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PROJECT REPORT




# POLYSULFONE - CHRYSOTILE

# R-G 144 ASBESTOS COMPOSITES

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FILE NO.: 1064

## SUMMARY

Coalinga Chrysotile asbestos has been compounded into polysulfone in amounts varying from 1% to 25%. The compounds that were extruder mixed displayed good hot strength up to the 15% loading level. The asbestos compounds can be Banbury mixed up to 10% with relative ease. At the 15% load level Banbury mixing becomes difficult and the resulting mixture is much darker in color than the extruded mixture. The text results show an immediate increase in tensile strength and modulus with the addition of asbestos. Tensile strengths of 11,700 psi, 14,200 psi and 15,400 psi have been obtained for the 10%, 15% and 20% compounds, respectively. At 20% asbestos the secant modulus is 1,030,000 psi. The unfilled polysulfone secant modulus was 340,000 psi. These significant increases are comparable to those achieved with the addition of short fiber glass to polysulfone. However, the glass is three to four times as expensive as the asbestos, giving the asbestos an economical advantage.

The elongation at the yield strength and the ultimate elongations of these compounds decrease with increasing asbestos content. These reductions are not of great consequence except in applications where there is a definite correlation between elongation and performance. With the increase in modulus, the 20% R-G 144 Polysulfone compound can support 10,400 psi at the same strain (1%) that the unfilled polysulfone can support 3,700 psi. The maximum recommended stress level for polysulfone at room temperature is 4,000 psi. The modulus increases are maintained at higher temperatures (to 175°C) indicating that the maximum recommended stress levels for high temperatur applications will also be increased. They probably could be at least doubled. The 20% asbestos compound has been fatigue tested and is at least as good as a 20% short fiber glass filled polysulfone.

The tensile impact value decreases, the Izod impact value remains the same and the heat distortion temperature increases with increasing asbestos content.

At and above the 15% loading level, the asbestos filled bar has shown consistently better stress crack resistance to ethyl acetate than the unfilled polysulfone, both materials being injection molded under identical conditions. Below the 15% load level, inconsistent stress crack results have been obtained.

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## II. Test Results: Injection Molded Bars

Table I shows a summary of the data obtained on these polysulfone R-G 144 compounds.

As evident from the table, the tensile strength, tensile modulus, heat distortion temperature and specific gravity increase with increasing asbestos content. The elongations and tensile impact decrease while the Izod impact remains the same with increasing resin content.

The stress-strain curves for these compounds are shown in Figure 1. The increase in the modulus of elasticity of these compounds is evident from these curves. With the increase in modulus, the 20% R-G 144 Polysulfone compound can support 10,400 psi at the same strain (1%) that the control can support only 3,700 psi. The maximum recommended stress level for polysulfone at room temperature is 4,000 psi. The 15% asbestos compound can support 8,700 at 1% strain.

The high moduli indicated in Figure 1 are maintained at high temperatures as indicated in the modulus temperature curve in Figure 2. This indicates that the maximum recommended stress levels for high temperature applications for these compounds will be increased.

Stress crack resistance of the compounds was studied. The results on the 1% to 10% filled bars were inconsistent. All the bars were molded into 200°F mold. Very few of the bars failed when immersed in 1,1,1 Trichloroethane. Some of the bars from the same compound failed and some did not when immersed in ethyl acetate. Bars from other moldings of the same material all failed. Above the 15% level more consistent results were obtained. The polysulfone-asbestos compounds after immersion in ethyl acetate for 1 minute still showed a few cracks, but the crack distribution was reduced 10 to 20 times. Since some cracks do develop along the edge of the specimens these moldings could not be used, for instance, in the electrodeless plating operation, without being annealed or molded into a hotter mold.

Table II shows a comparison of glass filled with the asbestos filled polysulfone. Comparing the 20% filled compounds we see that the asbestos filled material compound has the higher tensile strength, modulus and elongation. In the glass filled bars we see fairly good strength and modulus retention at 210°F. This retention would also be expected in the asbestos filled bars. The measured specific gravity of the 15% and 20% bars is low. They should be 1.43 and 1.49 respectively. The low readings indicate a high percentage of voids or a lower percentage of asbestos present in the specific gravity specimens. If this was the case in the test with tensile bars, then higher tensile strengths and elongations can be

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expected from well made tensile bars as the specific gravities are upgraded toward the calculated values.

Tensile Fatigue tests have been run on the 20% asbestos compound. The tests were run at 1800 cpm with the stress varying from zero to the maximum value. At a maximum stress of 2000 psi the specimen took 23,000,000 cycles to fail. A 40% glass filled polysulfone recently tested failed at 10,000,000 cycles at 2,400 psi. From this data it would seem that the asbestos filled compounds are as good or better in fatigue than the glass filled polysulfone.

