PULP-REINFORCED PLASTICS

February 1945

No. R1461

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
FOREST PRODUCTS LABORATORY
Madison, Wisconsin
In Cooperation with the University of Wisconsin

PULP-REINFORCED PLASTICS[1]

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SUMMARY

Strong and tough plastics were obtained by incorporating various powdered phenolic resins with high-quality paper pulp in aqueous suspension, forming the mixtures into mats, and after drying and conditioning, molding the mats under heat and pressure to flat test panels. The ultimate tensile strength of such plastics varied from 20,000 to 25,000 pounds per square inch, the ultimate edgewise compressive strength from 14,000 to 18,000 pounds per square inch, and the Forest Products Laboratory flatwise toughness from 13 to 24 inch-pounds per inch of width. The best of these materials approached in properties those of commercial aircraft-grade, cross-laminated paper plastic. Insofar as properties of the plastic are concerned, little variation occurred between the several grades of phenolic resin. The replacement up to 75 percent of the phenolic resin with soda spent-liquor lignin reduced the ultimate tensile strength and raised the water absorption, but the product appeared promising for uses not requiring the better properties obtained with unextended phenolic resin. The pulp plastics formed with lignin, lignin in combination with a wood-rosin byproduct, and lignin in combination with the wood-rosin byproduct and phenolic resin were inferior to those formed with phenolic resin. Increasing the percentage of resin substantially increased the flow of the mats and improved the water resistance of the plastic, but caused a considerable decrease in ultimate tensile strength and toughness.

To obtain a high-strength pulp plastic it is apparently necessary that the individual pulp fibers have high strength and that a good fiber-mat formation exists. The fiber bonding, such as occurs in paper, is believed to have a minor role, for beating the pulp actually decreased the tensile properties of the resulting plastics. Groundwood pulp plastics lacked toughness but still considerably exceeded the toughness of wood-flour-filled plastic.

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[1]This mimeograph is one of a series of progress reports prepared by the Forest Products Laboratory to further the Nation's war effort. Results here reported are preliminary and may be revised as additional data become available.

INTRODUCTION

During the last few years there has been considerable effort to supplement the widely used molded products made with wood-flour-filled phenolic resin with something of better mechanical strength, principally in regard to impact strength. For the most part, the trend has been to supplant the wood flour with a material more fibrous in nature. Products already on the market are produced from cotton-flock-filled phenolic resins, macerated-fabric-filled phenolic resins, chopped-tire-cord filled phenolic resins, diced-resin-filled paperboard, resin-impregnated or filled-sisal fiber, and resin-impregnated or filled-pulp forms.

The last two materials are unique in that they may be formed to the approximate shape of the article prior to molding. Such preforms may be much larger than would be practicable in a process depending on flow of the molding material. In this manner, one large motorcar company was able to make experimental trunk doors and fenders using pulp preforms. The publicity given this experiment has aroused widespread interest. The pulp-forming process had been developed prior to this experiment, however, and one pulp-molding company has been marketing such products for several years with considerable success. Another pulp molder has just started to turn out pulp-preformed plastics. Considerable research is now under way in this field.

This report presents the results of work at the Forest Products Laboratory on several types of wood pulps and resins and indicates the possibility of making considerable improvement in the properties of this type of plastic.

Literature

Little information is given in the literature regarding pulp-reinforced plastics. Parsons[2] described a commercial pulp plastic and gave mechanical properties of the material. In a later publication[3] he disclosed the application of the material to handwheels for destroyers. Haslanger and Mosher[4] described their pulp-preform research and also some of their experimental results. The process was briefly explained by Young and Box[5], who pointed out some of its advantages and application to manufacture of plastic diaphragms used in communications systems. The Plastics Catalogs for 1943 and 1944 contain brief sections under the heading "Phenolic Pulp Products", and give descriptions and photographs of marketed pulp plastics.

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[2]Parsons, W. E., "Molded Pulp Resin Products," Modern Plastics 19, No. 2:45, Oct. 1941.

[3]Parsons, W. E., "Down-East Handwheels for Destroyers," Modern Plastics 20, No. 12:61, Aug. 1943.

[4]Haslanger, R. U. and Mosher, R. H., "Phenolic Resin-Pulp Preforms," Modern Plastics 20, No. 11:76, July 1943.

[5]Young, S. H. A., and Box, R. J., "Pulp Preforming and Molding," Modern Plastics 21, No. 4:116, Dec. 1943.

Terms and Definitions

Since considerable confusion in terminology exists in this class of plastics, the following expressions and definitions are suggested and are so used in this report.

A pulp-reinforced plastic is a plastic with paper pulp introduced into the composition in a form other than as finished sheets of paper.

A pulp preform is a mass of resin-containing pulp ready to be molded into a plastic. Preforms may be of two kinds.

Shaped preforms are those bearing the shape of the finished molded article, either crudely or quite exactly, as contrasted to pulp preforms existing only as simple blanks that are subsequently flowed to more or less intricate shape.

Pulp forming is the process of producing a pulp shape, commonly called pulp molding or sometimes felting. It is referred to as pulp forming so as not to confuse this operation with the final plastic molding.

Suction-formed pulp is sucked onto a wire screen with one side of the wire exposed to the pulp slurry.

Pressure formed is the name of the process whereby pulp slurry is entirely confined by the container and one or more movable forces.

The resin is generally introduced into the pulp in one of two ways. If a suspension of powdered resin in water or a resin emulsion is added to the pulp slurry prior to the pulp-forming operation, the preform is said to be resin filled while if the pulp form is first made and then dipped into a solution of resin in water, alcohol, or other solvent, the preform is said to be impregnated. A third method, not common but sometimes used with lignin-enriched pulps, is to add a solution of phenolic resin in water to the pulp slurry and to depend on adsorption for retention of the resin.

Materials

The pulps used in this work were:

Forest Products Laboratory high-strength black spruce krafts.
A commercial black spruce kraft.
Forest Products Laboratory yellow birch neutral sulfite.
Forest Products Laboratory white spruce ground wood.
Commercial Mitscherlich sulfites.

The black spruce kraft pulps made at the Laboratory were specially prepared for producing high-strength phenolic resin laminates and the Mitscherlich pulps were those used in making an aircraft-grade laminate. The yellow birch neutral-sulfite pulp was included because this species and process are known to produce exceptionally strong hardwood pulps. The spruce ground wood was a newsprint grade slightly above average in strength. The physical and chemical properties of the pulps are given in table 1.

The resins used were: (1) powdered phenol-formaldehyde resins of a type recommended by the manufacturer, (2) lignin from paper-mill soda-process spent liquor, and (3) a resinous byproduct resulting from the refining of wood rosin.

EQUIPMENT AND DEVELOPMENT OF PROCEDURES

Pulp Forming

In the work so far undertaken on unflowed pulp-reinforced plastics, only flat disks have been made. There are several reasons for adopting this procedure. Specimens for physical tests are more readily obtained from flat panels. A shaped object requires both pulp-forming and plastic-molding dies that involve considerable expense.

Results with shaped objects, moreover, depend on the technique employed in making the shape and possibly on the shape itself. These factors complicate the study of the fundamental variables involved. The properties of a contoured piece of uniform thickness molded by applying pressure normal at all points to the surface of the preform should approximate those of a flat disk provided that the pulp formation is similar in both.

Pulp sufficient for a 1/8-inch panel was charged to a 4-gallon conical-bottom copper tank, a portion of the water was added, and the pulp was mixed with a high-speed propeller-type stirrer. A slurry was next made by adding to a small quantity of water the necessary amount of powdered resin or resins, 1 to 5 grams of a suitable wetting agent, and 1 percent zinc stearate to serve as a lubricant. This slurry was passed through an 80-mesh screen to remove lumps and was added to the pulp suspension. The whole was diluted to 1 percent consistency, and after thorough stirring, was ready for the forming operation. When a commercially experimental lignin was employed, it was necessary to precipitate the lignin on the fiber by means of hide glue and paper makers' alum to secure adequate retention. After incorporating the lignin with the pulp, 0.5 percent of hide glue in solution, followed by 0.5 percent of alum (based on the total pulp and resin charge) was added to the stock while it was being stirred. Stirring was continued from 15 to 30 seconds before charging to the forming apparatus. In this way, lignin retention values of 75 to 80 percent were secured, an amount comparable with retention values obtained with other resinous materials.

The pulp-forming mold consisted of a 2-foot long, 8-1/2-inch diameter, cylindrical vat with a perforated plate covered with 80-mech screen wire closing the bottom. A close-fitting hydraulically activated piston or force, the face of which was perforated and covered with 80-mesh screen wire, entered the top of the vat. Arrangement was made for applying vacuum or air pressure to both screen plates. Figure 1 shows the apparatus. In making the mat, the pulp was charged to the mold vat, was diluted to about 1 percent consistency, and was mixed by forcing air through the bottom screen plate. The piston was then moved downward and vacuum was applied to both screen plates. At the end of the downward stroke of the piston, the vacuum on the bottom screen was cut off, air pressure was applied, and the piston, with pulp cake held on by suction, was withdrawn from the vat. The mat was then released from the piston by cutting off the vacuum and substituting compressed air.

The mats were dried for 24 hours at 35° to 40° C. (95° to 104° F.) in a forced-circulation oven and then were conditioned for 24 hours or more in a 24° C. (75° F.), 50 percent relative humidity room before molding. The volatile content of the mats so treated was approximately 7 percent, on the basis of the loss of weight of a sample heated in an oven at 110° C. (230° F.) for several hours. When made for a 1/8-inch panel, the conditioned mats weighed approximately 180 grams and were 5/8 inch to 3/4 inch thick.

Plastic Molding

It was the original intention to mold the pulp mats in an 8-1/2-inch diameter disk mold. The mats, though 8-1/2 inches in diameter when wet, shrunk various amounts on drying depending on the kind of pulp and the degree of processing the pulp had received. As a result, some of the mats were confined at their periphery during molding while others were required to flow. Moreover, the mold used was cumbersome to handle and its use was time consuming, consequently cauls were employed.

To demonstrate the practicability of molding between cauls, several panels were made and their properties were compared with similar mats molded in a disk mold. The cauls used were stainless steel and the molding was done in a 14-inch by 14-inch steam-heated 125-ton capacity press. Table 2 indicates that if molding conditions are properly adjusted, plastics with substantially equivalent properties can be obtained by the two methods. With cauls, however, the pressure used is critical. If the pressure is too high, the pulp, in flowing, is likely to become discontinuous, leaving pockets of resin that are relatively free from fiber. This resin streaking may become pronounced if the pressure is excessive. That resin streaks affect some of the properties of the plastic is shown in table 3. Toughness and tensile strength may drop considerably in badly resin-streaked specimens. With plastic 69B, for example, the ultimate tensile strength was dropped by nearly a half and toughness by one-third as compared to unstreaked plastic 74.

Pressures at which good molding was obtained without the occurrence of resin-streaks were determined for given pulp and resin combinations. Figure 2 shows conditions that were satisfactory for a commercial black spruce kraft pulp with varying percentages of a commercial phenolic resin. For example, pulp mats 59A and 59B (table 3) containing 48 percent resin were molded at 3,000 and 2,000 pounds per square inch, respectively. Panel 59A was badly resin-streaked while panel 59B was incompletely molded. The curve indicates that for this resin content a pressure of about 2,300 pounds per square inch is best for preventing these defects.

The molding schedules varied with the type of pulp and resin, and with the amount of resin. Practically all straight phenolic-pulp plastics were cured for 13 minutes at 160° C. (320° F.) and were drawn hot. The pressing pressure used depended on the composition being molded. Lignin, wood-rosin byproduct, lignin and wood-rosin byproduct, and lignin wood-rosin byproduct phenolic-resin pulp plastics were molded under conditions that appeared to be adequate. These plastics were chilled to below 100° C. (212° F.) by cooling the platens before the pressure was released. The recorded molding time was the time the plastic was under pressure at the stated molding temperature. A mat and molded panel is shown in figure 3.

