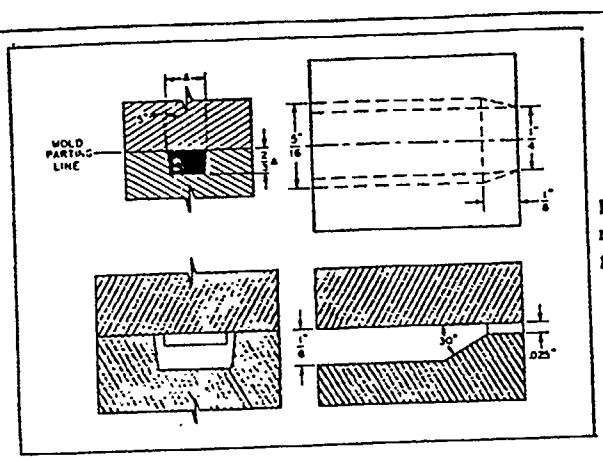


FIG. 8: A trapezoidal runner with a rectangular side gate.

the half round runner combined with an overlapping straight gate. This design lends itself to concealment of the gate in a position where it does not mar the appearance of the molded part. It also keeps finishing costs low.

In Fig. 13 the half round runner is combined with a rectangular gate in the form of a fan gate, usually located on the side or edge of the molded part. This type of gate is best suited to filling large, flat areas. It allows better distribution and spreads the material as it enters the cavity, resulting in improved flow and minimized flow lines.

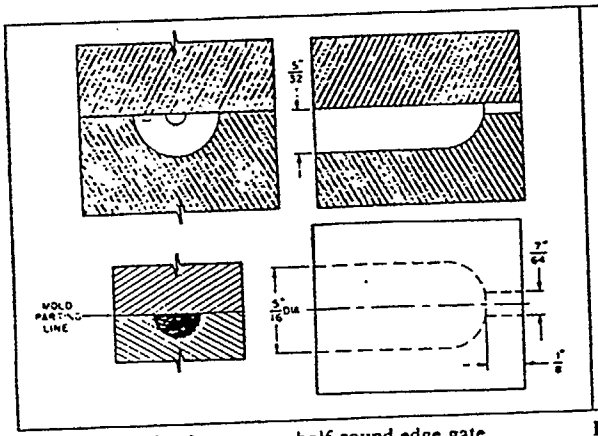


FIG. 9: Half circular runner, half round edge gate.

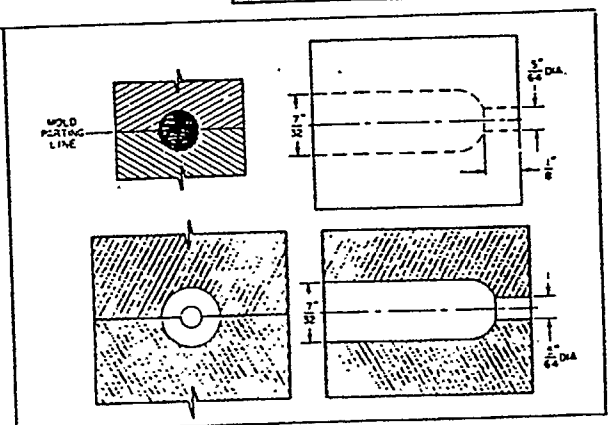


FIG. 10: Full circular runner, full circular center gate.

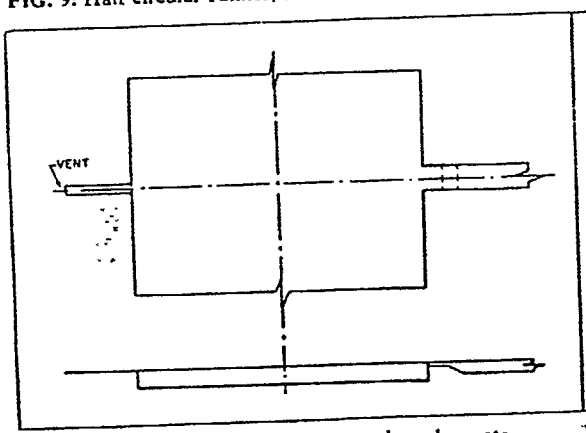


FIG. 11: Half round runner, rectangular edge gate.

