THE EFFECT OF FORMATION VARIABLES ON THE PROPERTIES OF WOOD PARTICLE MOLDINGS

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I INTRODUCTION

In recent years a great deal of interest has been shown in the possibility of making molded products from wood residues. This trend has resulted from a growing scarcity of wood resources, an increasing supply of improved synthetic resin[1] adhesives and the increasing cost of materials which moldings produced from wood residues could replace.

Many different products are being manufactured from wood residues by the die molding process. The basic processes are relatively simple and generally understood. However, the influence of formation variables on the characteristics of the final product is only generally known. Some of these formation variables are: wood species, particle size[2] and shape, type and amount of adhesive used, moisture content, pressure applied by the press, temperature in the mold, and pressing time. Since

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1 Resin is a solid or semisolid organic compound or mixture of organic compounds characterized by an indefinite melting point and amorphous structure. There are natural resins as well as synthetic resins.

2 Particle size is measured by the screen mesh that permits passage of the particles and the mesh upon which they are retained. A particle size classification of 20-40 means the particles have passed through a 20-mesh screen and they have been retained on a 40-mesh screen.

information is fundamental to an intelligent evaluation of product and process potentialities, it would be desirable to develop information on how the different variables effect the properties of the finished molding and present it in useful form.

Synthetic resin adhesives were first used with wood particles to produce flat sheets or panels. After this had been tried and proved successful, research was started on the molding of wood particles and synthetic resin adhesives. As a result, many types of molding compounds were produced, many of them specifically designed to be used in the production of items which, in the past, had been made of solid wood or formed from metal. The great advantage of molded items over other products lies in the fact that the formation variables influencing the properties of the finished product can be manipulated to produce those qualities desired.

Heavy duty shoe lasts are an example of a product machined from molded blanks of phenolic resin-bonded, wood residue material. Because of the wide range of shoe sizes and styles, it is more economical to carve the lasts from these blanks than it is to produce molds. Also, machined shoe lasts give superior service to the traditional carved hardwood last - usually hard maple - in shoe factories where both chemical and physical punishment are involved.

Molded wood residue blanks can be worked more easily than solid wood because of their uniform physical structure, but where the material is produced in high densities, harder tools are required for machining. Experimental pieces have been overlaid in post-molding operations with rubber, foil, printed paper, leather, and veneer.

The moldings discussed in this paper are a compromise of wood particles and plastic. The composite material is formed in a mold. A mixture of resin and wood particles is placed in the heated mold where it is subjected to pressure for a given time. When fine wood particles are mixed with a high percentage of resin (50 percent or more) the moldings look more like plastic than like wood. The moldings look like wood and possess its physical properties when coarse wood particles are mixed with a low percentage of resin (3 percent or less). Between the extremes of fine particles mixed with high resin content and coarse particles mixed with low resin content a wide variety of products can be made.

Wood particles mixed with resin can be molded into many useful articles. The following list of products reproduced from a report by Cooke (9, pp. 17-18) will suggest the diversity of uses and therefore diversity of properties which these molded articles may have:

- Paper roll plugs
- Rubber belting shipping cores
- Gutter stock
- Moldings
- Flat panels
- Radio and television cabinet parts
- Curve-sectioned furniture parts
- High-relief furniture parts
- Shipping spacers
- Croquet balls
- Textile spool ends
- Toilet seat rings and covers
- Hamper tops
- Toy parts
- Briquets
- Furniture knobs
- Casters
- Coasters
- Watch box inserts and miscellaneous display spacers
- Shuffle board discs
- Shoe lasts
- Automobile arm rests
- Chairbacks and seats
- Die stock
- Cutting blocks
- Dishes, such as salad and fruit bowls

In order to improve the properties of moldings with respect to their end uses, various materials can be incorporated into the mixture of wood particles and resin to give the moldings increased strength (chopped fiberglass), increased resistance to water absorption (alum and rosin sizes) and increased fire resistance (asbestos fibers and phosphates). It is possible to overlay molded products with resin impregnated paper, wood veneers, fiberglass and fabrics. There are several resins available including phenolics, melamines, and ureas which are suitable for this type of molding. The problem of what size particles, amount of resin and other additives to use has to be decided by the molder after he knows what physical properties are desired and what is his cost limit.

From the foregoing discussion it can be seen that many factors might be manipulated to produce moldings with desired physical properties. This study will be limited to the influence of the formation variables of particle size, resin content, moisture content and pressure, upon the strength, moisture absorption, surface hardness and specific gravity of a molding made from wood particles of Douglas fir and a powdered phenolic resin adhesive.

II LITERATURE REVIEW

Upon consulting the literature, considerable information was found describing processes for making die molded products from wood particles. For example, Miller Brothers Co. (20, p. 1) found the Austrians used wood residue moldings in World War I for gun stocks and that these stocks were superior to those shaped from hardwood lumber.

Wood residue, in the form of wood flour[3], has been used as a plastic filler[4] for many years. Wood has also been treated chemically in many ways in attempts to give it characteristics similar to plastic molding compounds currently on the market.

The report of the British Intelligence Objectives Sub-Committee (8, p. 26, Fig. 13 and 14) which were made available after World War II, indicated the Germans were producing wallboards from wood residues using cement and/or sodium silicate as a binder. The Germans were also making salad bowls from wood chips and urea formaldehyde synthetic resin adhesives.

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3 Wood flour is very fine wood particles which resemble wheat flour. These particles will pass through a 100-mesh screen.

4 Fillers are relatively inert components added to resin adhesives to control flow, provide body, or impart some other desirable quality.

Several of the references outlined the experimental procedures of other workers. In general, these men investigated formation variables by using several separate experiments. Thus, no positive indication was given of the interaction between variables as would be revealed through the use of a factorial experiment and analysis of variance. Furthermore, these investigations were designed to study the influence of variables upon the properties of flat panels rather than articles molded to final shape and size.

Since the dish moldings dealt with in this paper are not a hardboard[5] nor a plastic molding, they may be considered a fringe product related to both. For this reason, very few references could be found that related specifically to the subject area contemplated for this thesis.

The papers of other workers reviewed here present those findings related to the formation variables and their influence upon the properties of flat panels made from wood particles. The term "wood particles", as used in this paper, refers to small pieces of wood such as sawdust, planer shavings and special wood

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[5] Hardboard is a synthetic composition board which has a density of approximately 45 to 75 pounds per cubic foot (specific gravity 0.7 to 1.2). Hardboards may contain a synthetic resin adhesive.

flakes[6].

A. General Scope

The following paragraphs summarize the work done by others in this field.

Gottstein (16) investigated the effects of pressing time, temperature, sawdust particle size, pressure, resin particle size and moisture content of the sawdust upon the physical properties of hardboard. He used sawdust from Australian mills sawing the native ash-type hardwoods and a solid cresylic resin which was milled and fractionated into coarse and fine resin particles.

Turner and Kern (37) studied the effects of particle size, phenolic resin content and pressing pressure on the specific gravity, strength and water absorption of particle boards. They used mixed species and types of residue to cancel out all factors related to the wood and its reduction to particles. By following this procedure it was reasoned that the results would be widely useable. This mixture of wood was hammer-milled and then fractionated into coarse, medium, and fine particles.

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6 Flakes are specially generated, thin, flat particles with the grain of the wood essentially parallel to the surface of the flake. These flakes are usually generated by a diagonal cutting action to minimize fiber damage.

Sears (32) used both hardwood and softwood sawdust of a uniform particle size bonded together with a powdered phenolic resin. He dry-mixed powdered thermosetting resins with kiln dried sawdust that had been adjusted to the desired moisture content. This mixture was then placed in molds and pressed at various pressures and temperatures to densify the mix and cure the resin. In this way he investigated the effect of the type of wood (hardwood or softwood), resin content, moisture content and pressure on flexural strength, water absorption and density of the panel produced.

Turner (35) investigated the influence of particle size and shape on the strength and dimensional stability of resin bonded wood particle panels. He states that the structural element in a bonded aggregate of wood particles and resin binder is the particle, and the product formed from this aggregate, by subjecting it to heat and pressure, is mainly a reflection of the particle's characteristics.

Williams and Grano (42) set forth some of their findings concerning the molding of wood particles. They confined themselves to a study of the effect of pressure, resin content and wood species (hardwood or softwood) on strength, water absorption and density of molded articles. They maintained the foregoing variables are of the greatest importance in their effect upon the ultimate properties of the product.

B. Formation Variables' Influence On Bending Strength

There is a direct relationship between the pressure applied to the molding mix, while it is heated in the mold cavity, and the bending strength of the finished product.

Williams and Grano (42, p. 230) found that increased pressure improves the breaking strength of molded articles made from hardwoods or softwoods.

It was noted by Sears (32, pp. 94-99) that the increase in flexural strength resulting from an increase in pressure could be enhanced by adding more resin to the mix. By examining the graphs he presented, it was noted that at 6 percent resin content an increase of over 1,000 psi in flexural strength could be obtained by increasing the molding pressure from 200 to 500 psi. When the resin content was increased to 12 percent an increase of over 2,500 psi in flexural strength was obtained when the molding pressure was again increased from 200 to 500 psi.