Testing of the Plastics

Each plastic disk was assigned a number and furnished two tensile specimens, four compression specimens to determine ultimate strength, two compression specimens to determine elastic properties, five flatwise toughness specimens, and two water absorption samples. Tests, other than toughness, were made according to the methods outlined in "Federal Specification for Plastics, Organic: General Specification (Methods of tests) L-P-406, December 9, 1942," except that the water absorption values were not corrected for loss due to water-soluble matter. This correction appeared to be negligible for straight phenolic plastics, but was as much as 1 percent when the plastics contained experimental commercial lignin as the only resinous constituent. The toughness test was made on the Forest Products Laboratory intermediate-capacity toughness-testing machine. This machine, originally designed for testing wood, is a pendulum type and, as adapted for these tests, measures the energy required to break a 1/8- by 3/8- by 3-1/2-inch unnotched specimen on a span of 2-1/2 inches.

EFFECT OF PULP TYPE AND QUALITY

Some properties of the plastics made from a variety of pulps and phenolic resin are given in table 4. In all tests, the chemical-pulp plastics gave good tensile strengths, the range being from 20,000 to 25,000 pounds per square inch. These plastics had good toughness values, though the Mitscherlich-pulp plastics 135B and 139C were appreciably lower. With these Mitscherlich pulps, blistering was experienced, expecially when a type of resin which becomes fluid during molding was used. This may have been due to the pH of the pulp affecting the curing of the resin[6]. It could be overcome by increasing time or temperature of cure or possibly by decreasing volatile content. The yellow birch neutral-sulfite plastic 83 was among the best in spite of the characteristically short fiber of the hardwood. The proportional limit in tension considerably exceeded that obtained with the other plastics.

The ground-wood pulp plastics 86 and 113 had moderately good tensile strength but the toughness was considerably lower than that of the chemical-pulp plastics. Plastic 113 was noteworthy in that, while the resin content was only 12 percent, the properties, except for water absorption which was increased approximately three times by the reduction in resin, were comparable to plastic 86 containing 40 percent resin. The low resin material was molded at 180° C. (354° F.) in an attempt to obtain a stabilization of the fiber, such as occurs in forming "Staypak", the Laboratory's compressed heat-stabilized wood. This seems to have been accomplished, for the plastic did not disintegrate even on prolonged soaking. Where high water resistance is not essential, such low-resin products should have commercial application for low-cost, high-strength plastic panels.

It is difficult to correlate strength properties of the plastics with the potential paper-making properties of the pulps. The pulp mats before molding are bulky and weak, and apparently little fiber bonding exists. Presumably, therefore, strength, as manifested in a sheet of paper, is much less important than the intrinsic strength of the fiber and the surface characteristics which influence adhesion of resin to the fiber.

EFFECT OF BEATING THE PULP

Unbeaten Forest Products Laboratory high-strength kraft pulp and several batches of the same material beaten 20, 40, 60, or 80 minutes in a test beater were converted to pulp plastics. The Schopper-Riegler freeness values on the beaten pulp were 865, 810, 795, and 745 cubic centimeters, respectively. The phenolic-resin content was in all plastics approximately 40 percent. Results are shown in table 5.

Beating lowered the maximum strength and modulus of elasticity in tension. At 80 minutes, these values were lowered approximately 25 percent from those of unbeaten pulp. Other properties were practically unaffected. Beating, while aiding in the retention of resin, had the disadvantage of increasing the time of forming the mats.

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[6]Hanson, N. D. and Wilson, Perry, "Resins for Paper Base Laminates," Paper Trade Journal 118, No. 15:48, April 13, 1944.

EFFECT OF TYPE OF RESIN

Phenolic Resin Plastics

Table 6 shows the results obtained by varying the kind of phenolic resin in kraft-pulp plastics containing 40 percent resin. The resins differed in their fluidity during molding. In the fourth column of the table, numbers indicating this fluidity, which were assigned by an experienced observer, are given. Higher numbers were assigned to the more fluid products. Good plastics were obtained with all resins. In spite of the fact that the molding conditions might not have been optimum in all cases, only slight significant differences in plastic properties resulted. There appeared to be a tendency for the more fluid products to give a higher proportional limit in compression. Apparently good products can be obtained from a variety of powdered phenolic resins, the choice of resin being controlled by factors such as suspension characteristics and molding schedules rather than properties of the finished product.

Lignin Plastics

Pulp plastics made with lignin in place of phenolic resin were decidedly inferior in properties, as may be seen in table 7. With approximately 40 percent lignin content, ultimate tensile strengths were reduced to about a third and ultimate compressive strengths to about half of the values obtained with phenolic plastics. The lignin plastics also had lower toughness and considerably higher water-absorption values. The commercially available lignin gave inferior products in regard to water resistance as compared to the commercial experimental lignin. This is presumed to have been caused by poorer dispersion of the commercially available lignin, which was coarsely grained, as contrasted with the almost colloidal nature of the commercial experimental lignin. Blistering tended to occur with the commercial experimental lignin but this was overcome by precompressing the mats before molding, thereby eliminating a portion of the air which might otherwise be entrapped.

From these results it does not appear that lignin is a very promising binder for pulp plastics in spite of the fact that good lignin laminates have been produced at the Laboratory. Probably the ability of the lignin to cement the fibers together is low so that paper strength, such as that obtained in a paper laminate, is necessary for a high-strength lignin product.

Wood-rosin-byproduct Plastics

Wood-rosin-byproduct plastics were slightly inferior to the lignin plastics in ultimate tensile and compressive strengths and were worthless for exposure to water (table 7). Fuzzy edges were left in machining and the plastics appeared poor on inspection. Slight bending caused cracks to appear on the tension side of the specimen. It was difficult, moreover, to prevent sticking to the cauls during molding. Nevertheless, high toughness values were obtained. Apparently the resin disintegrates to a powder under light loads and the fibrous structure, freed from the embrittling resin, hangs together with considerable tenacity until the specimen is greatly deformed.

Lignin and Wood-rosin-byproduct Plastics

Pulp plastics containing approximately 40 or 50 percent total resin were made with 3-to-1 and 1-to-1 lignin and wood-rosin byproduct mixtures. As shown in table 8 these plastics had, in general, higher strength properties, especially ultimate tensile strengths, than straight lignin plastics, but water absorption values were higher and increased with increasing wood-rosin byproduct content. As with straight wood-rosin byproduct plastics, the high toughness values are believed to be somewhat misleading. Commercial experimental lignin and wood-rosin byproduct plastics were, in general, more water resistant than the commercially available lignin and wood-rosin byproduct plastics. Increasing the molding temperature from 160° to 170° C. (320° to 338° F.) improved the water resistance of the commercial experimental lignin plastics slightly but left much to be desired as far as this property is concerned.

Lignin Wood-rosin Byproduct Phenolic-pulp Plastics

Commercially available lignin-wood-rosin byproduct phenolic-resin pulp plastics containing approximately 40 or 50 percent total resin were made in mixtures with a ratio of 6 to 1 to 1 and 4 to 2 to 2 (table 9). These combinations, when molded at 160° C. (320° F.), showed little if any improvement in properties over those of the lignin wood-rosin byproduct mixtures. Increasing molding temperatures improved ultimate tensile and compressive strength somewhat and decreased the water absorption considerably. There are two possible explanations of the decrease in water absorption with increase in temperature: (1) The increased temperature overcomes a tendency of the lignin or wood-rosin byproduct to retard the cure of the phenolic resin or (2) the increased temperature may cause physical and chemical changes in the pulp. Whereas there is considerable spread in water absorption values with the various combinations molded at 160° C. (320° F.); when molded at 180° C. (354° F.) the water absorption values of the several mixtures are approximately the same.

Lignin-phenolic Plastics

Table 10 shows the properties of plastics containing approximately 40, 45, or 50 percent total resin in which lignin-phenolic mixtures with ratios of 3 to 1, 3 to 2, and 1 to 1 were used. The phenolic resin generally employed was one of the more fluid types. The incorporation of even one part phenolic resin to three parts lignin in a 40 percent total-resin plastic produced materials far superior to straight lignin-pulp plastics. With 1 to 1 combinations, the properties approached those of the phenolic plastics. Water-absorption values were higher than with straight phenolic plastics, but were within reasonable limits. All in all, the lignin-phenolic pulp plastics appear quite promising.

Fortified Hydrolyzed-wood Plastics

Hydrolyzed wood produced from chips by the Laboratory's acid process is pulplike in nature, will mold without supplementary resin, and has fair flow properties. The plastic, however, is lacking in strength and toughness. It appeared possible that this product could be improved considerably by fortifying with small amounts of kraft pulp, lignin, and phenolic resin. Mixtures of this kind using hydrolyzed sweetgum wood, lignin, and fluid-type phenolic resin were molded with the results given in table 11. Considering only the methanol-soluble lignin portion of the hydrolyzed wood to be resin, the total resin content was 37 percent. The kraft-pulp content varied from zero to 14 percent of the charge.

The incorporation of kraft pulp, to the extent of 14 percent, appreciably improved the toughness and tensile strength of the hydrolyzed wood plastic. To get a major improvement, however, would apparently require a high content of kraft.

EFFECT OF RESIN CONTENT

Increasing the resin content of the pulp mats greatly decreased the pressure required to mold them as shown in table 7. Figure 2 shows this effect with phenolic resins. Increasing the resin content from 32 to 58 percent decreased the required molding pressure from 3,750 to 1,000 pounds per square inch. This effect on ease of molding is further evidenced by the flow, as measured by the increase in the diameters of the plastic disks over the diameter of the unmolded mats. This is also shown in figure 2. On the basis of the diameter increase, expressed in inches per 1,000 pounds per square inch applied pressure, the plastic flow would be approximately doubled by raising the resin content from 40 to 50 percent, and quadrupled by raising it from 40 to 60 percent.

Maximum tensile strength, modulus of elasticity, and proportional limit values dropped with increasing resin content as shown in figure 4. Haslanger and Mosher[4] found little variation in maximum tensile strength with kraft-pulp reinforced plastics containing 15 to 55 percent phenolic resin. All the tensile strength values they obtained, however, were rather low, 12,000 to 13,000 pounds per square inch, and were obtained from specimens cut from a preformed rectangular panel molded at 880 pounds per square inch pressure.

As figure 5 indicates, the maximum compressive strength values were fairly constant with varying resin content except with the lowest resin content. The specific gravity, water absorption, and toughness values dropped with increasing resin content as shown in figure 6.

FIBER BONDING AND FIBER FORMATION

Three experiments were made in an attempt to determine the factors involved in producing a high-strength pulp plastic. It is reasonable to suppose that high tensile strength of the individual fibers is necessary. In paper and board, the orientation of fibers is important as well as the fiber-to-fiber bond established in drying the fibrous mass from the wet state.

In the first experiment, wet kraft pulp was dehydrated by treating it successively with alcohol, acetone, and benzene and then evaporating the benzene. By this means a bulky mass of fiber was obtained that substantially lacked fiber-to-fiber bonding. Powdered phenolic resin to the extent of 40 percent was then mixed with the pulp. The mixture was molded into a 4-1/4-inch diameter disk. The plastic had a tensile strength of only 12,400 pounds per square inch and a toughness of 13 inch-pounds per inch of width. In the second experiment an 8-1/2-inch diameter air-dry pulp mat containing 41 percent resin was placed in an atmosphere of acetone for about 15 hours. The absorbed acetone caused liquefaction of the resin which flowed and coated the fibers. This method of fixing the resin to the fiber may have a practical application. After drying, the mat was broken in a shredder without apparent resin loss. Disks of 4-1/4-inch diameter were molded from portions of the fluffy mass. Molding was difficult and fine surface resin streaks could not be avoided. The plastic had a toughness value of 11 inch-pounds per inch of width and a tensile strength of 13,900 pounds per square inch. In these two experiments there was little opportunity for orientation of the fibers. In the third experiment the procedure used in the second was repeated but instead of molding the shredded pulp directly, it was suspended in water and remade into an 8-1/2-inch diameter mat in the usual manner, promoting a high degree of horizontal orientation of fibers. By this treatment the resin content was reduced to 38 percent. The resulting mat was soft and appeared to have decidedly less fiber-to-fiber bonding than the usual product. The plastic had the following properties:

Maximum tensile strength.............	22,400 pounds per square inch.
Modulus of elasticity in tension.....	1,990,000 pounds per square inch.
Maximum compressive strength.........	15,200 pounds per square inch.
Toughness............................	24 inch-pounds per inch of width.
Water absorption.....................	2.8 percent.