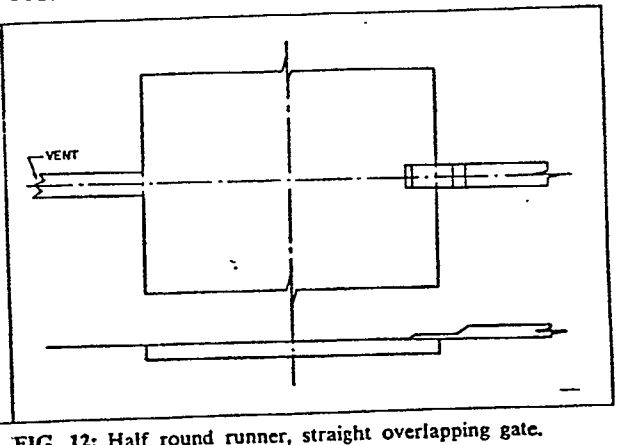


FIG. 12: Half round runner, straight overlapping gate.

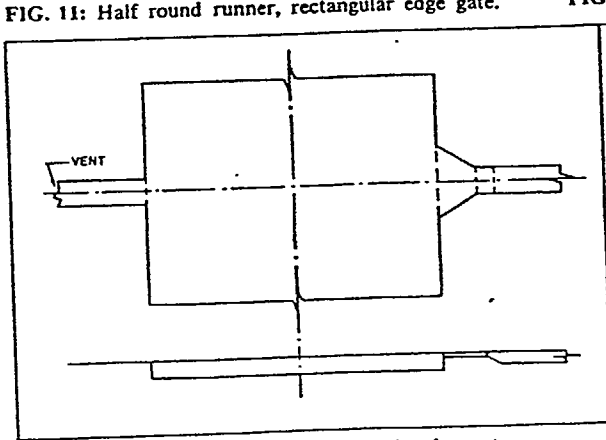


FIG. 13: Half round runner, side or edge fan gate.

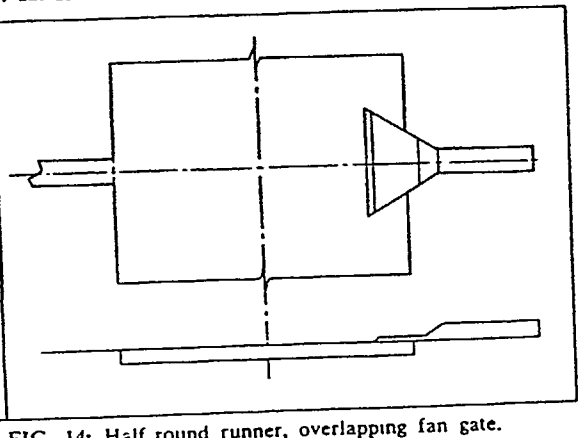


FIG. 14: Half round runner, overlapping fan gate.

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In Fig. 14, the fan gate is applied to the top, or face, of the molded article to improve flow.

The above information is intended as a guide to better mold design. However, actual runner and gate design, and recommended areas depend upon the following factors: 1) geometry of the molded part; 2) location of the gate or gates; 3) molding pressure desired; 4) number of cavities; 5) plasticity and heat sensitivity of the material selected for the application; 6) physical properties required in the molded part.

Detailed plunger molding pressure tests have been run to determine the effect of runner and gate designs on pressures required to fill mold cavities. The full round runner and gate system, Fig. 10, was taken as a standard.