We can conclude that the polysulfone asbestos compounds have mechanical properties as good as or better than short glass fiber filled polysulfone compound at the same load level.

At this time we would like to express an opinion. Many molders are now dry blending glass into polysulfone and then injection molding it on short reciprocating screw injection machines like the Van Dorn. Their hope is to obtain 90% of the mechanical properties of a well dispersed mixture and avoid a Banbury or twin screw compounding operation. We believe we could obtain only about 80% of the asbestos polysulfone mechanical properties in such a short screw injection molding cycle. Even then the pellet size would have to be reduced by half and bridging of the mixture in the feed hopper would have to be avoided.

## III. Test Results: Compression Molded Bars

A few compression molded polysulfone asbestos plaques were made to determine how much effect the asbestos fiber orientation during injection molding had on the tensile properties of these compounds. The data are presented in Table III. There is little difference in the tensile strengths of these compression molded bars. Their moduli are significantly different. These values are all lower than those of the injection molded bars. The next section discusses the reason for this effect.

## IV. Method of Reinforcement

The chemical structure of polysulfone indicated that is should be capable of developing hydrogen bonding between the exposed hydrogen of the brucite surface of the asbestos and the sulfone group of the polymer.

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Figure 3 shows a plot of the change in tensile strength with the addition of asbestos. For purposes of discussion we are using plasticized vinyl data[6] from a previous report. Using these data we can distinguish two components of $\Delta T$ in the compression molded polysulfone results and only one component in the plasticized vinyl results. This result assumes that the effect of any hydrogen bonding between the chlorine atom of the plasticized vinyl and the hydrogen atom of the brucite surface is very small or not effective. Figure 3 shows these two curves. We will base our discussion on the plasticized vinyl results.

Figure 4 is a plot of the injection molded polysulfone-asbestos and nylon 6-asbestos[2] results as well as the data of Figure 3.

If we subtract the hydrogen bonding effect from the injection molded polysulfone results, we obtain line A. Line B is the predicted results for an injection molded non-hydrogen bonding polymer based on whisker theory. Test results on an injection molded vinyl or polyethylene should fall between lines A & B.

From Figure 4 we also see that the nylon 6[2] results indicate a much higher hydrogen bonding effect than that in polysulfone. This correlates well with the potential hydrogen bonding effect indicated by the molecular structure of polysulfone and nylon 6. Figure 4 can be used to predict test results on other polymers whose hydrogen bonding potential may range from zero to that of nylon.

## PATENTABLE FEATURES

In discussions with V. Auerbach and R. Walton, we have determined that these compounds are probably not patentable. This is due to the existence of a German patent covering Nylon-Asbestos Compounds[7] and a Union Carbide patent by N. Zutty and G. Potter covering "Stress Crack Resistant Polyhydroxy-Ether Composition".

## ACKNOWLEDGMENTS

The authors would like to extend their thanks to the Polysulfone Group for their help and cooperation.

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L. M. Robeson

jmm

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6. W. P. Mulvaney, Coalinga Chrysotile Asbestos - Plasticized Vinyl Compounds. Report No. JS-206.

7. German Patent #1,196,863 on Injection Molding Compound of Polyamide and Fibrous Filling Materials.


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# APPENDIX I

## FIBER ALIGNMENT IN THE DIRECTION OF FLOW

Comparison of tensile properties of compression molded R-G 144 filled Nylon-6[2] and polysulfone with injection molded samples at the same R-G 144 loading has shown a noticeable increase in tensile strength and 1% tensile modulus for injection molding over compression molding.

This increase can be partially attributed to fiber alignment in the direction of flow as shown by the following analysis:

In order to illustrate the possibility of fiber alignment during injection molding, we must make an analogy with the solution of the equations of motion of a particle suspended in a viscous fluid undergoing steady-state laminar Couette flow (flow between two parallel planes with one plane stationary and the other plane moving at a constant velocity). Couette flow represents an ideal situation which can illustrate fiber alignment in the direction of flow where a velocity gradient exists.

The solution of the equations of motion for Couette flow of ellipsodial particles is presented in a classic paper[3] by Jeffery.

For Covette flow:

$$V_x = ky;\ V_y,\ V_z = 0 \qquad (1)$$

where $V_x$, $V_y$, and $V_z$ are the components of fluid velocity along the x, y, or z axes. Jeffery's solution predicts that the angular velocities of the axis of rotation in terms of the spherical coordinates 0 and Ø using the y axis as the polar axis (Figure 1a) are:

$$\frac{d\theta}{dt} = \frac{k\,(r_e^2 - 1)}{4\,(r_e^2 + 1)} \text{ Sin } 2\,\emptyset \sin 2\,\emptyset \qquad (2)$$

$$\frac{d\emptyset}{dt} = \frac{k}{(r_e^2 + 1)}\,(r_e^2 \cos^2 \emptyset + \sin^2 \emptyset) \qquad (3)$$

In Jeffery's analysis, $r_e$ is the axial ratio a/b where 2a is the length of an ellipsoid measured as the length of revolution and 2b is the equatorial diameter. For a rigid rod as the case with asbestos fiber $a >> b$ and $r_e >> 1$.