These experiments, though not conclusive, tend to indicate that fiber-to-fiber bonding plays only a minor role in giving strength to pulp plastics but that fiber felting or mat formation is important.

PLASTICS FLOWED FROM PULP PREFORMS

The molding of a cup- or box-shaped object with vertical side walls from a shaped-pulp preform presents difficulties. Either the side walls of the preform need to be high (3 to 5 times that of the molded object) or bag molding or expanding dies must be resorted to. Such objects may be flowed from flat-pulp preforms. Figure 7 shows a cup that was molded in this fashion and also a pulp preform such as was charged to the mold. Molding with such material is not so readily carried out as when conventional molding compounds are used. Uniform heating of the preform is essential. Probably thin walls and large distances of flow would be difficult, though high frequency heating should be helpful. The composition of the preform is important. If an attempt is made to improve flow by using excessively high resin content or too fluid a resin, resin pockets are apt to occur. Phenolic resin contents as low as 30 percent were successfully used though generally a content of 40 to 50 percent was desirable. Lignin-phenolic mixtures flowed well. Preforms made from cotton linters and also from long-fibered pulps made by cooking and beating caroa fiber and flax were successfully flowed.

On examining the polished section of a plastic flowed from a pulp preform, more or less regular and distinct flow lines may be observed (fig. 8). Turbulence in these lines is apt to be associated with a seam or resin pocket.

COMPARISON OF EXPERIMENTAL PULP PLASTICS

WITH COMMERCIAL PLASTICS

A comparison of some of the materials produced in this work with several commercial plastics, using the same test procedure, is given in table 12. Both the kraft and yellow birch neutral-sulfite-pulp phenolic-resin plastics equal the aircraft-grade paper laminate in toughness and water resistance and are roughly three-quarters as strong in tension and compression. The sisal plastic approaches these plastics in toughness but is considerably lower in other strengths while the cord-filled plastic is considerably lower in both toughness and tensile strength. A marked advantage in toughness and tensile strength is shown by the pulp plastics over the wood-flour-filled phenolic product, but wood-flour plastic excels in compressive strength and water resistance.

CONCLUSIONS

Strong, tough, contoured plastic articles can be molded from paper-pulp filled with phenolic resin. For best strength properties, chemical pulps with high intrinsic fiber strength should be used together with conditions which will insure good fiber formation. Fiber bonding resulting in drying the pulp from the wet state is not essential. Insofar as physical properties are concerned, a variety of powdered phenolic resins is applicable. For most purposes the resin content should be between 40 and 50 percent. Articles may be obtained by forming the pulp-resin mixture to shape before molding or, with some restrictions, by flowing flat blanks or preforms in the mold.

Plastics with good physical properties are possible when up to 75 percent of the phenolic resin is substituted with soda-process lignin.

Because of their suitability for shaped objects and the fact that they combine high impact strength with good tensile and compressive strengths, pulp-reinforced plastics are believed to be headed toward broader application.

Table 1.--Physical and chemical properties of pulps used in the preparation of pulp-reinforced plastics

Pulp type	Cook or grinder run	Shipment	Freeness (Schopper-Riegler)	Bursting strength	Tearing strength	Tensile strength	Density	Folding endurance	Cellulose Total	Cellulose Alpha	Lignin	Total pentosans	Chlorine No.
	No.	No.	Cc.	Points per lb. per ream	Gm. per lb. per ream	Lb. per sq. in.	Gm. per Cc.	Number of double folds	Percent	Percent	Percent	Percent	
White spruce ground wood	395	1,571	460	0.25	0.71	1,420							
Yellow birch neutral sulfite	5036-N	1,867	880	.24	.95	949	0.43	11	95.4	75.8	3.0	19.7	
			800	1.10	1.45	6,000	.65	370					
			550	1.28	1.00	10,400	.81	540					
Commercial black spruce kraft		1,942	865	.53	2.9	2,330	.49	75	93.8	76.5	3.7	11.2	4.1
			800	1.46	1.65	8,100	.72	1,000					
			550	1.62	1.15	12,800	.87	1,550					
Black spruce kraft	2639-40 41-42	1,700	866	.78	3.65	4,079	.49	658	93.4	74.8	4.6	9.8	4.1
			800	1.59	1.95	9,040	.70	1,175					
			550	1.76	1.46	12,540	.82	1,313					
Black spruce kraft	I-2676	1,999	845	.57	3.20	2,690	.51	190	93.3	74.9	3.8	9.7	4.1
			800	1.33	1.95	9,620	.70	1,188					
			550	1.76	1.53	12,460	.83	1,688					
Commercial black spruce Mitscherlich sulfite		1,720	850	.69	1.57	4,200	.60	230	93.0	79.0	.9	5.6	
			800	1.02	1.30	8,400	.78	460					
			550	1.00	.80	10,800	.90	650					
Commercial black spruce Mitscherlich sulfite		1,742	865	.60	1.50	4,310	.65	252	93.2	76.8	1.6	5.7	
			800	1.00	1.20	7,700	.81	450					
			550	1.10	.80	11,200	.90	850					

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Table 2.--A comparison of certain properties of pulp-reinforced phenolic plastics molded in an 8-1/2-inch disk mold and between stainless-steel cauls (High Strength Black Spruce Kraft Digestion Nos. 2639-40-41-42)

Plastic No.	Type of molding	Resin content[1]	Beating	Diameter of original mat	Diameter of molded disk	Diameter of molded area	Molding pressure	Properties[2]: Tension[3]: Ultimate strength	Properties[2]: Tension[3]: Modulus of elasticity	Properties[2]: Edgewise compression[3]: Ultimate strength	Properties[2]: Edgewise compression[3]: Modulus of elasticity	Properties[2]: Forest Products Laboratory toughness[4]: Flatwise	Properties[2]: Specific gravity	Properties[2]: Water absorption in 24 hours[5]
		Percent	Minutes	Inches	Inches	Inches	Lb. per sq. in.	Lb. per sq. in.	1,000 lb. per sq. in.	Lb. per sq. in.	1,000 lb. per sq.in.	In.-lb. per in. of width		Percent
53A	Cauls	40	0	8-7/16	8-3/4	7-3/4	3,000	24,600	2,000	16,000	1,600	26	1.40	2.3
53B	Cauls	40	0	8-7/16	8-3/4	8	3,000	23,400	1,900	16,700	1,700	22	1.40	2.5
52B	Cauls	40	40	8-7/32	8-7/16	7-1/4	2,000	17,900	1,400	16,000	1,400	26	1.41	2.6
Average								22,000	1,800	16,200	1,600	25	1.40	2.5
53D	Mold	40	0	8-7/16	8-1/2	8-1/2	4,000	19,600	1,900	15,700	1,700	22	1.40	2.3
50B	Mold	40	0	8-7/16	8-1/2	8-1/2	4,000	21,800	2,000	16,600	1,600	30	1.41	2.7
52C	Mold	39	40	8-7/32	8-1/2	7-3/4	4,000	19,600	1,800	16,700	1,900	21	....	....
Average								20,300	1,900	16,300	1,700	24	1.40	2.5

[1] Commercial phenolic resin used.

[2] Properties were determined from specimens prepared, conditioned, and tested in accordance with Federal Specification for Plastics, L-P-406, Dec. 9, 1942, unless otherwise noted. Machined edges were not otherwise finished prior to test. Compressive stress-strain properties were obtained by testing a 1- by 4-inch specimen as a laterally supported column. Ultimate compressive strength was obtained by testing specimens 1 inch wide by 1/2 inch long in pairs, 1 inch apart and parallel.

[3] Each property value represents the average of 2 tests.

[4] Forest Products Laboratory intermediate-capacity toughness machine, unnotched specimen, 3/8 inch wide by nominal 1/8 inch thick by 3-1/2 inches long, tested over 2-1/2-inch span. Each value represents the average of 5 tests.

[5] Specimens 2 by 2 by 1/8 inch thickness, values represent the average of 2 tests.

Z M 58414 F

Table 3.--A comparison of certain properties of resin-streaked and non-resin-streaked pulp-reinforced phenolic plastics

Plastic No.	Plastic disk defects: Resin streaked	Plastic disk defects: Test specimens containing resin streaks	Type of molding	Resin content	Molding pressure	Diameter of pulp-resin mat	Diameter of molded disk	Diameter of molded area of disk	Properties[1]: Forest[2] Products Laboratory toughness: Flatwise	Tension[3]: Ultimate strength	Tension[3]: Elongation[4]	Tension[3]: Proportional limit stress	Tension[3]: Modulus of elasticity	Edgewise compression[3]: Ultimate strength	Edgewise compression[3]: Yield (0.2 percent offset)	Edgewise compression[3]: Proportional limit stress	Edgewise compression[3]: Modulus of elasticity	Specific gravity	Water absorption in 24 hours[5]
				Percent	Lb. per sq. in.	Inches	Inches	Inches	In.-lb. per in. of width	Lb. per sq. in.	Percent	Lb. per sq. in.	1,000 lb. per sq. in.	Lb. per sq. in.	Lb. per sq. in.	Lb. per sq. in.	1,000 lb. per sq. in.		Percent
High Strength Black Spruce Kraft. Cook Nos.--2639-40-41-42																			
50B	Yes	None	Mold	40	4,000	8-7/16	8-1/2	8-1/2	30	21,500	1.8	4,500	2,000	16,600	6,200	1,900	1,600	1.41	2.7
50C	Yes	Tensile	Mold	40	4,000	8-7/16	8-1/2	8-1/2	25	14,600	1.0	5,800	1,900	16,200	6,200	2,300	1,600	1.41	2.7
50D	Yes	Tensile	Mold	40	4,000	8-7/16	8-1/2	8-1/2	26	18,800	1.6	6,400	1,700	16,700	5,500	1,700	1,400	1.41	2.8
59A	Yes	All specimens	Cauls	48	3,000	8-7/16	9	8-1/2	13	14,200	1.2	6,300	1,300	17,400	6,100	2,600	1,300	1.39	1.7
59B	No	None	Cauls	48	2,000	8-7/16	8-3/4	7	18	15,500	1.5	7,100	1,300	17,100	5,900	2,500	1,400	1.39	1.5
Commercial Black Spruce Kraft Pulp. Shipment No. 1942																			
69A	Yes	Tensile toughness	Cauls	40	3,000	8-3/8	8-13/16	8-1/8	15	13,000	.9	4,000	1,700	14,800	6,500	2,500	1,400	1.39	2.2
69B	Yes	All specimens	Cauls	37	4,000	8-3/8	9-1/16	8-7/8	12	10,900	.5	3,900	1,800	14,100	6,500	2,700	1,500	1.40	2.3
74	No	None	Cauls	40	3,000	8-3/8	8-11/16	7-15/16	19	20,100	2.1	5,300	1,600	16,500	5,800	2,300	1,400	1.39	1.9

[1] Properties were determined from specimens prepared, conditioned, and tested in accordance with Federal Specification for Plastics, L-P-406, Dec. 9, 1942, unless otherwise noted. Machined edges were not otherwise finished prior to test. Compressive stress-strain properties were obtained by testing a 1- by 4-inch specimen as a laterally supported column. Ultimate compressive strength was obtained by testing specimens 1 inch wide by 1/2 inch long in pairs, 1 inch apart and parallel.

[2] Forest Products Laboratory intermediate-capacity toughness machine, unnotched specimen, 3/8 inch wide by nominal 1/8 inch thick by 3-1/2 inches long, tested over 2-1/2-inch span. Each value represents the average of 5 tests.

[3] Each property value represents the average value from 2 tests.

[4] Elongation immediately before fracture, measured over a 2-inch gage length.

[5] Specimens 2 by 2 by 1/8 inch in thickness, values represent the average of 2 tests.