The rectangular runner and gate system, Fig. 8, required 35% higher injection pressure to fill the cavity in the same time. The half round runner and gate system, Fig. 9, required 15% higher injection pressures to fill the cavity in the same amount of time. In general, the greater the injection pressure the greater the wear or erosion on runners and gates. Therefore, the full round runner and gate should be used wherever possible.

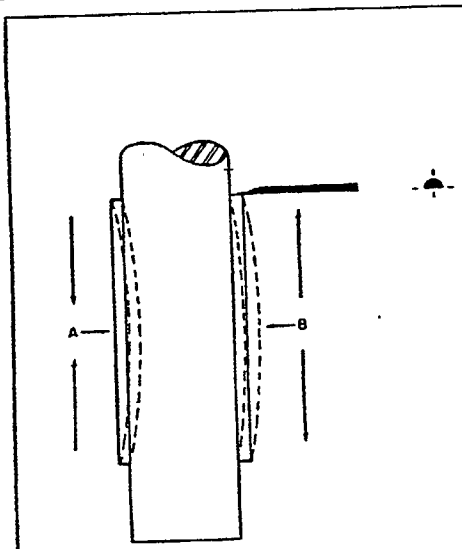


FIG. 15a: Incorrect gating of tubular part.

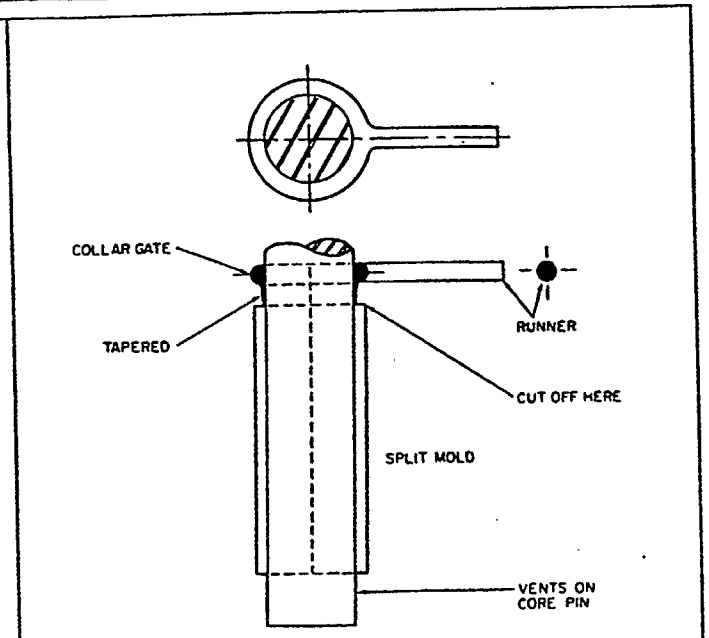


FIG. 15b: Correct gating of tubular part.

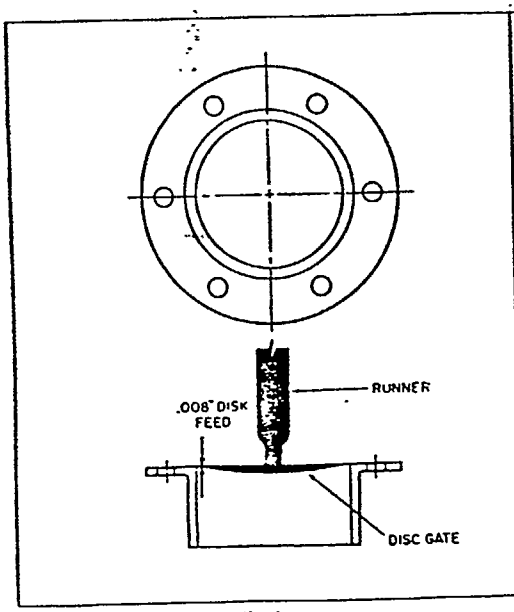


FIG. 16: Center disk or diaphragm gate.