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Integration of 2 yields:

$$\tan \Theta = \frac{k_1 \, r_e}{(r_e^2 \cos^2 \phi + \sin^2 \phi)^{1/2}}$$

which describes the orbit of each end of the rod (or rigid fiber).

Integration of 3 yields

$$\tan \phi = r_e \tan \left( \frac{2\pi \, t}{T} \right)$$

where the period of rotation, T, of the rod is

$$T = \frac{2\pi}{k} \left( r_e + \frac{1}{r_e} \right) \simeq \frac{2\pi \, r_e}{k} \qquad (r_e >> 1)$$

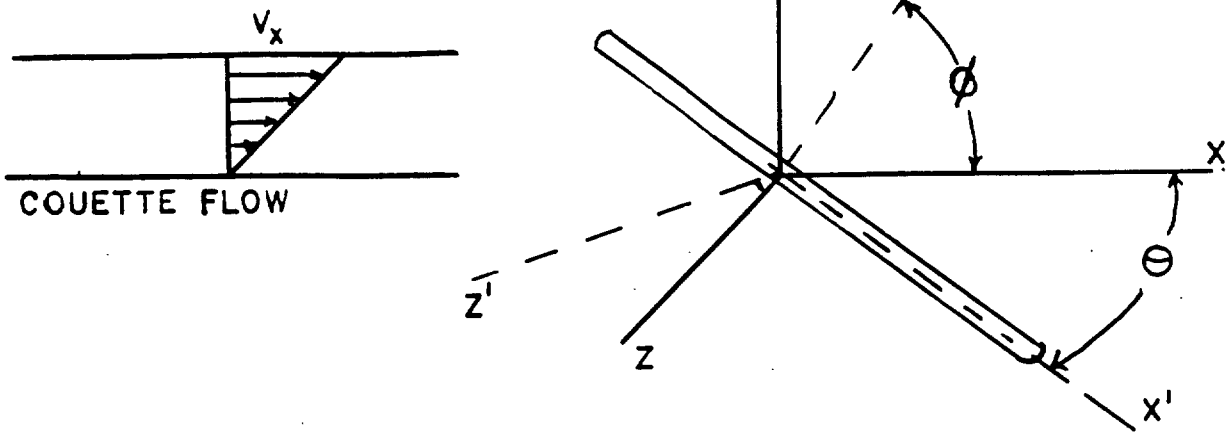
A plot of $\phi$ versus reduced time t/T (Figure 1b) illustrates clearly fiber alignment in the direction of flow (90° and 270°) as a rod with $r_e = 20$ spends 90% of its time in the orbit of $\pm 4°$ aligned with the direction of flow.

Experimental results[4] compare favorably with Jeffery's solution for Couette flow. Also recent observations of Mason & Goldsmith[5] show that rotation of the rigid rods involved in Poiseuille flow (steady-state laminar flow in a cylindrical conduit) can be satisfactorily analyzed by analogy with Jeffery's theoretical solution.

Obviously the flow pattern in injection molding is neither Couette, Poiseuille steady-state or laminar flow; however, definite velocity gradients exist and where these gradients exist fibers will be aligned in the direction of flow as predicted by Jeffery's analysis. Fiber alignment can, therefore, explain increases in tensile properties of injection molded samples compared with compression molded samples.