Z M 58415 F

Table 4.--Effect of pulp type and quality on certain properties of pulp-reinforced phenolic plastics

Plastic No.	Wood pulp: Type	Wood pulp: Oven-dry content	No. of panels tested[1]	Phenolic resin	Molding data: Time	Molding data: Pressure	Molding data: Temperature	Properties[2]: Forest[3] Products Laboratory toughness, Flatwise	Tension: Ultimate strength	Tension: Elongation[4]	Tension: Proportional limit stress	Tension: Modulus of elasticity	Edgewise compression: Ultimate strength	Edgewise compression: Yield (0.2 percent offset)	Edgewise compression: Proportional limit stress	Edgewise compression: Modulus of elasticity	Water absorption in 24 hours[5]	Specific gravity
		Percent		Percent	Minutes	Lb. per sq. in.	°C.	In.-lb. per in. of width	Lb. per sq. in.	Percent	Lb. per sq. in.	1,000 lb. per sq. in.	Lb. per sq. in.	Lb. per sq. in.	Lb. per sq. in.	1,000 lb. per sq. in.	Percent	
86	White spruce ground wood run #395	38	4	40	13	1,300	160	7	15,500	1.4	5,800	1,400	17,100	7,500	2,700	1,300	1.5	1.35
113	Do..........	42	1	12	13	4,000	180	7	14,000	1.0	6,500	1,800	15,200	9,400	4,100	1,500	4.6	1.39
83	Yellow birch neutral sulfite Dig. 5036-N	55	2	39	13	3,000	160	22	23,700	2.1	8,700	1,700	16,500	6,900	2,800	1,700	1.8	1.40
74	Commercial black spruce kraft	53	4	40	13	3,000	160	19	20,100	2.1	5,300	1,600	16,500	5,800	2,300	1,400	1.9	1.39
53	Black spruce kraft Dig. Nos. (2639-40-41-42)	31	2	40	13	3,000	160	24	24,000	1.9	6,300	1,900	16,300	6,200	2,500	1,600	2.4	1.40
134 C	Black spruce kraft Dig. No. 1-2676	36	1	40	13	2,750	160	19	25,100	1.9	4,600	2,000	14,900	7,400	2,300	1,900	1.9	1.38
137	Black spruce kraft Dig. No. 1-2676	36	2	41	13	2,125	160	23	23,800	1.8	4,700	2,200	15,100	7,700	2,400	1,700	2.8	1.40
135 B	Commercial Mitscherlich. Ship. 1720	85	1	40	13	2,750	160	13	20,600	1.7	4,600	1,800	14,000	6,400	2,000	1,800	2.2	1.41
139 C	Commercial Mitscherlich Ship. 1742	52	1	39	13	1,500	170	16	19,800	1.5	7,400	1,800	17,800	7,900	3,900	1,600	3.2	1.40

[1] Each panel furnished 2 tensile specimens, 4 compression specimens for ultimate strength determination, 2 compression specimens to determine elastic properties, 5 toughness specimens and 2 water-absorption specimens.

[2] Properties were determined from specimens prepared, conditioned and tested in accordance with Federal Specification for Plastics, L-P-406, Dec. 9, 1942, unless otherwise noted. Machined edges were not otherwise finished prior to test. Compressive stress-strain properties were obtained by testing a 1- by 4-inch specimen as a laterally supported column. Ultimate compressive strength was obtained by testing specimens 1 inch wide by 1/2 inch long in pairs, 1 inch apart and parallel. Values represent the average for the indicated number of tests.

[3] Forest Products Laboratory intermediate-capacity toughness machine, unnotched specimen, 3/8 inch wide by nominal 1/8 inch thickness by 3-1/2 inches long, tested over 2-1/2-inch span.

[4] Elongation immediately before fracture, measured over a 2-inch gage length.

[5] Specimens 2 by 2 by 1/8 inch in thickness.

Z M 58416 F

Table 5.--Effect of pulp beating on certain properties of pulp-reinforced phenolic-resin plastics[1]

Plastic No.	Beating treatment	No. of panels tested[2]	Phenolic resin	Molding data: Time	Molding data: Pressure	Molding data: Temperature	Properties[3]: Toughness[4]: Flatwise	Tension: Ultimate strength	Tension: Elongation[5]	Tension: Proportional limit stress	Tension: Modulus of elasticity	Compression: Ultimate strength	Compression: Yield (0.2 percent offset)	Compression: Proportional limit	Compression: Modulus of elasticity	Water absorption in 24 hours[6]	Specific gravity
	Minutes		Percent	Minutes	Lb. per sq. in.	°C.	In.-lb. per in. of width	Lb. per sq. in.	Percent	Lb. per sq. in.	1,000 lb. per sq. in.	Lb. per sq. in.	Lb. per sq. in.	Lb. per sq. in.	1,000 lb. per sq. in.	Percent	
53	0	2	40	13	3,000	160	24	24,000	1.9	6,300	1,900	16,300	6,200	2,500	1,600	2.4	1.40
54	20	3	40	13	4,000	160	25	21,300	1.9	5,600	1,800	16,100	6,700	3,000	1,700	2.1	1.41
55	40	3	39	13	4,000	160	23	19,800	1.8	6,600	1,600	16,100	7,000	3,100	1,500	2.3	1.41
56	60	3	39	13	4,000	160	24	18,600	2.0	5,900	1,400	16,600	6,400	2,900	1,700	2.2	1.41
57	80	3	38	13	4,000	160	23	17,700	2.0	5,000	1,400	16,100	6,200	2,600	1,500	2.5	1.40

[1] High strength black spruce kraft digestion Nos. 2639-40-41-42.

[2] Each panel furnished 2 tensile specimens, 4 compression specimens for ultimate strength determination, 2 compression specimens to determine elastic properties, 5 toughness specimens and 2 water-absorption specimens.

[3] Properties were determined from specimens prepared, conditioned and tested in accordance with Federal Specification for Plastics, L-P-406, Dec. 9, 1942, unless otherwise noted. Machined edges were not otherwise finished prior to test. Compressive stress-strain properties were obtained by testing a 1- by 4-inch specimen as a laterally supported column. Ultimate compressive strength was obtained by testing specimens 1 inch wide by 1/2 inch long in pairs, 1 inch apart and parallel. Values represent the average for the indicated number of tests.

[4] Forest Products Laboratory intermediate-capacity toughness machine, unnotched specimen, 3/8 inch wide by nominal 1/8 inch thickness by 3-1/2 inches long, tested over 2-1/2-inch span.

[5] Elongation immediately before fracture, measured over a 2-inch gage length.

[6] Specimens 2 by 2 by 1/8 inch in thickness.

Z M 58417 F

Table 6.--Effect of the type of powdered phenolic resin on the properties of pulp-reinforced plastics

Plastic No.	No. of panels tested[1]	Phenolic resin: Relative fluidity[2]	Phenolic resin: Amount	Molding data: Time	Molding data: Pressure	Molding data: Temperature	Properties[5]: Forest Products Laboratory toughness[3] (Flatwise)	Tension: Ultimate strength	Tension: Elongation[4]	Tension: Proportional limit stress	Tension: Modulus of elasticity	Edgewise compression: Ultimate strength	Edgewise compression: Yield (0.2 percent offset)	Edgewise compression: Proportional limit stress	Edgewise compression: Modulus of elasticity	Water absorption in 24 hours[6]	Specific gravity
			Percent	Minutes	Lb. per sq. in.	°C.	In.-lb. per in. of width	Lb. per sq. in.	Percent	Lb. per sq. in.	1,000 lb. per sq. in.	Lb. per sq. in.	Lb. per sq. in.	Lb. per sq. in.	1,000 lb. per sq. in.	Percent	
Commercial black spruce kraft, Shipment No. 1942.																	
79	2	4	40	13	2,500	160	23	21,900	2.2	5,900	1,800	15,900	7,300	2,700	1,700	2.4	1.41
84	2	4	40	13	1,500	160	19	22,500	2.1	6,500	1,600	15,500	7,000	2,600	1,400	2.3	1.40
81	2	4	40	13	3,000	160	22	21,900	2.1	6,600	1,800	16,300	7,100	2,500	1,700	2.5	1.40
85	2	4	41	13	2,000	160	20	20,900	2.2	6,100	1,600	15,400	6,900	2,500	1,500	2.5	1.40
80B	1	3	41	13	2,500	160	24	21,700	2.1	6,200	1,800	16,400	6,600	2,600	1,600	2.2	1.39
74	4	2	40	13	3,000	160	19	20,100	2.1	5,300	1,600	16,500	5,800	2,300	1,400	1.9	1.39
82	2	1	40	13	3,000	160	23	22,200	2.3	5,800	1,700	17,400	5,900	2,000	1,600	2.2	1.39
High strength black spruce kraft, Dig. No. I-2676.																	
137	2	4	41	13	2,125	160	23	23,800	1.8	4,700	2,200	15,100	7,700	2,400	1,700	2.8	1.40
134C	1	2	40	13	2,750	160	19	25,100	1.9	4,600	2,000	14,900	7,400	2,300	1,900	1.9	1.38

[1] Each panel furnished 2 tensile specimens, 4 compression specimens for ultimate strength determination, 2 compression specimens to determine elastic properties, 5 toughness specimens, and 2 water-absorption specimens.

[2] Numerals from 1 to 4 were assigned this fluidity by an experienced observer; the higher numbers being assigned the more fluid products.

[3] Forest Products Laboratory intermediate-capacity toughness machine, unnotched specimen, 3/8 inch wide by nominal 1/8 inch thickness by 3-1/2 inches long, tested over 2-1/2-inch span.

[4] Elongation immediately before fracture, measured over a 2-inch gage length.

[5] Properties were determined from specimens prepared, conditioned and tested in accordance with Federal Specification for Plastics, L-P-406, Dec. 9, 1942, unless otherwise noted. Machined edges were not otherwise finished prior to test. Compressive stress-strain properties were obtained by testing a 1- by 4-inch specimen as a laterally supported column. Ultimate compressive strength was obtained by testing specimens 1 inch wide by 1/2 inch long in pairs, 1 inch apart and parallel. Values represent the average for the indicated number of tests.

[6] Specimens 2 by 2 by 1/8 inch in thickness.

Table 7.--Some properties of various pulp-reinforced plastics

Plastic No.	No. of panels tested[1]	Resin: Type	Resin: Amount	Molding data: Time	Molding data: Pressure	Molding data: Temperature	Plastic flow (diameter increase)	Properties[2]: Forest Products Laboratory toughness[3]: Flatwise (1/8 inch thickness)	Tension: Ultimate strength	Tension: Elongation[4]	Tension: Proportional limit stress	Tension: Modulus of elasticity	Edgewise compression: Ultimate strength	Edgewise compression: Yield (0.2 percent offset)	Edgewise compression: Proportional limit stress	Edgewise compression: Modulus of elasticity	Water absorption in 24 hours[5]	Specific gravity
			Percent	Minutes	Lb. per sq. in.	°C.	In. per 1,000 lb. per sq. in.	In.-lb. per in. of width	Lb. per sq. in.	Percent	Lb. per sq. in.	1,000 lb. per sq. in.	Lb. per sq. in.	Lb. per sq. in.	Lb. per sq. in.	1,000 lb. per sq. in.	Percent	
Commercial black spruce kraft, Shipment No. 1942.																		
73	4	Phenolic	32	13	3,750	160	0.065	27	21,300	2.0	5,600	1,900	14,000	6,500	2,500	1,600	2.5	1.41
74	4	Do....	40	13	3,000	160	.111	19	20,100	2.1	5,300	1,600	16,500	5,800	2,300	1,400	1.9	1.39
75	3	Do....	48	13	2,250	160	.189	16	18,200	2.0	4,900	1,500	16,100	5,300	1,600	1,400	1.5	1.37
76	3	Do....	58	13	1,000	160	.363	10	11,300	1.4	3,800	1,200	16,700	4,700	1,300	1,100	1.2	1.35
70	2	Com. experimental lignin	30	[6]13	3,000	180	.118	15	6,400	.7	2,100	1,600	9,100	6,400	2,500	1,300	5.4	1.42
71	2	Do....	38	[6]13	2,250	180	.184	12	6,600	.9	2,300	1,500	7,300	6,100	2,500	1,200	5.3	1.41
72	2	Do....	47	[6]13	1,000	180	.354	12	4,800	.6	1,800	1,100	11,100	5,400	1,800	1,000	4.5	1.39
62B	1	Commercially available lignin	42	13	1,500	180	.203	19	6,500	.7	2,900	1,400	11,300	5,800	2,100	1,100	8.5	1.42
63	2	Do....	51	13	1,000	180	.304	16	6,100	1.3	2,300	1,200	9,800	6,000	2,300	1,100	7.6	1.40
64A	1	Do....	61	13	500	180	.486	14	4,700	1.7	1,500	900	8,500	....	2,100	800	8.9	1.38
65	2	Wood-rosin by-product	34	[7]8	2,000	115	.091	24	6,300	.6	2,800	1,700	6,600	7,700	3,300	1,300	74.1	1.38
66	2	Do....	41	[7]8	1,500	115	.122	25	5,300	.5	2,600	1,500	6,400	....	3,200	1,200	70.2	1.35
67B	1	Do....	50	[7]8	1,000	115	.121	25	4,100	.5	2,000	1,300	6,300	....	3,700	1,100	55.5	1.35
68B	1	Do....	60	[7]8	500	115	....	22	3,200	.5	1,600	1,100	4,900	....	3,500	1,000	53.2	1.31

[1] Each panel furnished 2 tensile specimens, 4 compression specimens for ultimate strength determination, 2 compression specimens to determine elastic properties, 5 toughness specimens and 2-water absorption specimens.