Also, the breaking strength of flat panels made from hardwoods and softwoods will increase as the resin content increases if other factors are held constant.

A comparison of panels made from hardwood and softwood species on the basis of flexural strength indicated that the softwood panels were the stronger. Under constant conditions of 9 percent resin content, 15 percent moisture content and 200 psi molding pressure, Sears' graphs showed hardwoods produced a flexural strength of 1,500 psi while softwoods produced 2,500 psi - approximately a 60 percent increase in strength.

When the resin content was held constant, hardwood panels equal to softwood panels in flexural strength could be obtained by increasing the pressure from 200 to 400 psi.

Another way of producing hardwood panels equal in flexural strength to softwood panels would be to hold the pressure and resin content constant and increase the moisture content of the molding compound.

Turner (35, pp. 219-220) noted in a study on particle boards that density was of primary influence and resin content was secondary in its effect on the strength properties of panels. In this paper he also demonstrated the marked effect that particle geometry and freedom of a given wood particle from damaged cell walls, had upon the strength of a panel. The shape of the particles in the molding mix was primary, while resin content was secondary in its influence on the strength of a panel.

Long flat flakes gave the highest strength values while granular or cubical particles gave the lowest strengths. When compared on the basis of a specific gravity of 0.80 and all other factors kept constant, flake particles gave a modulus of rupture of nearly 10,000 psi while granular-like particles gave a modulus of rupture of only 250 psi.

C. Formation Variables' Influence On Water Absorption

The water absorption of both hardwood and softwood panels decreased as pressure, moisture content and resin content were increased and the highest pressure, resin content and moisture content all produced the lowest water absorption, according to Williams and Grano (42, p. 230).

With regard to the effect of species of wood particles (hardwood or softwood) upon the water absorption properties of moldings, there seems to be a difference in the conclusions of two writers. Williams and Grano (42, p. 230) maintain that hardwood panels generally are more water resistant than softwood panels. On the other hand, Sears (32, p. 99) states that softwood panels display superior water absorption properties to hardwood panels produced under identical conditions.

Sears (32, p. 99) found when moisture content, resin content and pressure were increased, moisture absorption was reduced and specific gravity increased. From this one might infer that water absorption should decrease as specific gravity increases. This inference was substantiated by Turner and Kern. They reported that the water absorption varied inversely as the specific gravity of resin-bonded particle boards (37, p. 5). It was also noted that water absorption did not decrease as much as might be expected when the resin content was increased. For example, the resin content was increased from 5 to 20 percent for boards having a specific gravity of 1.0. This increase of 300 percent in resin content reduced the water absorption only 33 to 50 percent.

Gottstein made observations of the influence of pressing time and temperature on water absorption (16, pp. 313-315). In order to obtain high water resistance in molded panels he found the heating period should be extended beyond that needed to cure the resin. Under the conditions used, a 15-minute pressing time seemed to be the minimum. Gottstein also reported a high temperature during pressing was needed to obtain high moisture resistance. He used temperatures of 430°F. to 440°F. at a pressure of 500 psi.

D. Formation Variables' Influence On Specific Gravity

When the pressing pressure is increased the specific gravity increases. This occurs for both softwoods and hardwoods according to Sears (32, p. 99) and Williams and Grano (42, p. 230). Turner and Kern (37, p. 3) stated the role of variations in resin content and particle size was minor compared to pressure in its effect on specific gravity. He found the logarithm of modulus of rupture increased linearly when plotted against the logarithm of specific gravity. The slope of plotted lines was such that modulus of rupture increased about as the cube of specific gravity.

Turner found a direct relationship between specific gravity and strength. Since specific gravity was predominantly influenced by pressure, he concluded the direct way to achieve high strength is to increase pressure (35, p. 217).

The influence of the type of wood (hardwood or softwood) takes two aspects. In the first place, Williams and Grano (42, p. 230) found softwoods will produce panels of higher specific gravity than will hardwoods when molded under the same conditions. In the second place, according to Sears (32, pp. 99-103) softwoods will show a greater increase in specific gravity when subjected to the same increase in pressure.

With respect to moisture content and its effect on the specific gravity of wood particle boards, Gottstein made some comments (16, p. 317). When panels were formed under conditions of 500 psi pressing pressure and a temperature of 400°F., a moisture content of 10 percent was needed to produce good strength. Apparently, moisture content influences the plasticity of wood. This increase in plasticity leads to more intimate contact between individual wood particles and thereby produces conditions favorable to good adhesion. Also, the plasticizing effect water has on wood under the above stated conditions, leads to an increase in specific gravity over that of the original wood, in this case, Australian ash-type hardwoods.

E. Formation Variables' Influence On Dimensional Changes

Turner (35, pp. 217-222) states there were indications the resin content, density, and damage done to the wood particle during its generation all influenced dimensional changes of wood particle moldings. For a given type of particle, resin content was the influential factor in controlling springback[7]. When panels of equal

[7] Springback is the net increase in thickness of a particle board, when it has been exposed to high humidity and then dried back to its original moisture content.

specific gravity were compared with respect to springback, it was expected that those made from wood of high density would exhibit less springback than those made from low density wood.

Particles produced with a minimum of damage to the wood structure showed the lowest linear expansion. The linear expansion of panels made from cube-like particles was 10 to 20 times more than that of panels made from particles having undamaged wood fibers.

The foregoing summary of other experimenters' results has been necessarily brief. Different workers have limited themselves to given combinations of formation variables and therefore not all the results are directly comparable. However, examination of accumulated results from these various studies indicates trends and relationships that formation variables may have on the properties of molded items.

III EXPERIMENTAL PROCEDURE

A. Preliminary Study

1. Introduction

The experimental procedure was divided into a preliminary study and a final study. The preliminary study was extensive because equipment had to be developed and techniques perfected for work about which no detailed references were available. This preliminary study was considered to be as important as the final study since it was designed to furnish necessary background information.

On the basis of the foregoing literature survey a tentative list of formation variables and their magnitudes, presented in Table 1, was drawn up to serve as an outline for this part of the work. It was not known at the time if it were possible to make a molding of compound curvature using the magnitude of the variables outlined in this table.

Table 1

Tentative List of Formation Variables

Variable	Magnitude			
Particle size	Coarse	Medium	Fine	
Resin content (% O.D. wt. basis)	15	10	5	2.5
Moisture content (% O.D. wt. basis)	15	10	5	
Pressure (psi)	800	400	200	
Temperature (300°F.)	Constant	Constant	Constant	
Time (10 Min.)	Constant	Constant	Constant	

Particle Size	Mesh Passed Through	Mesh Retained On
Coarse	8	16
Medium	16	30
Fine	30	60

Letters were sent to various resin companies for their opinions on the feasibility of using the variable magnitudes set forth. Also, a request was made for suggestions on experimental procedures and for samples of resin. Many instructive comments as to the range of variables which might be investigated were received. Samples of resin were received but very little was learned of the experimental procedure which might be followed for such a project.

A specific request for information on die design was sent to a manufacturer of wood flour synthetic resin moldings of a dish or bowl shape. A negative attitude was expressed in the reply and nothing was learned. Suggestions regarding the properties which might be tested in evaluating a dish shaped molded product were obtained from the Forest Products Laboratory at Madison, Wisconsin.

It was thought that considering the variables indicated would give the most valuable information while keeping the size of the final experiment within practical limits. Regarding the list of variables selected for use, Mr. M. N. Paul, wood technologist with the Bakelite Company, stated: (22)

> "In answer to your letter of January 14, regarding the research project which you are undertaking, it is felt that the variables and ranges chosen for preliminary experimentation are quite satisfactory. It has been our experience that the variables which you are planning to consider cause most of the strength variations encountered in wood waste products."

2. Die Shape

A cup-shaped mold was first chosen because it is one of the standard shapes used by the plastics industry for evaluating the flow[8] characteristics of molding compounds. Since little information was available on the flow characteristics of a molding compound with resin contents as low as 15 per cent and with wood particle sizes as large as 8 mesh, it was decided to make a die with a right-angle bend as well as with a curve having a radius as small as one quarter of an inch. This die was made and is illustrated in Figure 1.

At first no preforming[9] operation was used; that is, the molding compound was placed in the chase[10], or retaining cylinder, leveled off and then pressed. This procedure, coupled with a die shaped as described above, gave an evaluation of the flow characteristics of the molding compound under the most difficult molding conditions.

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8 Flow is a qualitative description of the fluidity of a plastic material when subjected to heat and pressure during the process of molding.

9 A preform is a given weight of molding mix shaped prior to final molding. This shape may or may not approximate the shape of the finished molding and it may or may not contain a temporary binder. The preform will contain a weight of mix adequate to make the finished molding.