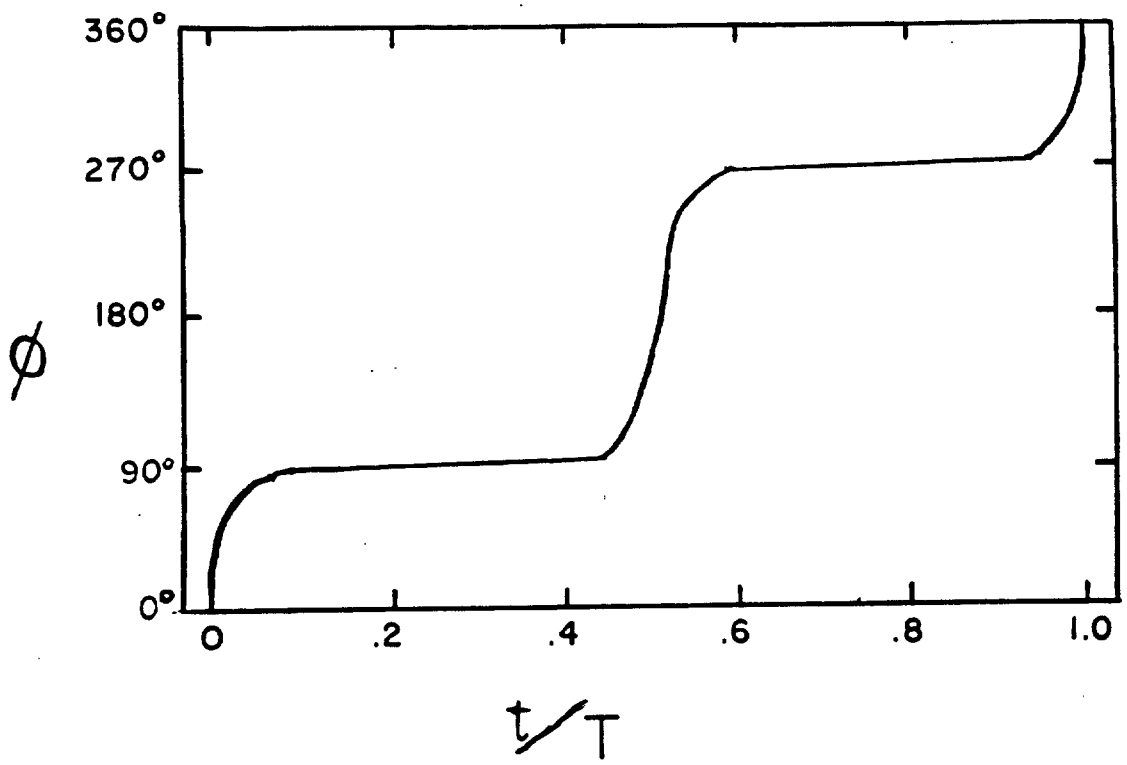


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REPRESENTATION OF COORDINATE AXIS FOR FIBER

FIGURE Ia