[2] Properties were determined from specimens prepared, conditioned and tested in accordance with Federal Specification for Plastics, L-P-406, Dec. 9, 1942, unless otherwise noted. Machined edges were not otherwise finished prior to test. Compressive stress-strain properties were obtained by testing a 1- by 4-inch specimen as a laterally supported column. Ultimate compressive strength was obtained by testing specimens 1 inch wide by 1/2 inch long in pairs, 1 inch apart and parallel. Values represent the average for the indicated number of tests.

[3] Forest Products Laboratory intermediate-capacity toughness machine, unnotched specimen, 3/8 inch wide by nominal 1/8 inch thickness by 3-1/2 inches long, tested over 2-1/2-inch span.

[4] Elongation immediately before fracture, measured over a 2-inch gage length.

[5] Specimens 2 by 2 by 1/8 inch in thickness.

[6] Repressed for an additional 5 minutes at 180° C. to eradicate blisters.

[7] Repressed for an additional 8 minutes at 115° C. to refinish blemished surfaces.

Z M 58419 F

Table 8.--Some properties of lignin-wood-rosin byproduct pulp plastics[1]

Plastic No.	Lignin type	No. of panels tested[2]	Resin content: Lignin	Resin content: Wood-rosin by-product	Resin content: Total	Molding data: Time	Molding data: Pressure	Molding data: Temperature	Properties[3]: Forest Products Laboratory toughness[4] Flatwise	Tension: Ultimate strength	Tension: Elongation[5]	Tension: Proportional limit stress	Tension: Modulus of elasticity	Edgewise compression: Ultimate strength	Edgewise compression: Yield (0.2 percent offset)	Edgewise compression: Proportional limit stress	Edgewise compression: Modulus of elasticity	Water absorption in 24 hours[6]	Specific gravity
			Percent	Percent	Percent	Minutes	Lb. per sq. in.	°C.	In.-lb. per in. of width	Lb. per sq. in.	Percent	Lb. per sq. in.	1,000 lb. per sq. in.	Lb. per sq. in.	Lb. per sq. in.	Lb. per sq. in.	1,000 lb. per sq. in.	Percent	
105	Commercially available	2	30	10	40	13	1,875	160	21	11,500	0.9	5,400	1,900	12,600	8,100	2,900	1,700	10.7	1.40
106	Do..........	2	20	20	40	13	875	160	31	9,500	1.0	5,200	1,700	10,400	7,800	3,100	1,500	16.9	1.39
107	Do..........	2	38	13	51	13	1,125	160	19	11,700	1.3	4,700	1,600	10,900	7,100	2,600	1,500	12.5	1.37
108	Do..........	2	24	24	48	13	625	160	26	10,100	1.2	5,000	1,600	10,700	7,500	2,400	1,400	15.1	1.37
131A	Commercial experimental	1	30	10	40	13	1,750	160	23	11,700	1.3	3,700	1,700	11,900	6,700	2,300	1,500	11.1	1.39
132A	Do..........	1	20	20	40	13	1,000	160	26	9,800	1.8	3,600	1,600	11,600	7,000	2,500	1,400	12.0	1.38
133A	Do..........	1	36	12	48	13	1,250	160	22	11,800	1.6	3,400	1,600	10,200	6,500	2,200	1,400	11.0	1.35
131B	Do..........	1	30	10	40	13	1,750	170	22	11,500	1.4	3,900	1,500	12,600	6,400	2,200	1,500	8.2	1.39
132B	Do..........	1	20	20	40	13	1,000	170	25	12,000	1.7	4,100	1,700	12,500	7,100	2,300	1,500	10.8	1.38
133B	Do..........	1	35	12	47	13	1,250	170	17	10,300	1.6	3,300	1,500	12,300	6,700	2,200	1,400	10.8	1.37

[1] High strength black spruce kraft pulp.

[2] Each panel furnished 2 tensile specimens, 4 compression specimens for ultimate strength determination, 2 compression specimens to determine elastic properties, 5 toughness specimens and 2 water-absorption specimens.

[3] Properties were determined from specimens prepared, conditioned and tested in accordance with Federal Specification for Plastics, L-P-406, Dec. 9, 1942, unless otherwise noted. Machined edges were not otherwise finished prior to test. Compressive stress-strain properties were obtained by testing a 1- by 4-inch specimen as a laterally supported column. Ultimate compressive strength was obtained by testing specimens 1 inch wide by 1/2 inch long in pairs, 1 inch apart and parallel. Values represent the average for the indicated number of tests.

[4] Forest Products Laboratory intermediate-capacity toughness machine, unnotched specimen, 3/8 inch wide by nominal 1/8 inch thickness by 3-1/2 inches long, tested over 2-1/2-inch span.

[5] Elongation immediately before fracture, measured over a 2-inch gage length.

[6] Specimens 2 by 2 by 1/8 inch in thickness.

Z M 58420 F

Table 9.--Some properties of lignin-wood-rosin byproduct-phenolic resin pulp plastics[1]

Plastic No.	Lignin type	No. of panels tested[2]	Resin content: Lignin	Resin content: Wood-rosin by-product	Resin content: Phenolic	Resin content: Total	Molding data: Time	Molding data: Pressure	Molding data: Temperature	Properties[3]: Forest Products Laboratory toughness[4]: Flatwise	Tension: Ultimate strength	Tension: Elongation[5]	Tension: Proportional limit stress	Tension: Modulus of elasticity	Edgewise compression: Ultimate strength	Edgewise compression: Yield (0.2 percent offset)	Edgewise compression: Proportional limit stress	Edgewise compression: Modulus of elasticity	Water absorption in 24 hours[6]	Specific gravity
			Percent	Percent	Percent	Percent	Minutes	Lb. per sq. in.	°C.	In.-lb. per in. of width	Lb. per sq. in.	Percent	Lb. per sq. in.	1,000 lb. per sq. in.	Lb. per sq. in.	Lb. per sq. in.	Lb. per sq. in.	1,000 lb. per sq. in.	Percent	
109B	Commercially available	1	30	5	5	40	13	1,500	160	23	11,000	0.9	5,100	2,000	11,700	7,300	2,300	1,600	8.9	1.40
110	Do.	2	20	10	10	40	13	1,000	160	29	10,300	.8	5,200	2,000	11,800	7,600	2,600	1,500	12.1	1.40
111A	Do.	1	37	6	6	49	13	1,000	160	22	11,900	1.8	4,100	1,600	12,800	7,500	2,500	1,500	10.4	1.38
112A	Do.	1	24	12	12	48	13	1,000	160	20	13,200	1.6	4,900	1,700	12,700	7,500	2,600	1,600	19.9	1.37
127A	Do.	1	30	5	5	40	13	1,500	170	20	12,500	1.1	4,200	1,900	13,300	7,600	2,900	1,700	7.0	1.39
128A	Do.	1	20	10	10	40	13	1,000	170	28	13,000	1.1	5,600	2,000	13,100	7,200	2,600	1,500	8.4	1.39
129A	Do.	1	37	6	6	49	13	1,000	170	22	12,000	1.3	3,900	1,700	13,400	6,900	2,800	1,400	9.5	1.37
112B	Do.	1	24	12	12	48	13	1,000	170	20	14,800	1.6	5,200	1,800	13,700	7,200	1,900	1,600	12.3	1.38
127B	Do.	1	30	5	5	40	13	1,000	180	24	11,000	1.2	4,200	1,700	12,800	....	....	....	6.7	1.41
128B	Do.	1	20	10	10	40	13	1,000	180	28	15,200	1.2	5,600	1,900	13,200	7,200	2,800	1,500	6.7	1.39
129B	Do.	1	37	6	6	49	13	1,000	180	19	12,000	1.4	3,600	1,700	12,000	6,700	1,900	1,400	7.4	1.35
130B	Do.	1	24	12	12	48	13	1,000	180	21	13,200	1.4	3,900	1,800	13,100	7,000	2,700	1,500	7.4	1.37

1 High-strength black spruce kraft pulp Cook No. 1-2676.

2 Each panel furnished 2 tensile specimens, 4 compression specimens for ultimate strength determination, 2 compression specimens to determine elastic properties, 5 toughness specimens and 2 water-absorption specimens.

3 Properties were determined from specimens prepared, conditioned and tested in accordance with Federal Specification for Plastics, L-P-406, Dec. 9, 1942, unless otherwise noted. Machined edges were not otherwise finished prior to test. Compressive stress-strain properties were obtained by testing a 1- by 4-inch specimen as a laterally supported column. Ultimate compressive strength was obtained by testing specimens 1 inch wide by 1/2 inch long in pairs, 1 inch apart and parallel. Values represent the average for the indicated number of tests.

4 Forest Products Laboratory intermediate-capacity toughness machine, unnotched specimen, 3/8 inch wide by nominal 1/8 inch thickness by 3-1/2 inches long, tested over 2-1/2-inch span.