10 A chase is the main body of a mold.

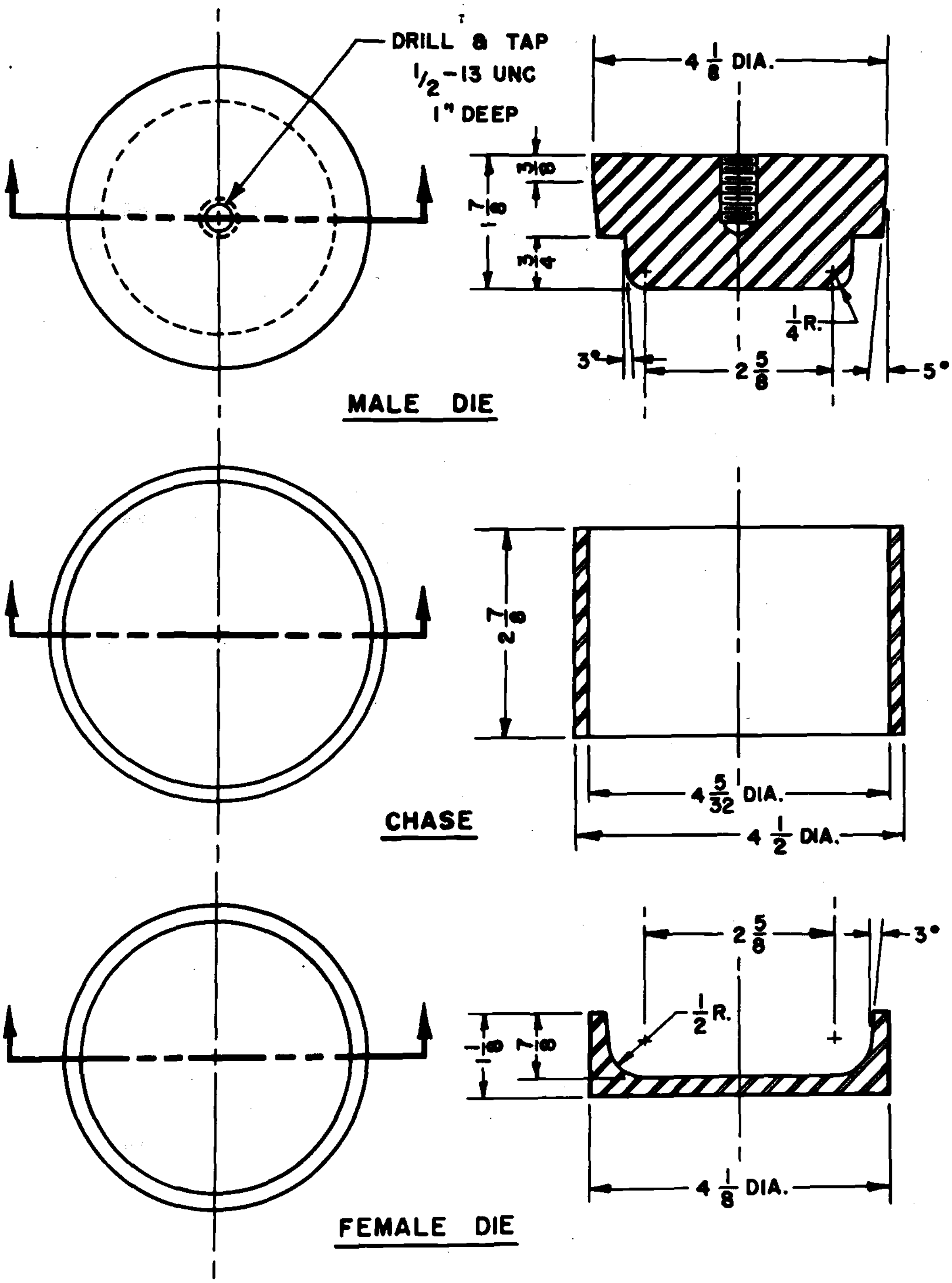

Figure 1. Cup-shaped dies.

It was found that products could be made in the cup-shaped die with a wide variety of particle size classifications. However, high densities were produced in the horizontal portions of the molding (bottom and lip) and low densities were produced in the vertical walls of the cup (Fig. 2).

Also, it was noticed that fractures appeared on the surface of the molding on the inside of the cup at the point of tangency of the one-quarter-inch-radius curve and the vertical wall. Fractures were noted on the outside of the cup at the point of intersection of the horizontal lip and the vertical wall.

Various attempts were made to eliminate the high - and low - density spots and the fractures on the inside and outside of the molding. Crude methods of preforming were tried. It was demonstrated that the darkened areas appearing on the moldings were high-density spots resulting from differential pressures as well as from uneven distribution of the wood particles. The surface fractures were not eliminated by preforming or by varying pressures from 320 to 500, and even to 1000 psi. It was noted that the closer the preform conformed to actual size of the finished molding, the smaller became the fractures. Careful preforming produced more uniform density throughout the molding.

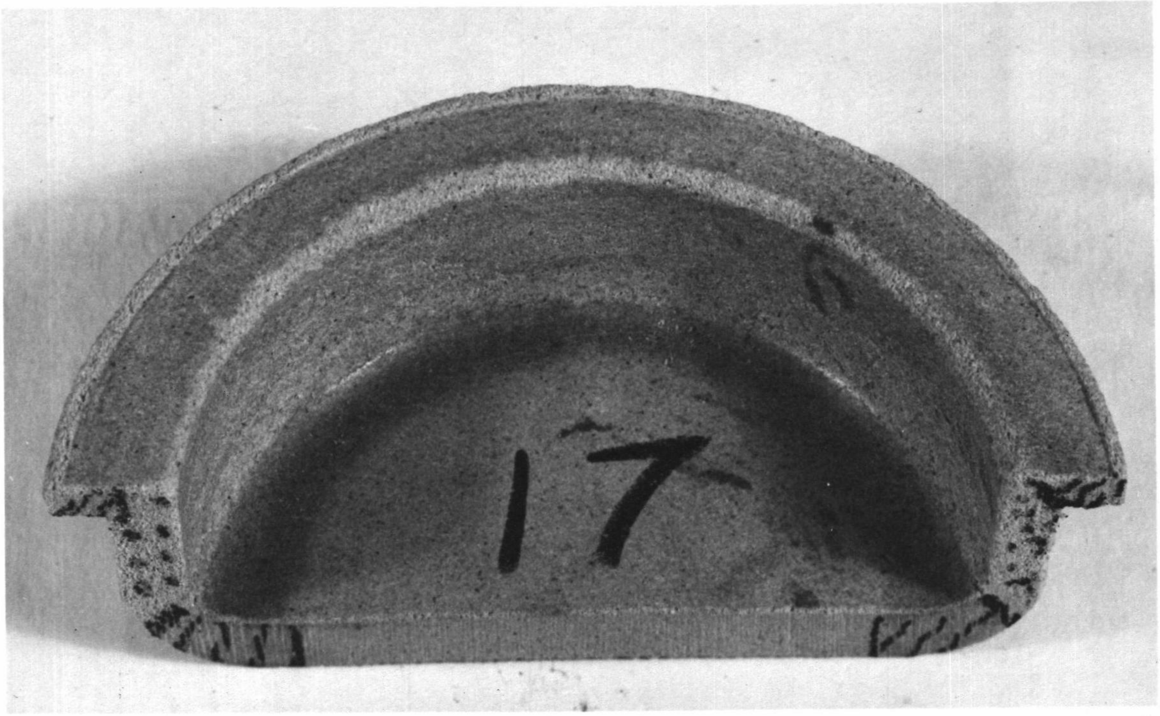

Figure 2. One-half of a cup-shaped molding showing dark high density spots and light low density spots.

Again the literature was consulted. Blake (4, pp. 925-927) concluded that, unless fairly simple shaped moldings were made, the influence of the formation variables upon the strength properties of the product would be obscured by the strength or weakness inherent in the shape of the product.

With respect to die design, Mr. Edward G. Locke of the Forest Products Laboratory, Madison, Wisconsin suggested (18):

> "I noticed in a recent article on 'castwood' in issue 25, of the Weyerhaeuser News that the Forestrong Company, Los Angeles, had used a plate (among other articles) to evaluate the molding properties of Weyerhaeuser's Silvaloy and Prestock. Possibly you could use the same type of die and thus have something to compare your results."

Dies were made for a simple dish-shaped molding, (Fig. 3). It was found that more uniform densities were produced and fractures on the inside of the moldings had been eliminated.