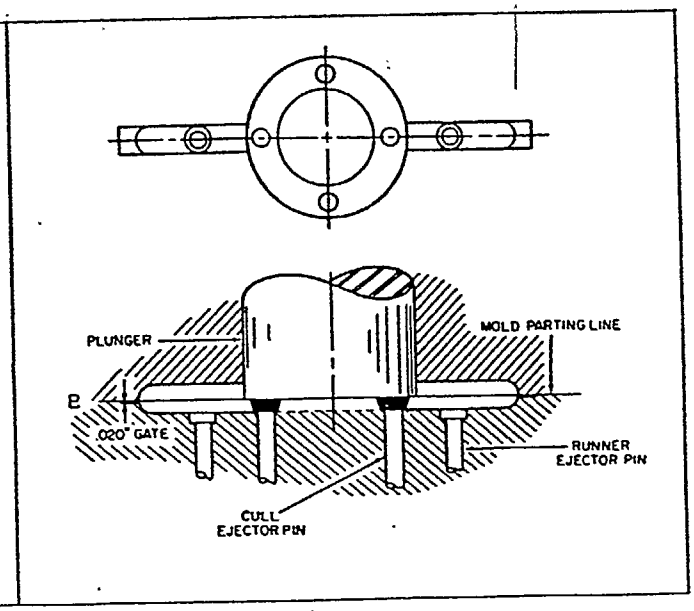


FIG. 17: Improved ring cull design.

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In the molding of tubular parts, difficulties with internal stresses, dimensional accuracy, and warpage can usually be controlled by proper gating. Warpage is probably the greatest problem, and may be due to pressure stresses in the part upon ejection from the cavity, and upon removal of the core pin. The use of the overlapping rectangular or edge gate (Fig. 15a) for tubular parts is not recommended because the flow of material is not uniform around the core pin. The material flows down one side, as illustrated by "B", and when the side is partially filled the flow is diverted to side "A", filling it completely. Then the continuing flow fills side "B". In this short time interval the material becomes semi-set. Side "B" is molded to the right density, while side "A" is compressed to a lower or varied density. When the piece is ejected from the core pin, side "B" starts normal shrinkage. But side "A" continues to shrink further, and a warped part results. Figure 15b illustrates the collar or ring gate, designed to obtain concentricity, which is placed to fill the cavity on the inside edge of the core pin. This technique insures a uniform flow of material down around the core pin.

Figure 16, p. 12, shows a disk, or diaphragm, gate used to flow the material from the runner into the cavity at an even rate of distribution, and in a flow pattern to control density. When the part is molded, the disk gate may be removed by punching or turning. If the gate is 8 mils thick or less, the disk gate can be removed by a tumbling operation.

Figure 17, p. 12, shows an improved design of cull at the end of the plunger. This ring design reduces the amount of material required to a minimum and permits fast cure of the cull. Note the locations of both the cull and runner ejector pins.

Mold vents

Mold cavity vents are very important in transfer or plunger molding. Vents are very small grooves in the parting line of the mold from the lip of the cavity to the outer edge of the mold, opposite to and farthest from the gate. Vents are normally 1 to 3 mils deep, and from 25 to 125 mils wide. These vents allow the escape of heated compressed air and gases as the hot plastic material enters the cavity at high velocity. Entrapment of these gases would degrade or burn the material, causing porosity and resulting in the production of mechanically weak molded parts.

Finishing or deflashing

Molded parts, as they are removed from the mold, carry a degree of flash, or excess material, which escaped from the mold cavity during molding. This flash may be removed by tumbling the molded parts in a horizontal cylindrical barrel revolving at a rate of between 15 and 25 rpm. Included with the charge of molded parts are wooden pegs, or small wooden blocks, which will assist in removing the flash. The barrel usually has an octagonal cross section with alternate open and closed panels. The open panels are covered with screens of wire mesh to permit fragments of flash to fall out of the barrel as the unit revolves. Small blocks of dry ice are sometimes charged into the tumbling barrel along with the molded parts and wooden pegs. In this case the flash on the molded article becomes cold, and a cleaner flash break results. If dry ice is used, the barrel must be closed and have only small vents.