5 Elongation immediately before fracture, measured over a 2-inch gage length.

6 Specimens 2 by 2 by 1/8 inch in thickness.

Z M 58421 F

Table 10.--Some properties of kraft-pulp lignin-phenolic plastics

Plastic No.	No. of panels tested[1]	Resin: Lignin: Kind	Resin: Lignin: Amount	Resin: Phenolic	Resin: Total	Molding data: Time	Molding data: Pressure	Molding data: Temperature	Properties[2]: Forest[3] Products Laboratory toughness: Flatwise	Properties: Tension: Ultimate strength	Properties: Tension: Elongation[4]	Properties: Tension: Proportional limit stress	Properties: Tension: Modulus of elasticity	Properties: Edgewise compression: Ultimate strength	Properties: Edgewise compression: Yield (0.2 percent offset)	Properties: Edgewise compression: Proportional limit stress	Properties: Edgewise compression: Modulus of elasticity	Water absorption in 24 hours[5]	Specific gravity
			Percent	Percent	Percent	Minutes	Lb. per sq. in.	°C.	In.-lb. per in. of width	Lb. per sq. in.	Percent	Lb. per sq. in.	1,000 lb. per sq. in.	Lb. per sq. in.	Lb. per sq. in.	Lb. per sq. in.	1,000 lb. per sq. in.	Percent	
High strength kraft (Cook No. 1-2676):																			
101A	1	Commercially available	30	10	40	13	1,500	170	22	14,600	1.2	5,100	2,000	15,000	8,100	3,300	1,700	5.9	1.40
102B	1	Do........	20	20	40	13	1,500	170	21	17,800	1.4	7,800	1,900	13,800	7,600	2,700	1,600	4.6	1.40
103A	1	Do........	37	12	49	13	1,250	170	19	12,000	1.2	3,700	1,800	15,300	7,100	2,900	1,500	5.2	1.39
104	2	Do........	24	24	48	13	1,250	170	18	14,600	1.4	5,800	1,800	16,400	7,700	2,900	1,500	3.6	1.36
98	2	Commercial experimental	31	11	42	13	2,000	170	21	16,400	1.6	5,000	1,800	14,200	6,700	2,600	1,600	4.0	1.39
89	3	Do........	21	21	42	13	1,800	170	22	19,600	1.8	5,300	1,900	16,500	7,400	2,800	1,600	3.1	1.41
88B 99 114	4	Do........	36	12	48	13	1,500	170	20	14,000	1.7	3,800	1,600	14,100	6,600	2,600	1,500	3.6	1.37
100 115	3	Do........	28	19	47	13	1,600	170	20	16,700	1.8	5,200	1,700	15,300	7,100	2,500	1,600	3.1	1.39
Commercial kraft pulp, Shipment No. 1942.																			
77	3	Commercial experimental	32	11	43	13	2,000	170	17	12,000	1.4	4,400	1,700	11,800	5,700	2,100	1,400	3.8	1.39
78	3	Do........	21	21	42	13	2,000	170	17	14,100	1.5	4,800	1,600	14,500	6,100	2,500	1,500	3.2	1.39

[1] Each panel furnished 2 tensile specimens, 4 compression specimens for ultimate strength determination, 2 compression specimens to determine elastic properties, 5 toughness specimens and 2 water-absorption specimens.

[2] Properties were determined from specimens prepared, conditioned and tested in accordance with Federal Specification for Plastics, L-P-406, Dec. 9, 1942, unless otherwise noted. Machined edges were not otherwise finished prior to test. Compressive stress-strain properties were obtained by testing a 1- by 4-inch specimen as a laterally supported column. Ultimate compressive strength was obtained by testing specimens 1 inch wide by 1/2 inch long in pairs, 1 inch apart and parallel. Values represent the average for the indicated number of tests.

[3] Forest Products Laboratory intermediate-capacity toughness machine, unnotched specimen, 3/8 inch wide by nominal 1/8 inch thickness by 3-1/2 inches long, tested over 2-1/2-inch span.

[4] Elongation immediately before fracture, measured over a 2-inch gage length.

[5] Specimens 2 by 2 by 1/8 inch in thickness.

Z M 58422 F

Table 11.--Some properties of hydrolyzed wood plastics containing small amounts of high-strength kraft pulp[1]

Plastic No.	No. of panels tested[2]	Plastic content							Molding data			Properties[6]										
		Kraft pulp	Hydrolyzed wood			Resins added		Total resin[3]	Time	Pressure	Temperature	Forest[4] Products Laboratory toughness	Tension				Edgewise compression				Water absorption in 24 hours[7]	Specific gravity
			Lignin	Soluble Lignin content	Amount	Commercial lignin	Phenolic	Soluble lignin + commercial lignin + phenolic				Flatwise	Ultimate strength	Elongation[5]	Proportional limit stress	Modulus of elasticity	Ultimate strength	Yield (0.2 percent offset)	Proportional limit stress	Modulus of elasticity		
		Percent	Percent	Percent	Percent	Percent	Percent	Percent	Minutes	Lb. per sq. in.	°C.	In.-lb. per in. of width	Lb. per sq. in.	Percent	Lb. per sq. in.	1,000 lb. per sq. in.	Lb. per sq. in.	Lb. per sq. in.	Lb. per sq. in.	1,000 lb. per sq. in.	Percent	
94	2	0	30	15	73	16	11	37	13	2,000	170	5	7,400	1.1	4,100	1,200	14,800	6,700	2,700	1,100	2.4	1.39
95	2	4	30	15	69	16	11	37	13	2,000	170	6	8,600	1.2	3,900	1,300	14,400	6,500	2,300	1,200	2.6	1.40
96	2	6	30	15	66	16	11	37	13	2,000	170	6	8,600	1.2	3,800	1,400	14,800	6,300	1,900	1,300	2.6	1.40
97	1	14	30	15	58	17	12	37	13	2,000	170	9	10,600	1.4	4,500	1,400	14,200	6,600	2,100	1,400	2.6	1.40

[1] Black spruce kraft pulp Cook No. 1-2676.

[2] Each panel furnished 2 tensile specimens, 4 compression specimens for ultimate strength determination, 2 compression specimens to determine elastic properties, 5 toughness specimens and 2 water-absorption specimens.

[3] Based on finished mixture.

[4] Forest Products Laboratory intermediate-capacity toughness machine, unnotched specimen, 3/8 inch wide by nominal 1/8 inch thickness by 3-1/2 inches long, tested over 2-1/2-inch span.

[5] Elongation immediately before fracture, measured over a 2-inch gage length.

[6] Properties were determined from specimens prepared, conditioned and tested in accordance with Federal Specification for Plastics, L-P-406, Dec. 9, 1942, unless otherwise noted. Machined edges were not otherwise finished prior to test. Compressive stress-strain properties were obtained by testing a 1- by 4-inch specimen as a laterally supported column. Ultimate compressive strength was obtained by testing specimens 1 inch wide by 1/2 inch long in pairs, 1 inch apart and parallel. Values represent the average for the indicated number of tests.

[7] Specimens 2 by 2 by 1/8 inch in thickness.

Z M 58423 F

Table 12.--Comparison of experimental pulp-reinforced plastics with several commercial plastics

Reinforcing agent	Type of resin	Approximate resin content	Forest Products Laboratory toughness flatwise (1/8 inch thickness)	Tension: Ultimate strength	Tension: Proportional limit stress	Tension: Modulus of elasticity	Edgewise compression: Ultimate strength	Edgewise compression: Proportional limit stress	Edgewise compression: Modulus of elasticity	Water absorption in 24 hours[1]	Specific gravity
		Percent	In.-lb. per in. of width	Lb. per sq. in.	Lb. per sq. in.	1,000 lb. per sq. in.	Lb. per sq.in.	Lb. per sq. in.	1,000 lb. per sq. in.	Percent	
Commercial											
Wood-flour filled	Phenolic	50	2	7,100	5,500	1,000	24,100	3,300	1,000	0.6	1.34
Sisal filled	Phenolic	40	20	10,400	....	1,100	12,600	....	1,100	3.4	1.33
Chopped tire-cord filled	Phenolic	50	15	4,600	2,700	1,100	22,000	2,600	900	1.6	1.34
Aircraft-grade paper laminate[2]	Phenolic	35	19	27,200	9,800	2,700	20,800	5,400	2,300	2.4	1.40
Experimental pulp filled											
Black spruce kraft	Phenolic	40	24	24,000	6,300	1,900	16,300	2,500	1,600	2.4	1.40
Black spruce kraft	Lignin	38	12	6,600	2,300	1,500	7,300	2,500	1,200	5.3	1.41
Black spruce kraft	Lignin-phenolic 3 to 1	43	21	16,400	5,000	1,800	14,200	2,600	1,600	4.0	1.39
Black spruce kraft	Lignin-phenolic 1 to 1	42	22	19,600	5,300	1,900	16,500	2,800	1,600	3.1	1.41
Yellow birch neutral sulfite	Phenolic	39	22	23,700	8,700	1,700	16,500	2,800	1,700	1.8	1.40
Black spruce Mitscherlich	Phenolic	39	16	20,200	7,400	1,900	17,800	3,900	1,600	3.2	1.40
Spruce ground wood	Phenolic	40	7	15,500	5,800	1,400	17,100	2,700	1,300	1.5	1.35
Spruce ground wood	Phenolic	12	7	14,000	6,500	1,800	15,200	4,100	1,500	4.6	1.39

[1] Specimens 2 by 2 by 1/8 inch in thickness.

[2] Cross laminated.

Z M 58424 F

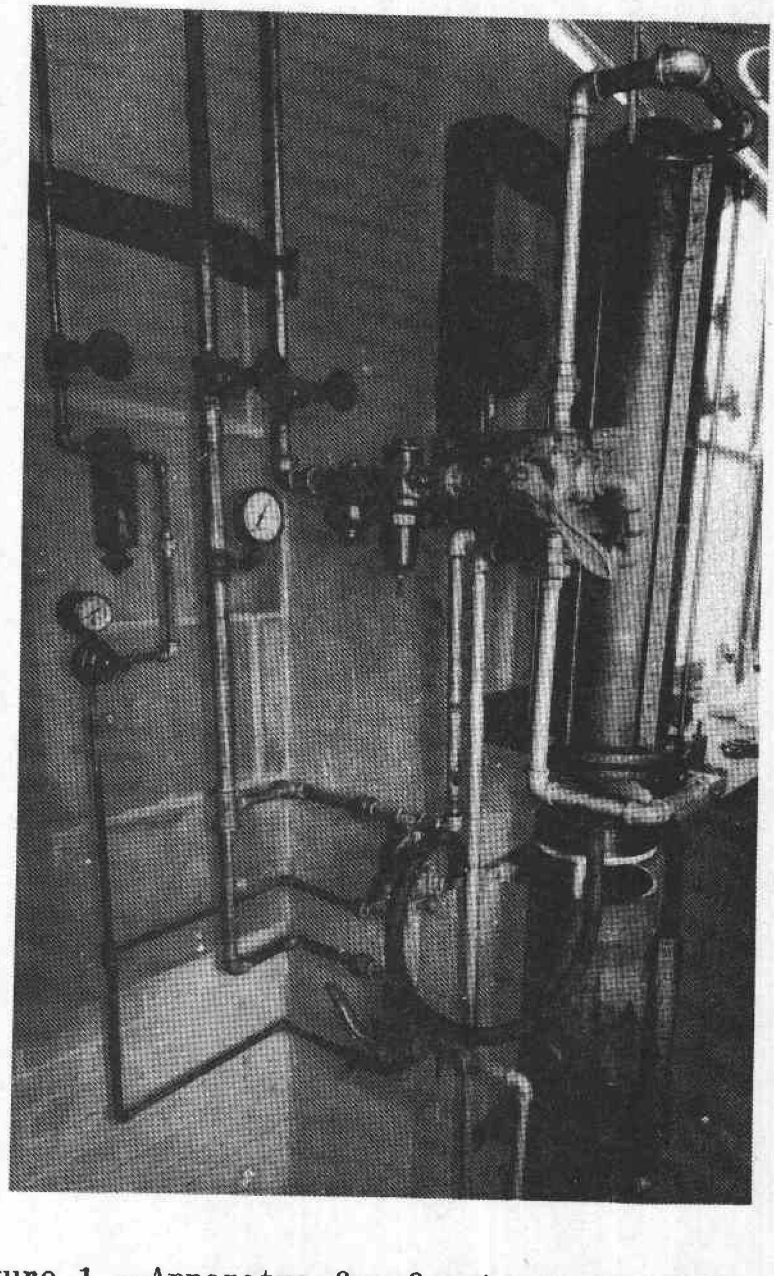

Figure 1.--Apparatus for forming resin-filled pulp mats.