3. Particle Size

When preliminary experiments were made, it became obvious that a change in the original particle classification was necessary. The following table shows the original and final classifications:

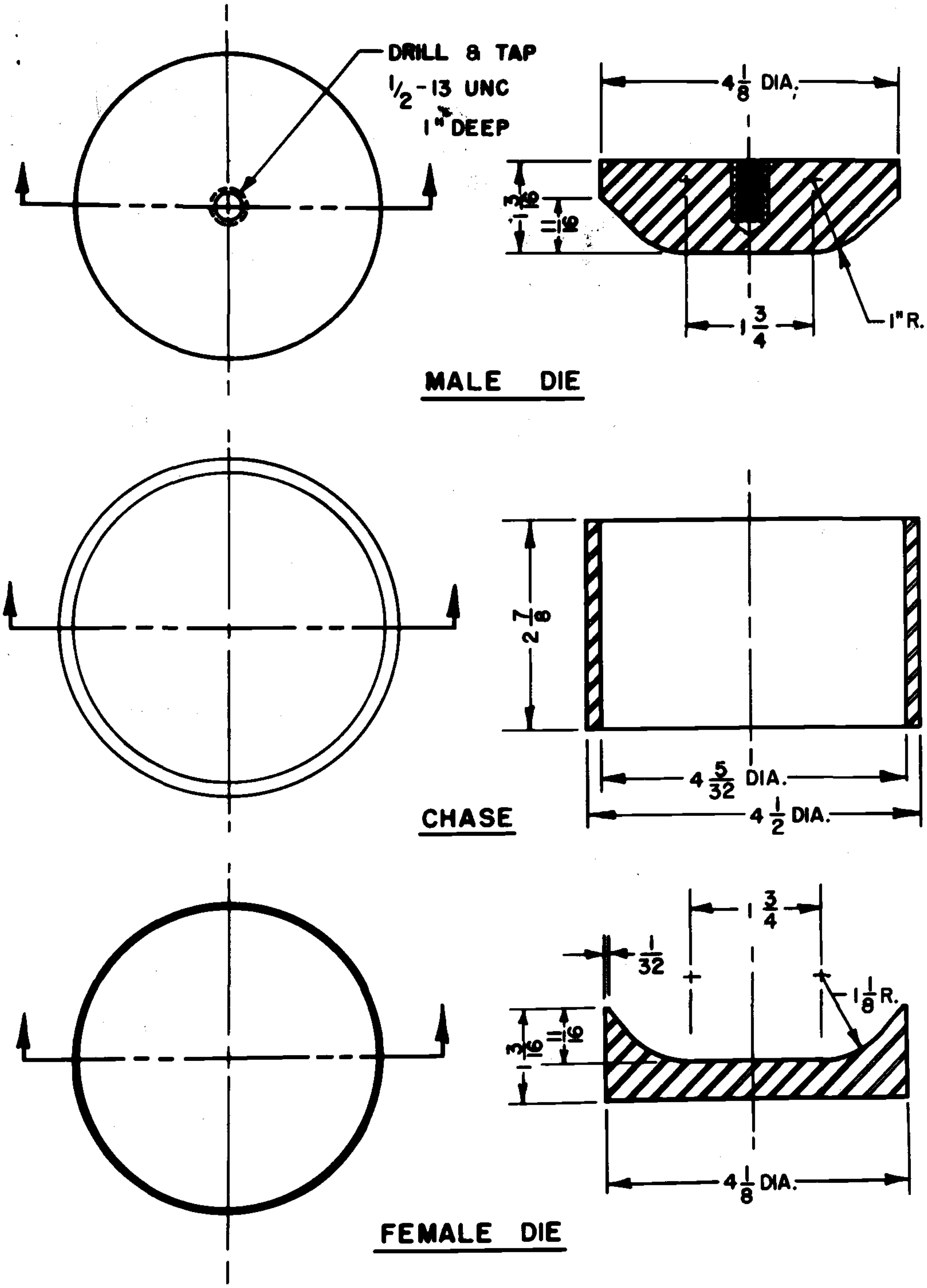

Figure 3. Dish-shaped dies.

Table 2

Comparison of Original and Final Particle Classifications

Grade of Particle	Passed Through Original	Passed Through Final	Retained On Original	Retained On Final
Coarse	8	10	16	20
Medium	16	20	30	40
Fine	30	40	60	pan

Various grinders were tested to find out what a three-way break-down would give, on a weight basis, under the original classification. The particles produced by passing chips once through a John Deere Hammer Mill, Gruendler Hammer Mill and Reitz Disintegrator were fractionated and weighed.

The 8-16 particle classifications from the two hammermills were used to make moldings in the cup-shaped die. These moldings were found to be completely unsatisfactory. The particles would not flow and voids resulted in the walls of the molding.

It was found that passing dried chips through the Gruendler Mill with a 3/16-inch screen and then passing the resultant particles twice through the John Deere Mill with a 3/32-inch screen produced particles satisfactory for production of acceptable products. This procedure was followed in the final experiment.

The new screen classification gave a more even breakdown of the ground chips, on a weight basis, into the three screen classifications. Also, this new classification made the results obtained from the experiment more comparable with those from other published works.

4. Resin Content

Initially, it was decided to use resin contents in the range of 2.5, 5, 10 and 15 percent (oven-dry weight basis). It was found that satisfactory products could be made with 2.5 percent resin content in the cup-shaped die at a pressure of 3,000 psi using 20-40 mesh particles. However, high - and low - density spots occurred and surface fractures appeared on the inside curves.

A product of low strength resulted when a mix of 5 percent resin and 10-20 mesh particles was produced in the dish-shaped die. Therefore, it was decided to set as the lower limit a resin content of 5 percent. The 5 percent resin and 10-20 mesh particles were used at moisture contents of 8.5 and 24.2 percent (oven-dry basis). It was observed that products of acceptable quality could be made at either moisture content.

Regarding resin content, it was suggested by Edward G. Locke (18) that:

> "One of the important requirements in a molding program such as you are planning is that the charge will flow in the mold. We notice that you plan to use 2.5 percent as a lower limit for resin content. There are at the present time several companies compression-molding articles like chair backs and toilet seats. Resin contents vary considerably and are as high as 20 percent. The lower limit appears to be approximately 15 percent, apparently to obtain satisfactory flow during compressing. Possibly, though we are not positive, your 5 percent resin content should be considered a lower limit, at least until you know that you can successfully mold material at that resin content. We would suggest that you do your preliminary work at 15 percent."

This advice was followed until particle sizes had been established and several preforming techniques had been tried.

It was observed that when high resin content and fine particles were used good flow was produced. The lower the resin content and the larger the particles the poorer was the flow. However, with this type of molding compound, the flow at best was limited and was dependent more on particle size and shape than on resin content. Stick-like particles passing through an 8-mesh screen would not make a satisfactory product in the cup-shaped die. Granular-like particles which passed through a 6-mesh screen made a satisfactory product, although voids occurred periodically in the sides of the cup.

The powdered phenolic resin used in this experiment was Resinox 743 manufactured by the Monsanto

Chemical Company. The manufacturer's data stated that this resin cured at temperatures ranging from 300° to 325°F. Bending tests performed on cup-shaped moldings made from wood particles having a moisture content of 15 percent indicated the resin in the molding was completely cured after eight minutes in the press at 325°F.

5. Moisture Content

It was believed that only wood particles of low moisture content could be used for this type of molding in order to avoid a tendency for blisters[11] to occur under the high pressures and temperatures involved in the molding procedure. By trial and error in the preliminary experiments, it was found that through proper preforming and breathing[12] of the molding, low - and high - density spots as well as water marks and blisters could be eliminated. By this means blister-free moldings were made from wood particles at moisture contents as high as 24 percent.

11 A blister is a small or large raised area on the surface of a plastic. This raised area somewhat resembles a human skin blister, with more or less sharply defined boundaries.

12 Breathing, or gasing, is the temporary release of pressure to permit gas to escape. When the clearance between cavity and plunger in the mold is limited, the gas generated by the heat or chemical reaction cannot escape past the plunger and it may be trapped in the molding to result in blisters.

Proper preforming distributes wood particles in the mold so a uniform density results throughout the product. Assuming the moisture content is evenly distributed throughout the wood particles, a layer of particles of uniform thickness should result in an even distribution of moisture in the molding being hot pressed.

Several means were tried for adjusting the moisture content of the particles. A Hobart Mixer was used along with a high-pressure atomizer. It was found that much of the moisture was deposited on the mixing paddle. This caused balls of high moisture content wood particles to form and a wide range of moisture contents resulted within one mixer batch. In attempting to adjust the moisture content to 10 percent by this means, moisture contents of 8.0 to 16.8 percent were obtained. A hand atomizer was also used to make moisture adjustments. The device permitted a longer spraying time, but the same clinging of moisture to the mixing paddle was encountered. Conditioning rooms were tried and it was found that an even distribution of moisture could be attained.

With respect to moisture content, one resin manufacturer stated (12, 13):

> "A moisture content of 10 to 15 percent in the wood should produce the strongest, most dense board. Some volatile matter will be given off during the pressing from the resin and the moisture in the wood. By breathing after the press has been closed for 1/2 to 1 minute, the danger of blisters forming due to the volatile gas should be eliminated (12).
>
> A more dense product can be made with the same pressure by increasing the moisture content of the wood waste (13, p. 2)."

6. Pressure

Irrespective of the pressure used, it was found that inadequate flow of the molding mix took place in the cup-shaped mold with all particle size classifications. When preforming was tried, a better product was produced, but vertical walls of the cup were of lower density than other zones of the molding.