ANGULAR POSITION DURING PERIOD OF ROTATION

FIGURE Ib

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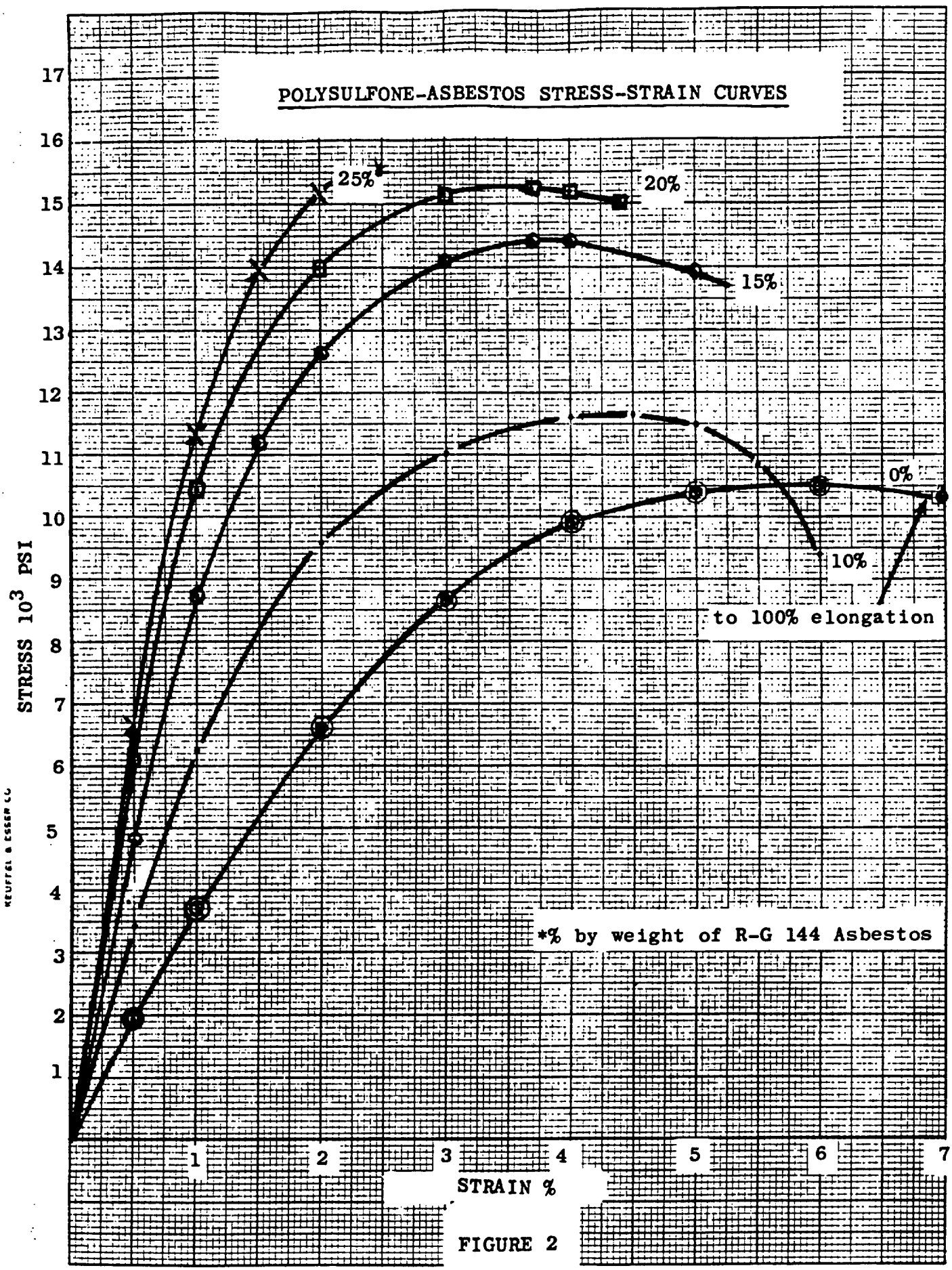
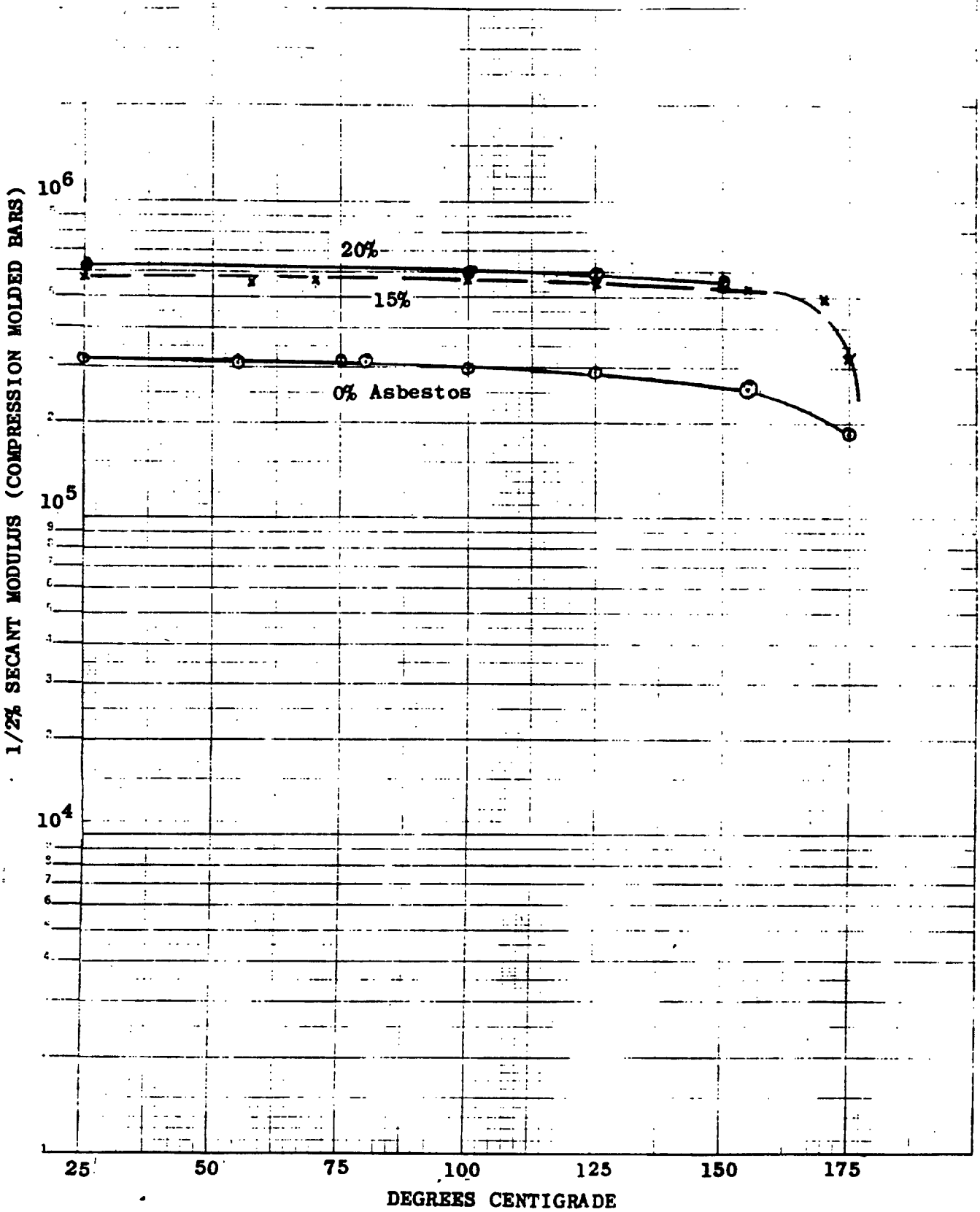