Z M 58496 F

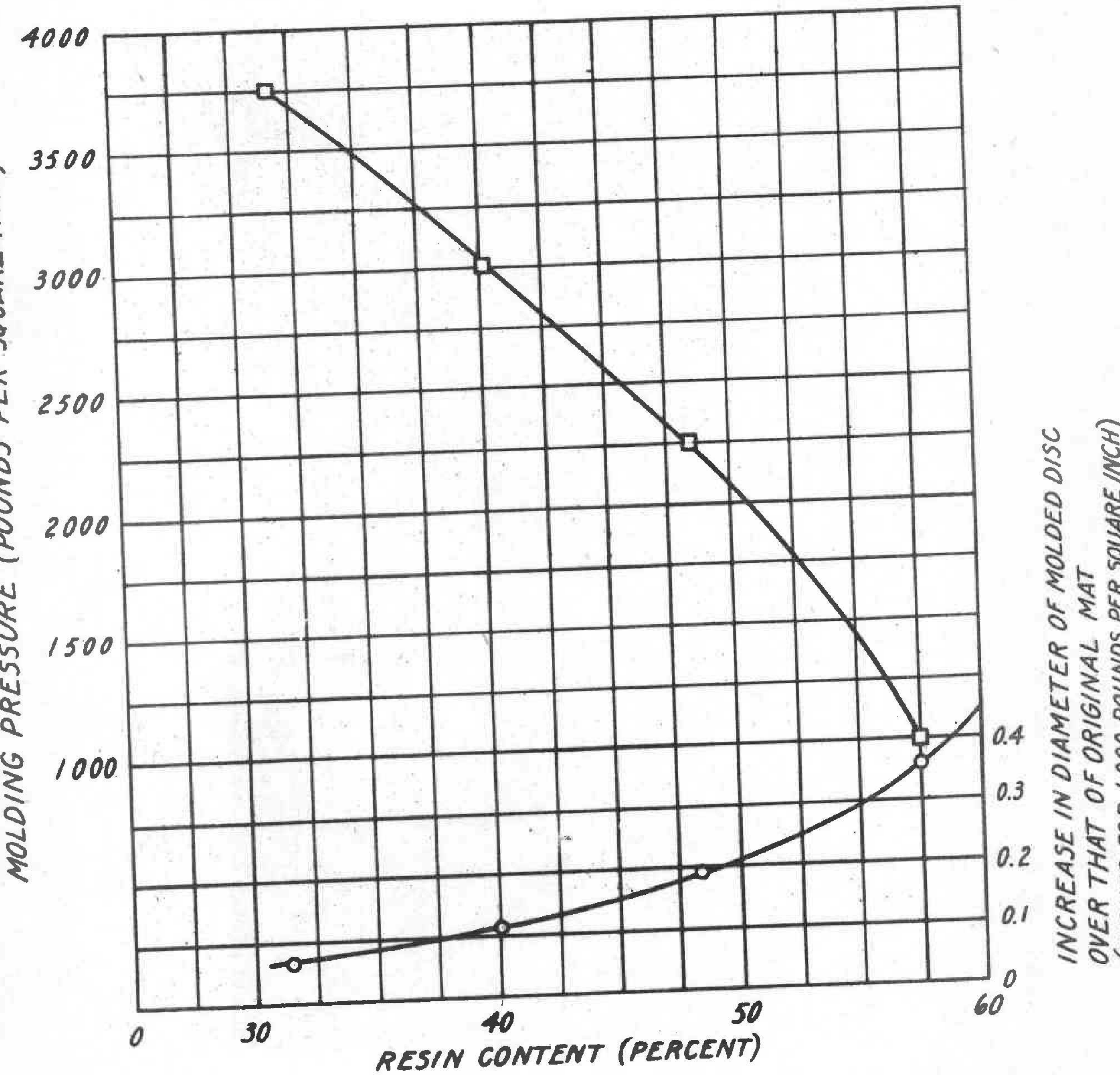

Figure 2.--Molding pressure requirement and plastic flow of kraft-pulp phenolic plastics of varying resin content.

Z M 58409 F

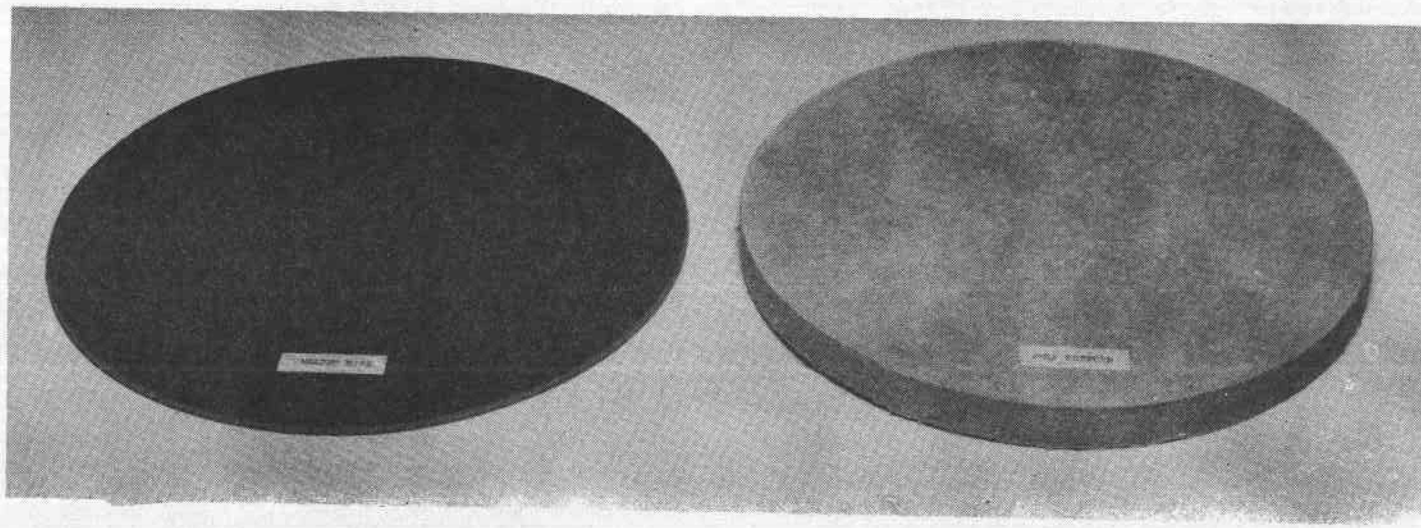

Figure 3.--Plastic disk made from resin-filled pulp mat (left) and resin-filled pulp mat before molding (right).

Z M 58497 F

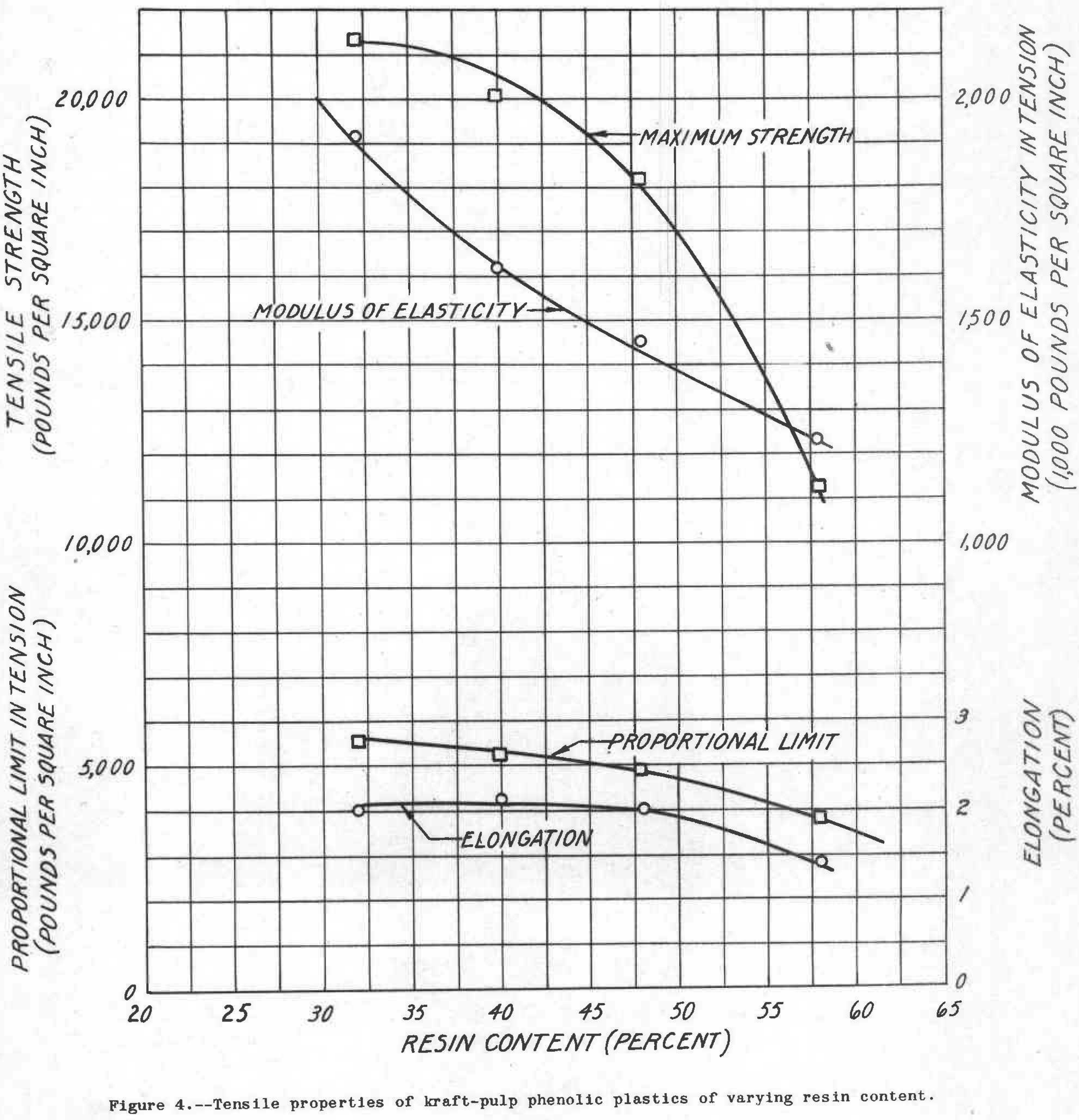

Figure 4.--Tensile properties of kraft-pulp phenolic plastics of varying resin content.

Z M 58410 F

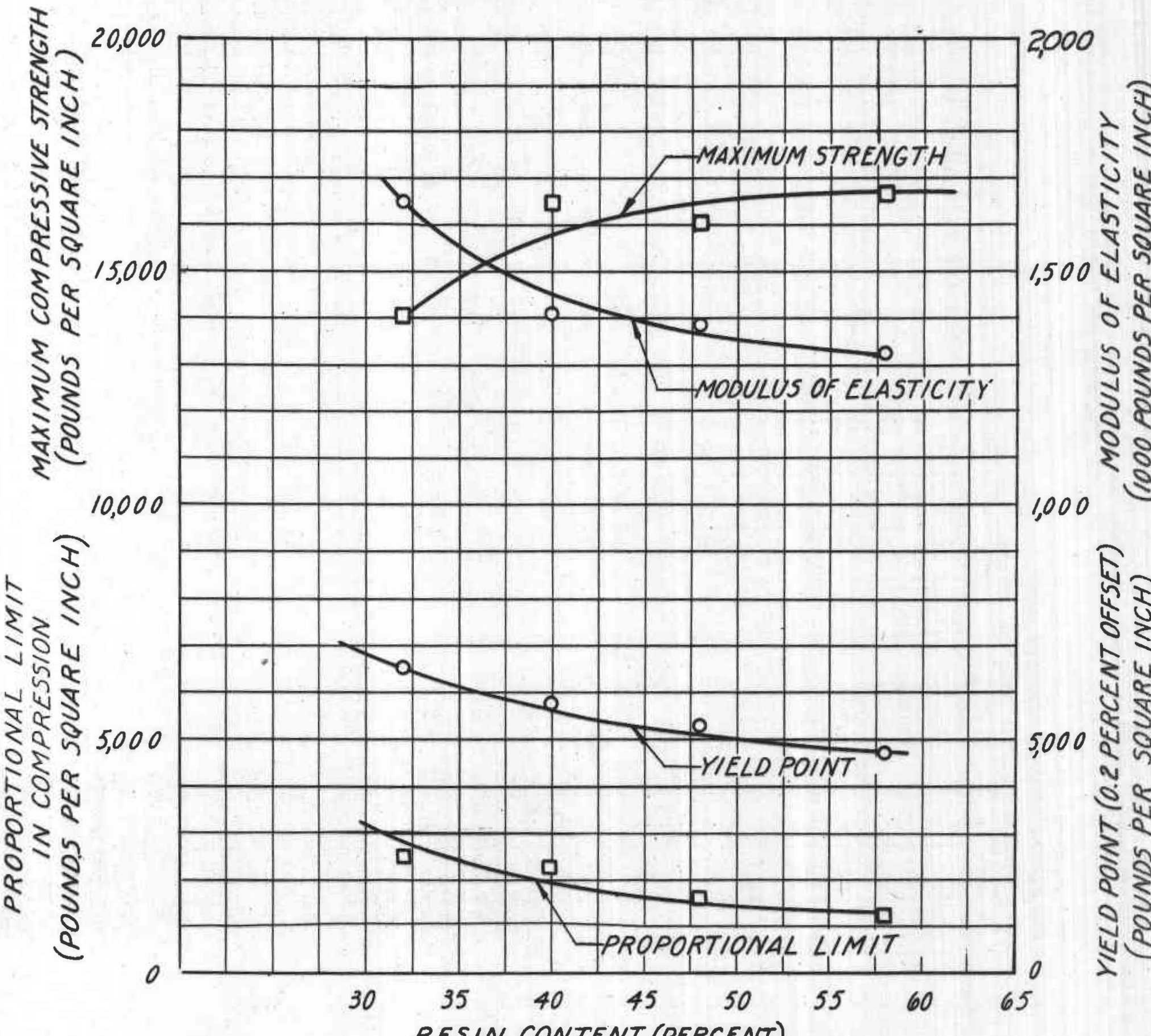

Figure 5.--Edgewise compressive properties of kraft-pulp phenolic plastics of varying resin content.