Low density spots developed, since it was possible only to exert "squeeze" pressure normal to the cup's vertical walls when the die closed. At low pressures the density appeared much more uniform than at high pressures, since at lower pressures the force on the vertical walls would be approximately equal to that exerted on the bottom and top horizontal portions of the mold.

Variations in the pressing cycle did not seem to influence surface cracks appearing in the cup-shaped moldings. However, a low pressure (320 psi) together with more exact preforming did reduce the cracking.

Since wood particles do not readily flow in a mold, it was found that flow could be enhanced by increasing the pressure exerted on the wood particles by the dies from 200, 400 and 800 psi to 500, 1000 and 1500 psi respectively. Small voids in the moldings were eliminated.

Pressures applied to the dies were computed based on the assumption that the material being pressed was a perfect fluid. If this was the case, equal pressures would be exerted in all directions throughout the molding irrespective of the shape of the dies. The actual pressures exerted were somewhat less than those calculated based upon the foregoing assumption, because the flow properties of the molding mix were reduced by friction between the wood particles. However, this was the most accurate computation of specific pressure that could be made based upon standard plastics molding practice.

In order to determine the specific pressure exerted on the molding mix by the dies, the projected area of the molding was computed with respect to the direction of the applied force. In other words, the cross section of the greatest area where the dies open was computed and the total force was divided by this to get the pressure per square inch (10, v. 2, lesson 22, p. 12-16). The diameter of the dies was four inches in the direction in which the force was applied. Therefore, the projected area in this direction was 12.58 square inches. Since the specific pressures required by the experiment were to be 500, 1000, and 1500 psi, the total forces which must be applied to the dies were 6,290, 12,580 and 18,870 pounds (projected area x specific pressure). The hundreds of pounds of force which were applied to the dies had to be estimated because the pressure gauge of the press was calibrated for total force in 1000 pound increments.

7. Effectiveness of the Hobart Mixer for Powders

A test of mixing efficiency was performed on the Hobart Mixer. One test was made by adding one percent of powdered charcoal to the wood particles and mixing these together for five minutes. The uniformly grayish color of the resulting mixture was an indication that blending was satisfactory and that concentrations of charcoal did not occur in spots throughout the mix. A concentration of charcoal did occur, but only in a very thin layer, around the inside of the bowl.

Another test of mixing efficiency was made using fluorescent yellow dye. An amount of dye equal to one percent of the weight of the powdered resin was added to the mixture of resin and wood particles and the ingredients were mixed for five minutes. The mixer bowl and its contents were observed under an ultraviolet lamp. No concentrating of the dye could be observed. By additional tests, it was found that dye fractions of less than one percent of the weight of the wood particles worked best.

As the percentage of powdered resin was increased and as the wood particle size increased there was an increasing tendency for the particles and resin to separate. Excess resin settled to the bottom of the mixer bowl, leaving the particles on top of most of the resin yet covered with a layer of it.

It can be stated that for particles larger than the 10-20 mesh classification powdered resin should not be used, but rather the resin should be applied in liquid form by a spray device.

Laboratory work demonstrated that no improvement in the resin and wood particle blending was obtained with mixing cycles longer than five minutes.

8. Testing Procedures

Since work with the original cup-shaped die was discontinued, no tests were applied to moldings made with these dies. The following tests were used to evaluate the properties of the dish-shaped moldings:

(a) Rockwell superficial hardness test

(b) Water absorption test

(c) Specific gravity test

(d) Strength index test

Tests a, b, and c were selected from a large number of tests which could have been used because they revealed some of the properties important in evaluating a molding.

The Rockwell Superficial Hardness test was applied to this product because surface hardness is an important property of moldings. Although Rockwell tests are not generally applied to wood materials, this particular test was used because it was simple and quick to perform, the machine could be fitted with devices to permit testing of small curved pieces, and the equipment was readily available.

Wood is a hygroscopic material. Since the moldings were essentially wood, it was considered advisable that tests be made to evaluate this property of the product. A water absorption soak test was performed over two and 24-hour periods.

Many properties of wood-base materials are related to specific gravity. Test pieces were cut from three positions in each molding for a study of the variation in specific gravity between variable combinations as well as in relation to position in the molding. Three specific gravity wafers were removed from the same positions in each molding as shown in Figure 4B.

Several tests were experimented with, in an attempt to develop an index of strength for moldings. Various types of test heads were used together with several jigs[13] for holding test pieces on the scales of the testing machine. Due to the curved shape of the test pieces, difficulty was experienced in developing tests that were reproduceable. Finally, it was decided to use a form of bending test where one-half of each molding was tested in the manner illustrated by Figure 5.

Influence of the shape of the test piece upon strength of the material is an important factor to be considered. It appeared that, if all dimensions of the piece were held constant, variations in strength due to the shape of the piece likewise would be constant. Use of a cutting jig, Figure 4A, permitted the dimensions of all test pieces to be held constant, except the thickness which varied depending on the combination of formation variables used in making a particular molding. Bending

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13 A jig is a device that guides work to the tool or the tool to the work.

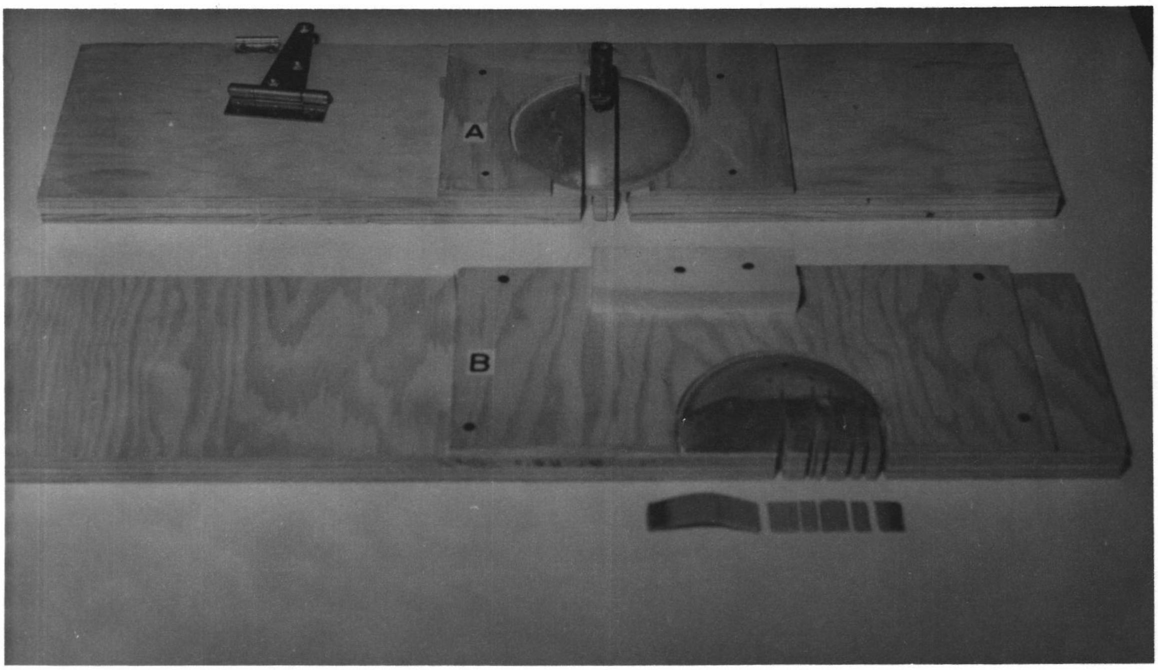

Figure 4. A. Jig for holding moldings during the cutting of test pieces. B. Jig for supporting the center strip, cut on A, while the three specific gravity wafers are cut.