FIGURE 2


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FIGURE 3

POLYSULFONE-ASBESTOS E-T CURVES



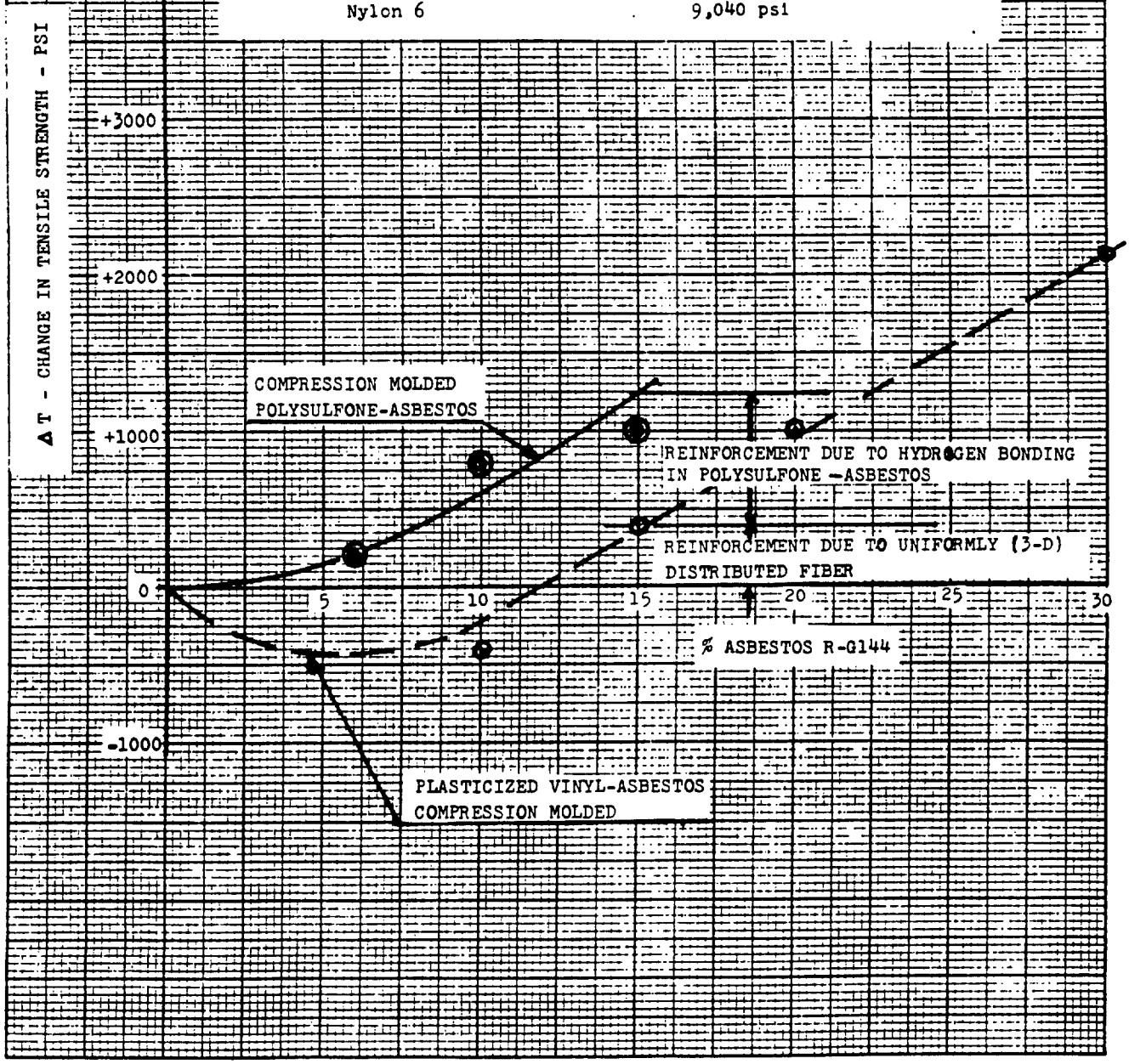

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FIGURE 4

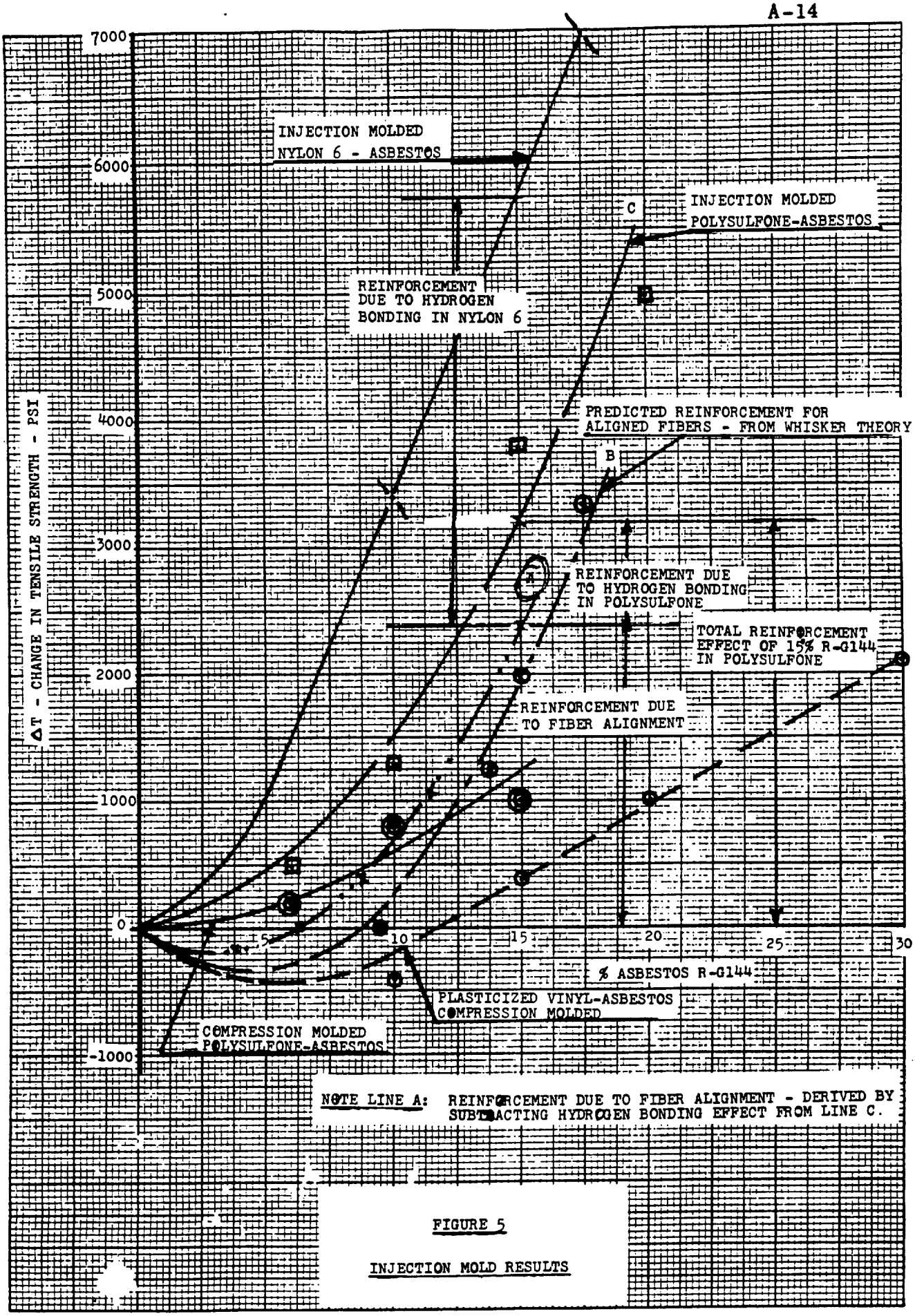
COMPRESSION MOLDED RESULTS

| Polymer | Yield Tensile Strength |
|---|---|
| Plasticized Vinyl | 3,700 psi |
| Polysulfone | 10,400 psi |
| Nylon 6 | 9,040 psi |




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NOTE LINE A: REINFORCEMENT DUE TO FIBER ALIGNMENT - DERIVED BY SUBTRACTING HYDROGEN BONDING EFFECT FROM LINE C.