A significant innovation in the deflashing process is the "blast" tumbler. This utilizes a stream of small pellets, usually crushed fruit pits, projected at high speed at the molded parts, which are tumbled over a continuous belt mechanism within the unit. The pellets, since they are not as hard as the molded parts, are nonabrasive to the material. Yet they remove flash not only from the periphery of the molded part, but from holes and recesses as well.

On large moldings where complex design makes tumbling or deflashing impractical, it is necessary to deflash by hand using a file or broaching tool. Hand filing is a costly finishing method and should be avoided if possible. Large molded parts may also be finished with a flexible abrasive belt known as a sanding belt. In designing molds for parts to be finished on a sanding belt, the mold should be made to produce a vertical flash for most efficient sanding.

Mold design

Good mold design plays a very important part in the economics of molding and, in many cases, is dependent upon design of molded parts (Fig. 19). Dimensional tolerances of the parts that are too close are costly because of the care required in all phases of molding.

A high luster mold surface induces better plastic flow, and permits easier removal of the finished part from the mold. Chrome plated cavities provide the best mold release and surface luster on the molded part.

One of the most important considerations in the design of the molded part is wall thickness variations. Since the thickest section of the molded part will determine the minimum cure of the part, the thinnest possible sections consistent with strength and intended functional load should be considered. Uniform distribution of anticipated stresses should be recognized, but merely increasing wall thickness is not always the answer. This extra thickness increases not only material cost, but molding cost due to the longer cure times required. A less expensive solution is use of a higher impact material, or proper ribbing and filleting of the thin sections. A good commercial average for wall thicknesses is a minimum of 55, and a maximum of 312 mils. Since heavy sections tend to shrink more than thin sections, a combination of thin and thick sections should be avoided wherever possible. Unbalanced stresses induced by these variations will cause distortion in the molded part.

To facilitate removal of the part from the mold, draft (taper) on the side walls of the part, both inside and out, is essential. This draft angle should be a minimum of ¼ degree, or about 4 mils/inch.

Molded parts should be designed with rounded corners, or radii, of not less than 62 mils wherever possible. Sharp corners should be avoided, since they form areas of stress concentration which can result in cracks in the molded parts, and/or mechanically weak sections.

Undercuts

Small grooves or nicks may be ground into the side of the force of the mold

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to hold the molded part on the force plug, rather than in the cavity, when the mold opens. These undercuts should be ground on the mold in such position that they will not detract from the appearance of the molded part, or interfere with the function of the assembled unit. Undercuts should be kept as small as possible, and adjacent to the knockout pins. Large undercuts in the design of the molded part may require special side draw pins which may complicate the molding procedure. In some instances it is advisable for the processor to subsequently machine side holes and other undercuts in the molded part being made in order to finish the part properly. Or, he should transfer mold.

Dimension maintenance

Many factors affect the dimensions of molded parts. Where close tolerances are required in the assembled unit, it is sometimes advisable to bake the parts in an oven after molding, at temperatures ranging from 200 to 300° F., for periods of from ½ to 3 hrs., depending upon design of the molded part, materials used, and final dimensions required. Shrink blocks used with the mold may control warpage, but will not necessarily overcome after-shrinkage. However, certain fundamental conclusions can be drawn regarding the extent and form of shrinkage.

Fundamentally, it may be concluded that the following factors increase shrinkage regardless of whether parts are compression or plunger molded: a) lower molding pressures; b) higher molding temperatures; c) shorter cures; d) low material preheat temperatures; e) high moisture content of materials; f) soft plasticities of materials; g) greater thicknesses of parts.