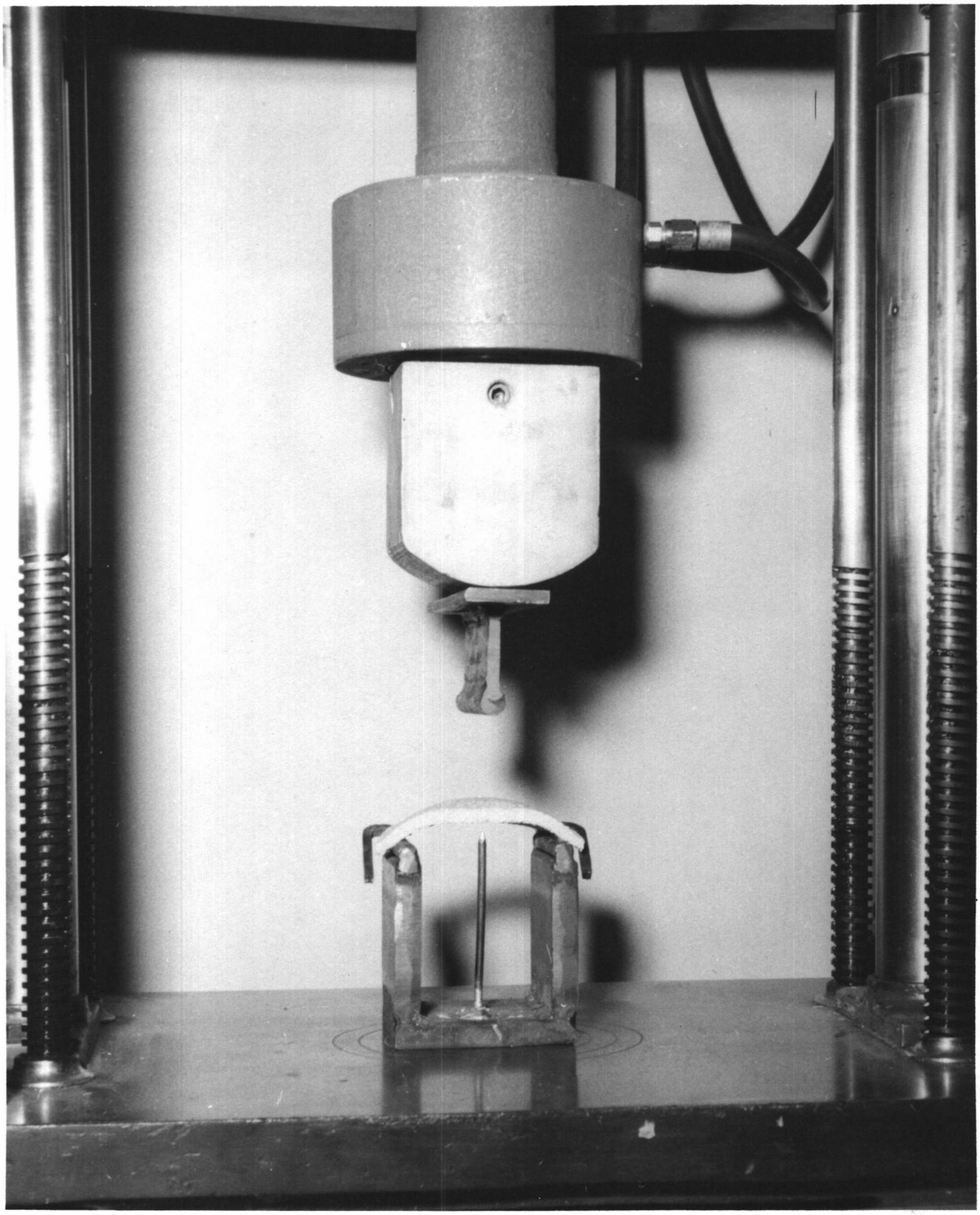

Figure 5. Test piece and supporting jig in the testing machine prior to application of force.

stress determined for square or rectangular beams by conventional bending tests varies as the square of the depth of the test specimen. It was decided to divide the maximum load at failure or rupture, derived from the modified bending test on the half-moldings, by the square of the molding's mid-thickness. The strength estimate so determined is considered an "index" rather than a true measure of strength and is a useful comparison within the experiment. This test is not suggested for general use or for comparison with results of tests made on flat material.

Procedures followed in making these tests are described in the section under the heading of final study.

Upon the basis of preliminary experiments, discussion and correspondence, the final list of formation variables and their respective magnitudes were drawn up.

Table 3

Final List of Formation Variables

Variable	Magnitude		
Particle size	Coarse	Medium	Fine
Resin content (% O.D. wt. basis)	15	10	5
Moisture content (% O.D. wt. basis)	15	10	5
Pressure (psi)	1500	1000	500
Temperature (325°F.)	Constant	Constant	Constant
Time (8 min.)	Constant	Constant	Constant

Particle size	Mesh Passed Through	Mesh Retained On
Coarse	10	20
Medium	20	40
Fine	40	pan

B. Final Study

The procedure followed in the final study included; the preparation of the moldings, the physical tests performed on the finished moldings and statistical analysis of the results.

1. Preparation of the Moldings

Solid green Douglas-fir mill waste was picked at random from the waste conveyor of a local lumber plant and the bark was removed with a band saw. The bark-free wood was passed through a chipper, chip breaker and chip screen, and the resulting chips were dried in a dry kiln to a moisture content of six percent. The chips were spread on a clean floor and thoroughly mixed.

Mixed, dried chips were reduced to particles by passing them through two hammer mills. The chips were first passed through a Gruendler hammer mill with a 3/16-inch screen, and the resultant particles were put twice through a John Deere hammer mill with a 3/32-inch screen. By passing it through a Sweco vibrating screen separator, the product of this milling was separated into coarse, medium, and fine particles; that is, 10-20, 20-40, and 40-pan mesh range classes. This material was stored in sealed cans until needed.

Each molding represented a given combination of a particle size, a resin content, a moisture content and a pressure. In one day 27 moldings could be produced. These 27 moldings were all of one particle size. The particular particle size to be used in any given day was chosen at random from the three sizes available.

In three days 81 moldings or one replicate of the experiment could be made. The order in which replicates were made was not randomized.

Once the particle size had been selected for a given day's work, the initial moisture content of the stock particles was determined by using a Cenco moisture balance. This moisture content value was placed in its space on the computation sheet, Figure 6.

Data for Replicate Number 1   Date: August 2, 1954

Particle Size: 40-pan   Resin Content: 5%

1. Initial Particle M.C. 6.5% (wet base)
   M.C. 7.0% (O.D. base)

2.

500 gms.	X 1.07	= 535 gms.
O.D. particles needed	O.D. Initial M.C.	Wet base weight of particles

3. Additives

(a) Resin

5%	X 500 gms.	= 25 gms.
Resin (solids) content	O.D. particles in batch	100% resin solids used

(b) Zinc Stearate

1%	X 500 gms.	= 5 gms.
Zinc Stearate	O.D. particles in batch	Zinc Stearate used

4. Weight of Mold Charge

M.C. Required	M.C. Particles (wet base)	(O.D. base)	Mold Charge
5%	5.4%	5.8%	40x1.058 = 42 gms.
10%	8.8%	9.6%	40x1.096 = 44 gms.
15%	13.6%	15.6%	40x1.156 = 46 gms.

Figure 6. Computation Sheet.

The initial moisture content (M.C.) 6.5 percent for the example illustrated in Figure 6, was then converted to the oven-dry (O.D.) basis, 7.0 percent in the same example.

Next, the order in which the three resin contents were mixed with the particles was determined by referring to a table of random numbers. The equivalent of approximately 1500 grams of oven-dry particles was needed to make 27 moldings. Since three resin contents were to be mixed with these particles, a batch of damp particles equivalent in weight to 1500 grams of oven-dry material was divided into three parts. In each part was sufficient material to make nine moldings.

The required weight of damp particles for the case illustrated in Figure 6, 535 grams, was determined by multiplying 500 grams (one-third of 1500 grams) by 1 plus the initial oven-dry moisture content, or 500 (1 + .07).

The next step was to compute the weights of resin adhesive and zinc stearate mold release[14] to be added to the particles. These weights were obtained by multiplying the oven-dry equivalent particle weight of

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14 Mold release is a substance applied to molds to prevent finished moldings from adhering to its surface. To prevent such sticking, mold releases are applied either to the surface of the mold or they are added to the molding mix.

500 grams by the required percentages of resin and zinc stearate. Since the resin used was in a powdered form, it was assumed that it was 100 percent resin solids. Therefore, no adjustment was made for the presence of water in the resin when making the calculations. Some liquid resins contain a high percentage of water or other solvent and therefore it is necessary to know the amount of pure resin (solids) added.

The required weight of moist particles (535 grams, Figure 6) was placed in the bowl of a Hobart Mixer together with the required amount of resin (25 grams) and zinc stearate (5 grams). Then these materials were mixed together for five minutes. This mixture contained one particle size and one resin content.

To achieve the three desired moisture contents required of a given particle size-resin content combination, the mixture was divided into thirds and each third was spread out on a tray. The trays were placed in appropriate humidity chambers for 24 hours.

A constant dry-bulb temperature of 100°F. was used for all the moisture contents because it was the lowest dry-bulb temperature that could be controlled in the humidity chambers over the range of moisture contents desired. A dry-bulb temperature of 100°F. was used to minimize the influence that temperature might have on the finished moldings by effecting the wood particles and resin in the molding mix. The time of humidifying was held constant at 24 hours to eliminate any time-temperature effect on the molding mix.

At the end of 24 hours, the moisture content of the particles and resin on each tray had reached that requirement for the experiment, 5, 10, or 15 percent. It was found, based on a sample size of 36 in each case, that the moisture contents resulting from conditioning were $5.1 \pm .57$, $10.1 \pm .49$ and $15.3 \pm .81$.

Following a moisture content check on the humidified material, the mix was agitated in the Hobart Mixer for two minutes to break up any lumps caused by increased moisture content and to insure even distribution of moisture and resin.