Z M 58411 F

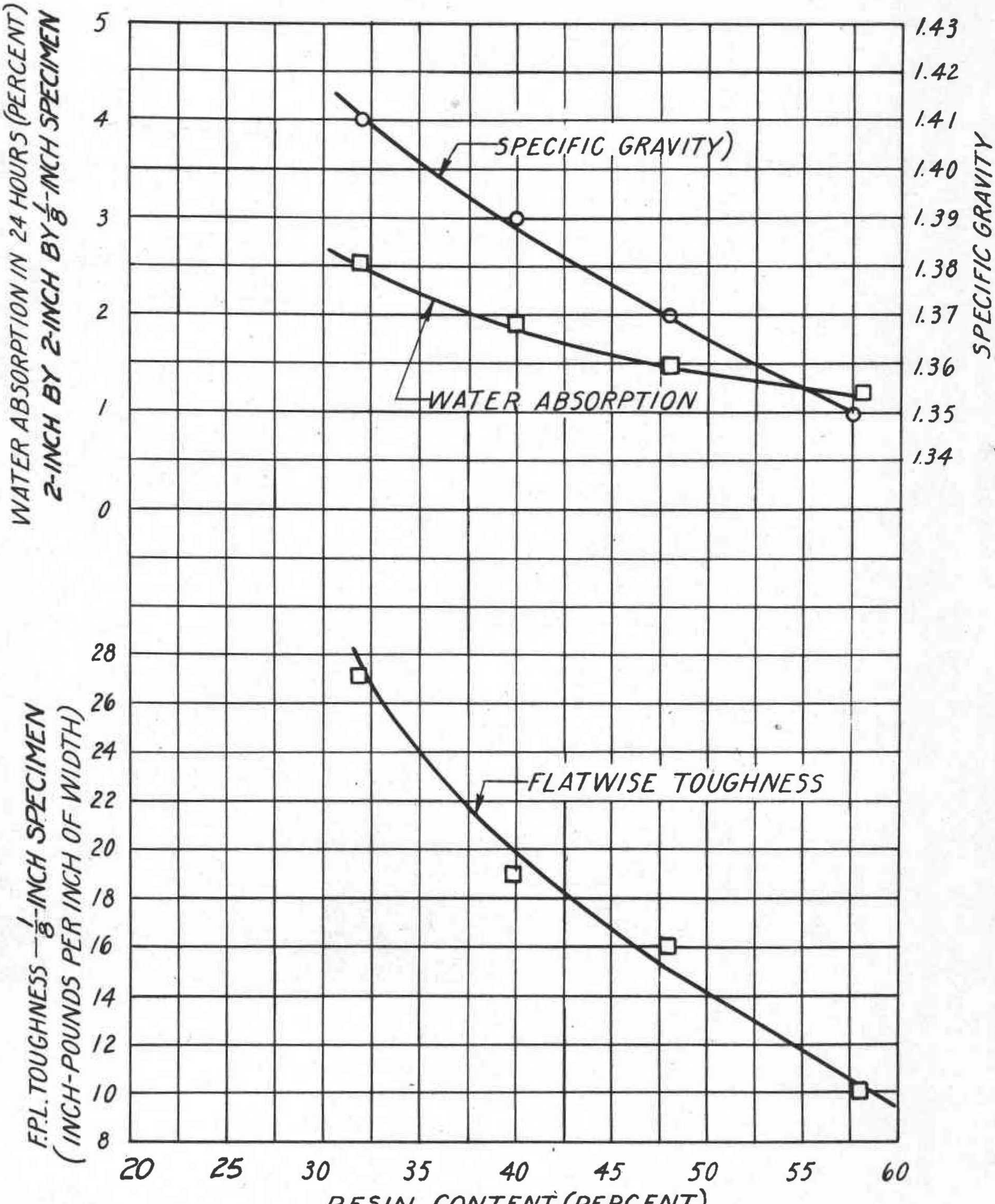

Figure 6.--Toughness, specific gravity, and water absorption of kraft-pulp phenolic plastics of varying resin content.

Z M 58412 F

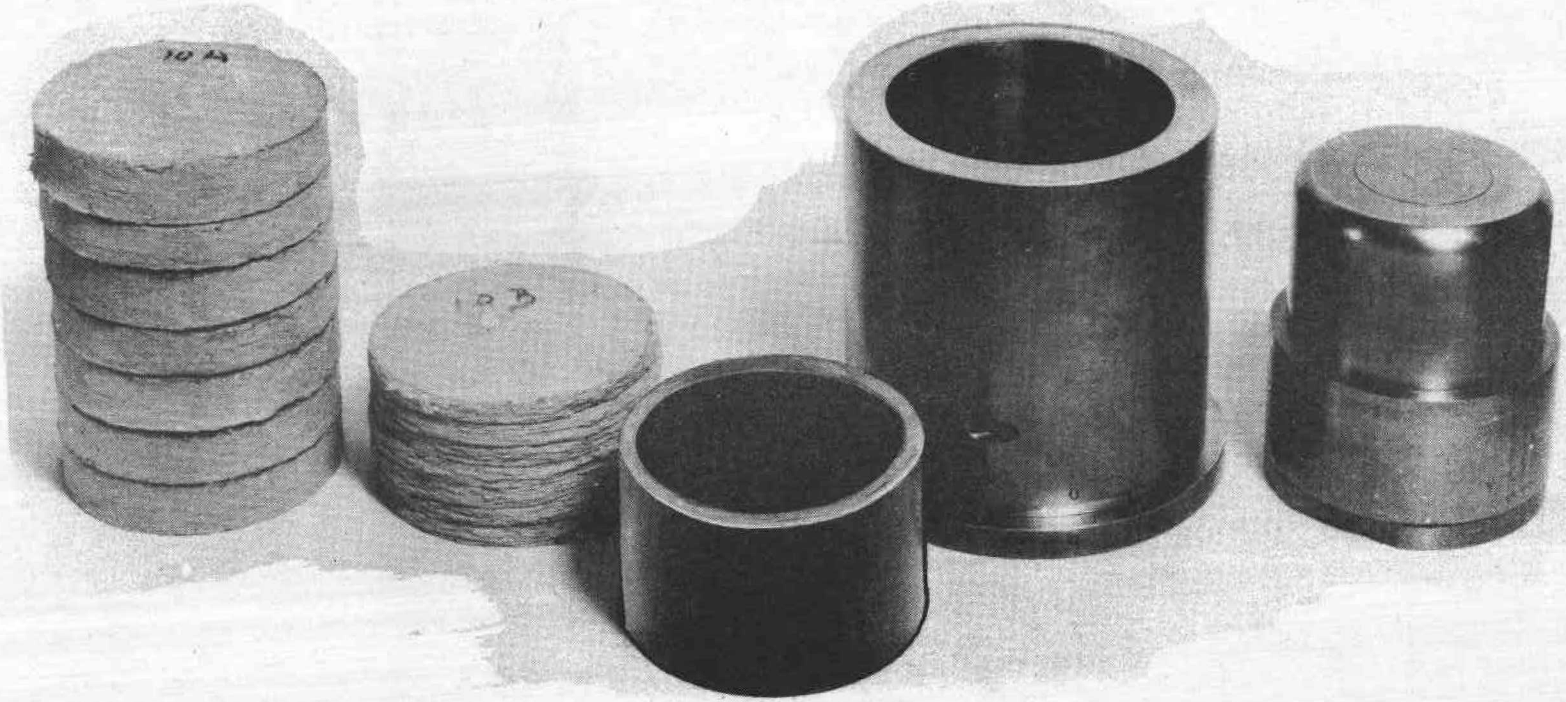

Figure 7.--Preform, cup flowed from resin-filled pulp mat, and mold.

Z M 58498 F

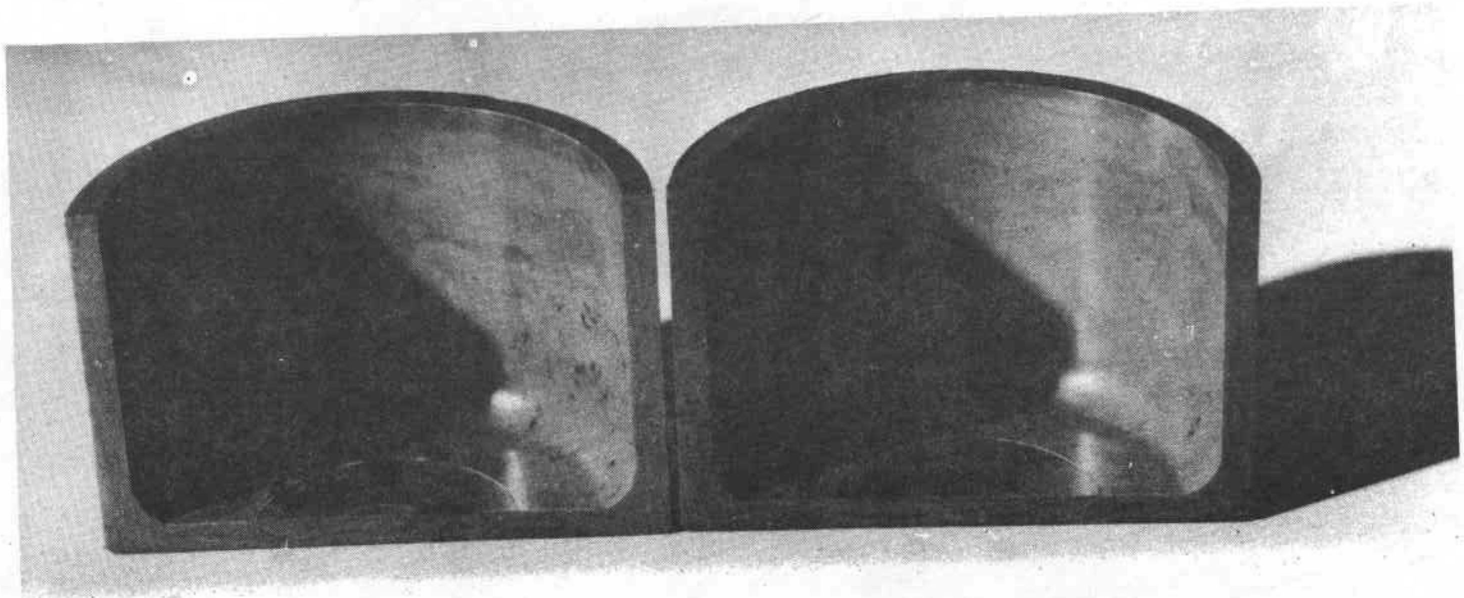

Figure 8.--A section through a flowed-pulp-plastic cup showing the flow lines.

Z M 58499 F