In plunger molding, the smaller the gate cross-sectional area the greater the part shrinkage because less internal pressure and lower density are developed in the molded part.

injection molding of thermosets

In 1961 the first inline screw plasticizing injection machines for thermosets were produced. In 1963 Stokes Equipment Div., Pennsalt Chemicals Corp., Philadelphia, Pa., announced the first automatic screw plasticizing transfer press "Injectoset" (2). Industry reaction was immediate, starting a new era of thermosetting plastics now being called a resurgence.

Developments in screw and barrel design followed rapidly, and by 1965 commercial inline injection machines were available that could injection mold almost all types of thermosetting materials with economy in both time and equipment.

At present, screw injection presses for thermosetting materials are being produced by 10 manufacturers in the United States and 14 manufacturers in other countries. It is estimated that by 1970 only 65% of the major thermosetting materials will be molded by the compression method, 15% by the semi-automatic transfer or plunger methods, and 20% by screw injection.

Relatively high molding costs have, in the past, inhibited the growth of thermosetting applications. Specifically, these costs have involved intricate and expensive molds, and high capital investment and labor costs.

It is recognized in the industry that the cost of making preforms runs in the vicinity of 2¢/lb., and that an added production cost of approximately 35¢/hr. is required to operate radio frequency preheaters. In injection molding no preforms or separate preheating techniques are required, since cold powder is fed directly from the loading hopper into the screw barrel. Figure 1 graphically shows comparative cure times for different methods.

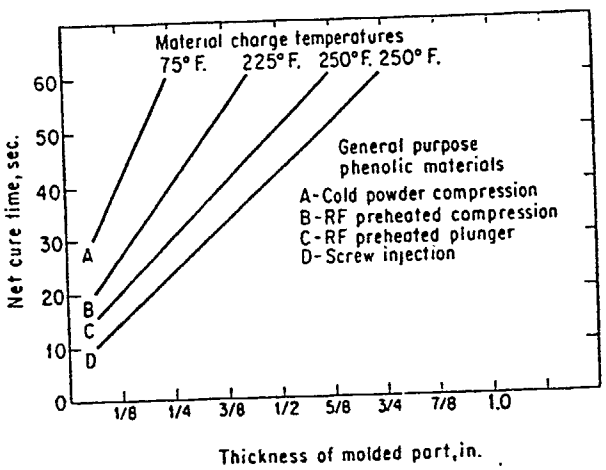


FIG. 1: Reduction in cycle times resulting from use of preheated charges of phenolic materials.

Molding cycles

The basic reason for the rapid growth in injection molding of thermosets is the shorter molding cycles which can be obtained through fast temperature control and homogenizing of the material being plasticized in the screw barrel. The time saving compared to injection molded thermoplastics is indicated in Fig. 2.

In thicknesses above ⅛-in., thermoset molding cycles may be faster than those for similar thermoplastic molded parts. Most thermoplastic materials have low rates of heat conductivity. A thermoplastic is injected into a cold mold where dwell time must be long enough for it to become sufficiently rigid to be removed without distortion.

Stock temperatures in the range of 220–260° F. are normally attained by screw injection of thermosets. Since injection of material into the mold seldom exceeds 5 sec., high mold temperatures in the order of 375–410° F. may be used. Thermosetting materials cure or polymerize in the mold and are ejected hot. The result is extremely fast cycles or cure times.

Special types of phenolic and other thermoset molding materials specifically formulated for screw injection molding are available. However, in many cases, standard formulations can be used depending upon screw design and type of part being molded.

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Screw design

Most thermoplastic injection machines can be converted for the molding of thermosets by the installation of a new screw and barrel especially designed for these materials. The screw barrel length-to-diameter ratios for thermosets are normally smaller than for thermoplastics. The compression ratio (screw base diameter, back-to-front) seldom exceeds 1.1:1 for thermosets as compared to approximately 25:1 for thermoplastics. This lower screw compression ratio results from the differences in fluidities of thermoplastic and thermosetting materials when hot. Most thermoplastic materials become molasses-like fluids, while thermosets become soft, flexible putty.