The procedure described above resulted in sufficient material for nine moldings. A table of random numbers by nines was used to determine the order in which the three moisture contents were combined with the three pressing pressures used for making the moldings. The contents of each tray was divided into nine parts of 40 grams each, oven-dry weight basis. To determine the actual moist weight of the humidified particles required to provide 40 grams of oven-dry wood particles, 40 grams was multiplied by 1 plus the moisture content, oven-dry weight basis, of the particles; viz. 1.058, 1.096 and 1.156, Figure 6. The moist equivalents of 40 gram charges were 42, 44 and 46 grams respectively for the moisture contents cited. These weights of wood particles, resin and moisture were placed in moisture proof cardboard cartons.

The process just described for preparing nine molding charges was repeated for the two other resin contents (10 and 15 percent) required in the experimental design. Thus, 27 moldings were made in one day.

The molding was done in an electrically heated Preco hydraulic press fitted with the dies previously described (Fig. 7 and 8). A pressing temperature of 325°F. on the die faces was used throughout the experiment. The charge to be compressed was poured from its carton into the chase of the die, and an extension was placed on top of the chase to accomodate a hardwood preforming plug (Fig. 9) which was inserted and twisted back and forth several times to give the molding charge in the chase a shape similar to that of the finished molding. When preforming was complete, the extension of the chase and the hardwood preforming plug were removed and the female die and chase were placed in the press.

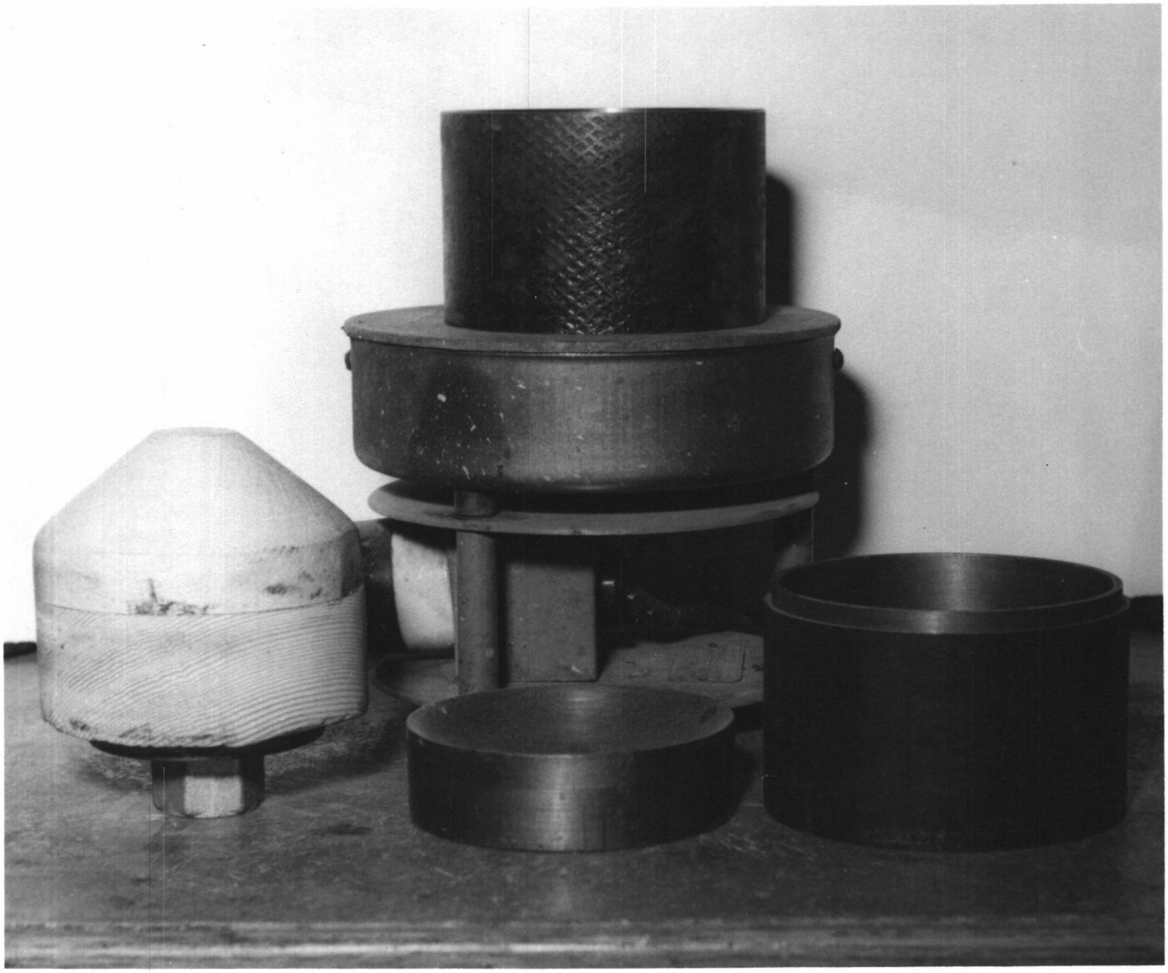

Figure 7. Bottom row: hardwood preforming plug, female die and chase. Top: chase extension on hot plate.

Figure 8. Press with the dies and chase in position just prior to closing the press and the application of the compressive force.

A clock was set for eight minutes, the press was closed, and the required pressure was applied. As soon as the required pressure was reached, the hydraulic valve on the press was opened, the pressure was released, and the dies were "breathed". The press was closed again, and the required pressure was reapplied. When one minute of the pressing period had elapsed, the dies were breathed again. This procedure was followed after an additional two minutes had elapsed, so altogether there were three breathing periods. Following the last breathing period, the dies were closed for the remaining five minutes of the pressing cycle. At the end of eight minutes the press was opened, and the molding was removed hot from the dies.

The dies were kept clean and polished at all times. If any particle clung to the dies, steel wool was used to remove them. As each group of nine moldings was completed, the dies were removed from the press and polished with jeweler's rouge, and a thin coating of silicone mold release was smeared over the die faces. Excess silicone was removed by rubbing the faces of the dies with a soft cloth.

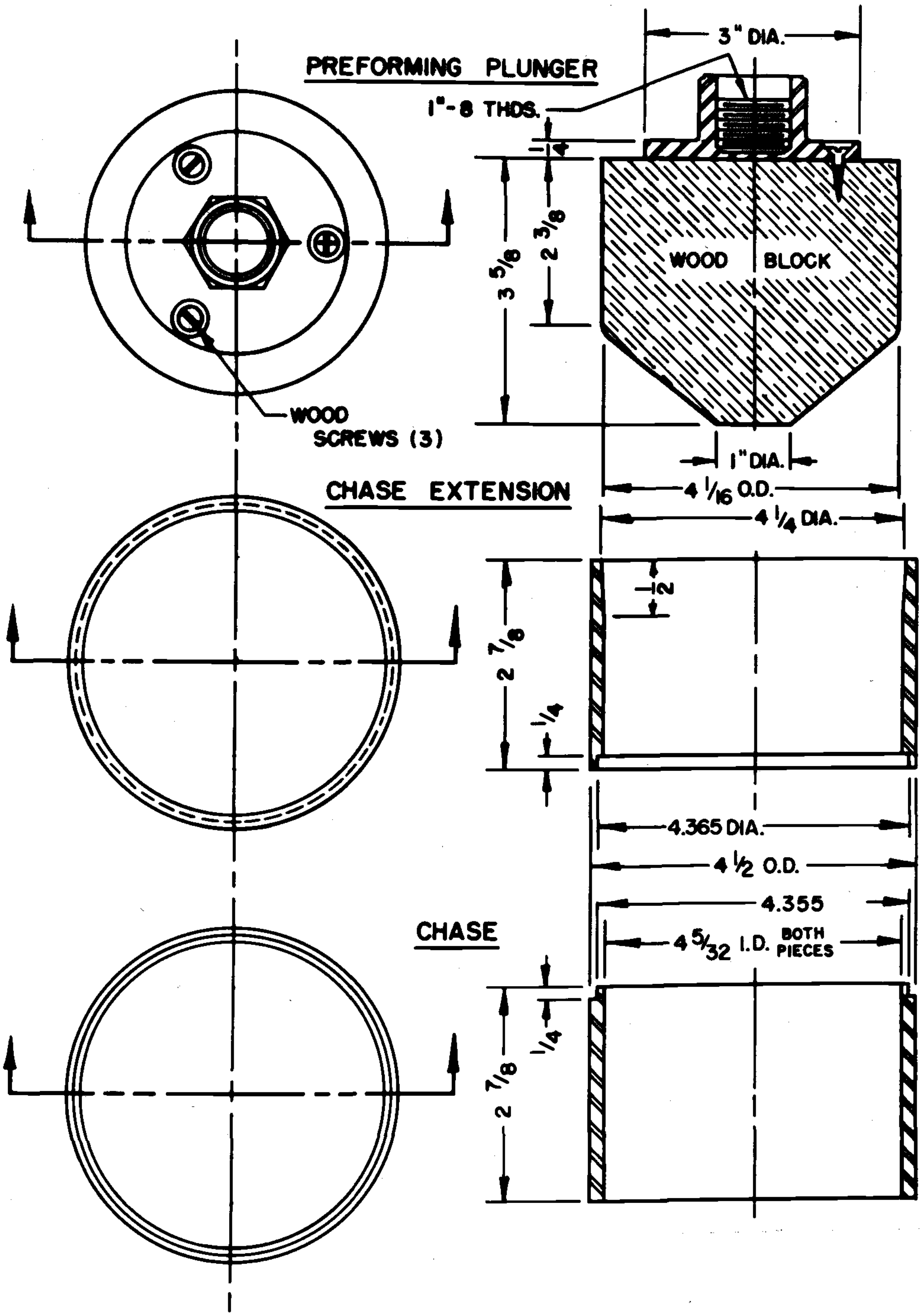

Figure 9. Chase extension and preform.