FIGURE 5

INJECTION MOLD RESULTS

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TABLE I

POLYSULFONE* - R-G144 ASBESTOS COMPOUNDS

| Material Notebook # 8496-77 | % R-G144 | Tensile Strength $10^3$ psi Yield | Tensile Strength $10^3$ psi Ultimate | Modulus 1% Secant $10^3$ psi | % Elongation at Yield | Ultimate Elongation % | HDT °C. | Tensile Str. Range $10^3$ psi | Modulus Range $10^3$ psi | Izod Impact ft.lb./in. Notch | Tensile Impact ft.lb./in.$^3$ | Specific Gravity | # of Spec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Injection Molded | | | | | | | | | | | | | |
| -1 | 0 | 10.3 | | 340 | 5.7 | 67 | 170 | | | 1.1 | | | |
| -1 | 0 | 10.4 | | 371 | 5.7 | 100 | | 10.38-10.42 | 357-386 | 1.16 | 316 | 1.2414 | 5 |
| -2 | 1 | 10.45 | | 372 | 5.6 | 37.5 | | 10.40-10.50 | 369-377 | 1.2 | 382 | | 5 |
| -12** | 1 | 10.4 | | 385 | 5.6 | 100 | | 10.35-10.4 | 378-391 | 1.2 | | 1.2466 | 5 |
| -3 | 3 | 10.5 | | 403 | 5.3 | | | 10.40-10.65 | 380-414 | 1.2 | | 1.2577 | 5 |
| -13** | 3 | 10.5 | | 398 | 5.4 | 100 | | 10.40-10.5 | 382-410 | 1.2 | 315 | | 5 |
| -4 | 6 | 10.9 | | 446 | 4.9 | 7.5 | | 10.8-10.95 | 486-506 | 1.2 | | 1.3412 | 5 |
| -5 | 10 | 11.7 | | 624 | 4.4 | - | | 11.70-11.70 | 547-645 | 1.2 | | | 5 |
| -6 | 15 | 14.4 | | 864 | 3.[illegible] | [illegible] | 180 | 14.00-14.60 | 862-873 | 1.33 | 136 | | 6 |
| -11** | 15 | 13.8 | | 852 | 3. | [illegible].1 | 181 | 13.65-14.1 | 830-870 | 1.23 | | | 5 |
| -7 | 20 | 15.4 | | 1,030 | 3.7 | 4.4 | 181 | 14.6-16.1 | 1,010-1,045 | 1.21 | 98 | | 5 |
| -8 | 25 | -- | 14.3 | 1,152 | - | 1.7 | 10[illegible] | 13.50-15.20 | 1,135-1,185 | 1.16 | 106 | 1.4090 | 5 |

*P-1700 Batch 6712

**Banbury mixed.

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## TABLE II

### MECHANICAL PROPERTY COMPARISON - INJECTION MOLDED BARS

| | Polysulfone Glass Compounds | | | | | Polysulfone Asbestos-Compounds | | |
|---|---|---|---|---|---|---|---|---|
| % Fiber | 0 | 20* | 20* | 30* | 30* | 10 | 15 | 20 |
| Temperature of Test °F | 73 | 73 | 210 | 73 | 210 | 73 | 73 | 73 |
| Specific Gravity | 1.24 | | | | | | 1.34 | 1.38 |
| Tensile Strength $10^3$ psi | 10.3 | 13.5 | 9.98 | 16.5 | 12.2 | 11.7 | 14.2 | 15.4 |
| Tensile 1% modulus $10^5$ psi | 3.55 | 7.51 | 6.85 | 10.3 | 5.36 | 6.24 | 8.58 | 10.30 |
| % Elongation, at yield | 5.7 | | | | | 4.4 | 3.9 | 3.7 |
| % Elongation, ultimate | 75 | 2.8 | 2.7 | 2.4 | 4.4 | | 5.7 | 4.4 |
| Flexural Strength $10^3$ psi | 15.2 | 21.9 | 17.1 | 24.5 | 19.0 | | | |
| Flexural Modulus $10^5$ psi | 3.9 | 8.1 | 7.7 | 11.6 | 10.2 | | | |
| Izod Impact (notched) 1/8" ft.-lbs./in. | 1.2 | 1.3 | -- | 1.81 | -- | 1.2 | 1.3 | 1.2 |
| Heat Distortion Temp. °C. @264 psi | 170 | 183 | -- | 185 | -- | 180 | 181 | 181 |
| Fiber Length - avg. inch | -- | <.125 | <.125 | <.125 | <.125 | 2μ to 20μ | | |

*Data from the Liquid Nitrogen Processing Corporation.

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TABLE III

POLYSULFONE - R-G144 ASBESTOS COMPOUNDS

| Material Notebook # 8496-77 | % R-G144 | Tensile Strength $10^3$ psi Yield | Modulus 1% Secant $10^3$ psi | % Elongation at Yield | Ultimate Elongation % | Tensile Str. Range $10^3$ psi | Modulus Range $10^3$ psi | Spec. |
|---|---|---|---|---|---|---|---|---|
| Compression Molded | | | | | | | | |
| 89-0 | 0 | 11.1 | 360 | 5.6 | 65.+ | 11.10-11.15 | 353-374 | 5 |
| 89-1 | 10 | 11.9 | 569 | 4.5 | 6.5 | 11.9 -11.9 | 557-581 | 2 |
| 89-2 | 15 | 12.1 | 632 | 4.1 | 4.4 | 12.0 -12.2 | 615-650 | 2 |
| 89-3 | 6 | 11.3 | 444 | 5.0 | | 11.1 -11.5 | 426-464 | 5 |

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