Some thermoset injection machines now being produced have hollow screws using water "bubblers" to maintain more accurate screw temperatures and closer control of plasticizing temperature. Machines using solid screws must rely on accurate control of barrel temperature, screw backpressure, and rpm for control of plasticizing temperature. Controlled screw temperatures are recommended for the more heat-sensitive thermosetting materials, such as the one-step phenolics and melamines.

Screw rotation

The speed of the screw in rpm is a very important factor in the proper plasticizing of the material passing over the flights. Screw rpm is determined by the plastic being molded and the capacity of the screw vs. the actual charge for each shot. Screw speeds between 50 and 90 rpm are normal.

Rotation of the screw occurs only during the back stroke or plasticizing stage of the molding cycle, which can be either electrically or hydraulically driven. Injection machines using either electric motor or hydraulic motor drive have proven very satisfactory in the molding of thermosets.

Thermoplastic screw injection barrels are normally heated to temperatures between 350 and 600° F. using electric heater bands. Thermoset materials require barrel temperatures of about 150° F. on the back or feed end, approximately 200° F. in the middle of the barrel, and 190° F. at the nozzle. The heating medium usually is hot water or hot oil circulated through channelled metal jackets around the machine barrel.

Screw backpressure plasticizing

Screw rotation forces the molding material over the screw flights and accumulates it in the front of the barrel. Screw plasticizing pressure is the pressure developed at the tip of the screw on the charge of material. The amount of backpressure of the screw tip on the material is determined by a gage on the injection hydraulic cylinder. The pressure is controlled by a flow valve governing the rate of hydraulic oil flowing from the cylinder back into the oil reservoir.

If the flow valve is open wide, the rotating screw easily forces the material forward, little frictional shear is developed, and the material is not highly compressed in front of the screw. As the flow of oil is restricted through the flow valve, pressure is built up on the material, frictional shear becomes greater, the temperature of the material increases, and the oil pressure in the cylinder becomes greater. The higher the backpressure, the slower will be the plasticizing or back travel time of the screw after the injection shot has been made.

Screw rpm and plasticizing pressure should be so coordinated that the plasticizing time does not exceed 30 sec., otherwise the hot metered charge accumulating ahead of the screw may precure. This would cause plugging of the barrel nozzle and prevent injection of the material into the mold at the start of the injection stroke, or forward motion of the screw.

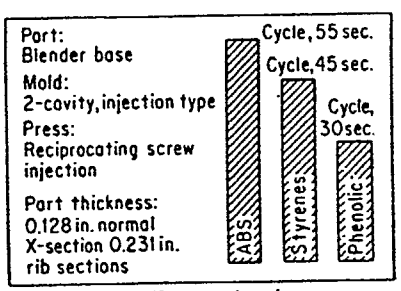


FIG. 2: Molding cycle time comparison for two thermoplastics vs. general purpose phenolic in the same mold.

Insufficient back- or plasticizing pressure will result in low material temperatures; this can prevent proper flow of material into the mold on the injection stroke if the material has not reached its proper plastic state. Normal plasticizing pressures range from 500–1500 p.s.i. on the front end of the screw. Gage pressure is usually calibrated to read the injection cylinder pressure in p.s.i. If the cross section area of the hydraulic cylinder is 50 sq. in. and the cross section area of the screw barrel is 5 sq. in., the ratio is 10:1. Therefore, if the gage reads 80 p.s.i., plasticizing pressure on the material in the barrel is 800 p.s.i.

Injection speed is the time required for the forward stroke of the screw ram to inject the material into the mold cavities. Optimum injection times should range between 5 and 10 seconds. Too fast cavity fill or injection time may cause air and gas to become entrapped in the cavities, resulting in porous and/or blistered parts. Too slow injection time may cause the material to set up, or precure, before the cavities are filled to proper density, with resulting porous and/or nonfilled parts.

Injection pressures will vary greatly according to type of material being molded, geometry of runners and gates, and geometry of the molded parts.

Normally, for phenolic and melamine materials, the injection pressure will range between 12,000 and 20,000 p.s.i. on the material at the front of the barrel. A secondary or holding pressure of between 5000 and 10,000 p.s.i. follows the injection pressure stroke to maintain sufficient pressure on the sprue and runners until the material becomes cured or rigid. This secondary pressure tends to reduce sticking or "packing" of the material in the sprue and runners during cure.

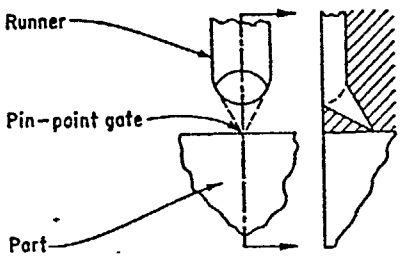


FIG. 3: Tunnel (submarine) gate.

Injection mold runner and gate design for thermosetting materials is described in the Compression and Transfer portion of this article. In addition, tunnel or submarine gating, shown in Fig. 3, is normally used for small parts where the breakoff of the gate would

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be a finishing problem and detrimental to finished part appearance. The gate is tunneled into the side of the cavity on an angle which will permit the tapered sprue to be withdrawn with the runner system separately from the molded part. The submarine or tunnel gate should be as small as possible, and the sprue surface be highly polished.

Venting of a thermoset injection mold is extremely important because of the volatile gases produced during plasticizing, and the fast fill time of the mold—generally about 6 seconds. Unless the gases and air in the mold can be readily expelled, severe burning or oxidizing of the material and staining of the surface of the mold in the gas entrapment area will occur.

Vents are very small grooves in the parting line of the mold, extending from the lip of the cavity to the outer edge of the mold farthest from the gate. Normally 0.001–0.003 in. deep and from 0.025–0.125 in. wide, they may be enlarged depending upon the particular flow pattern of material in each mold. As many as four or six vents may be required in intricately shaped cavities. Vents can readily be ground into the mold after initial shots have been made and the entrapped air or gas areas determined.

Table 1, the thermoset injection molding checklist, may be used as a guide when starting a job, and for troubleshooting when molding problems are encountered in production.

The interrelation of the many press and molding conditions can have a major effect on the properties of the molded parts. Therefore, accurate recording of molding conditions must be maintained for each production run and/or evaluation.—End

Table I: Thermoset injection molding check list*

Key: × = remedy
+ = increase
− = decrease

Problem	Conditions	Injection pressure	Screw r.p.m.	Plasticizing pressure	Material feed setting	Nozzle temperature	Barrel temperature	Mold temperature	Nozzle orifice	Sprue diameter	Polish sprue bushing	Gate size	Cavity vents	Cure time	Softer plasticity	Lubricate material	Fan gate	Polish mold
Press defects																		
Screw wears		−	−			+								×	×			
Screw squeals		−	−			+									×			
Screw won't bottom	+		−	−	−	−								×	×			
Nozzle setup					−			+										
Sprue sticks	−				+					×			+					
Slow injection	+		+		+	+		+	+	×	+			×				
Erratic injection	+		+		−	−				×				×				
Slow plasticizing		+	−			+									×			
Material too hot		−	−		−	−												
Material too cold		+	+		+	+												
Part Defects																		
Parts stick	−						−				+		+	×				×
Mold stains			−				−								×			×
Non-filled parts	+		+	+		−	−		+		+	+		×				
Mold flashes	−		−	−			+											
Parts blistered	+		+	+			+				+	+	+					
Gas trapped			+				−					+					×	
Flow lines	−	+	−				−											×
Dull surface			−				−				+	+						
Porosity	+		−	+	−		−						+					
Flexible at discharge			+				+											

* Reprinted from SPE Journal, March 1968

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