2. Procedure for Testing the Moldings

The moldings were allowed to cool to room temperature, then code numbers were affixed with labelling tape. When this had been done the moldings were stored in the press room until they could be cut into test pieces.

Tests were performed to collect data in such form as to permit analyzing effects of formation variables studied upon the properties of the moldings.

(a) Preparation of Test Pieces.

A jig was made, Figure 4, to hold the moldings while they were cut into three parts on a band saw. The jig was made by pouring catalyzed (polyester) resin, reinforced with chopped fiber glass, into the female die. This casting was nailed to a piece of 3/4-inch plywood. A circular hole, with a diameter equal to that of the dies, was cut in a piece of 1/4-inch plywood, and this was placed over the top of the plastic disc and nailed to the piece of 3/4-inch plywood. The center of the plastic disc was determined and a line was drawn at right angles to the edge of the piece of 3/4-inch plywood. Three-eighths of an inch was measured out on either side of this line and two lines were drawn parallel to the center line. Saw cuts were made along these two lines, through the plastic and plywood base. These two cuts were three-quarters of an inch apart.

The moldings were placed on this jig concave side down. The clamp shown in the Figure 4A was tightened on the center of the molding and the jig was placed on the band saw table against the sawing guide. The hinges that can be seen on one side of the jig were used as positive stops, in order to insure that the band saw cut the moldings in the same place each time.

During the cut-up operation, a center strip had been removed from each molding. Figure 4B shows the three specific gravity wafers cut from this 3/4-inch center strip; one was cut from the center of the strip, one at the bend, and one near the outer edge. These wafers were cut using the cut-up jig shown in Figure 4B to insure that the pieces would be from the same position in each strip. Since three pieces were cut from each of the 324 strips, there were 972 specific gravity wafers.

(b) Index of Strength Tests.

One-half of each molding was placed in a constant temperature and humidity room and left there until repeated weighings showed that it had reached a constant weight. This room had a constant temperature of 70°F. and a constant relative humidity of 65 percent and will henceforth be referred to as the "12 percent room". The midpoint of the molding was marked on its cut edge and a line was drawn from this point 1/4-inch in toward the side of the piece. An Ames thickness gauge was used to measure the thickness of each piece at this point.

For index-of-strength tests the molding was placed on the testing jig, shown in Figures 5 and 10, with the curved sector against the square guide bar and the tips of the piece in vertical alignment with the wings of these bars. The center line on the cut face was checked for alignment with the pointed rod in the center of the jig. This procedure insured the positioning of each piece in exactly the same manner. The test jig and the piece of molding were placed on the scales of a Tinius Olsen electro-mechanical universal testing machine fitted with a Baldwin Air Cell. With this device, loads from zero to 200 pounds could be measured in 1/2-pound increments with a Tate-Emery indicator. The load was applied to the molding at a rate of .01 inches per minute through a 3/8-inch diameter test head secured to the air cell. Load-deflection curves were plotted as the tests were made, the loads being recorded at each additional .01 inch deflection until maximum load was achieved.

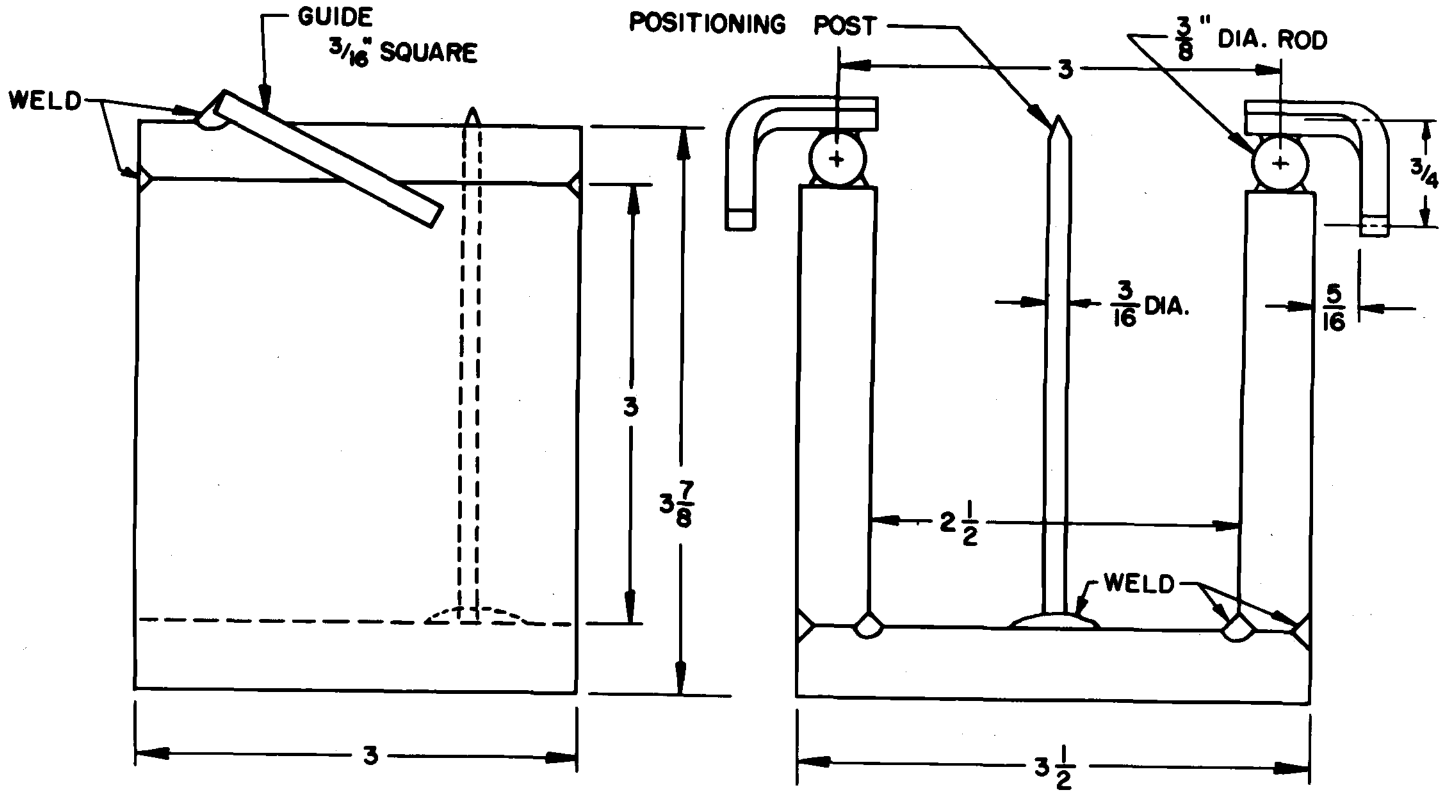

Figure 10. Testing jig.

When these tests had been completed for the 324 moldings prepared for the experiment, values of strength index were computed using the relationship $S.I. = \frac{P}{h^2}$:

where S.I. is the strength index, P is the maximum load and h is the thickness of the piece at the midpoint of the sample.

(c) Water Soak Test.

The other half of each molding resulting from the previously described cutting operation was used to make a water soak test.

First of all, the two points of each half molding were cut off with a belt sander and the moldings placed in the "12 percent room" until they reached equilibrium with the room conditions.

Pans filled with one and one-half inches of tap water, with a pH of 7.2, were placed in this room until the water had reached room temperature, which in this case was 65°F.

The 324 halves of the original moldings to be tested were divided into 12 groups of 27 each. A clock was set for 20 minutes. The first group of 27 moldings were wrapped in aluminum foil and taken out of the "12 percent room" and weighed on a Toledo Balance to the nearest one-tenth of a gram. Due to the soft nature of some of the moldings, material would slough off during handling, and so weighing more accurately than one-tenth of a gram was not justified.

After each molding had been weighed, it was rewrapped in foil to prevent moisture loss. When a batch of 27 had been weighed, they were taken back to the "12 percent room" and fastened to brass rods with elastic bands (Fig. 11). When a 20-minute working interval was up, the particular group of 27 moldings was immersed in the pan of water. This procedure was repeated in subsequent 20 minute periods until the 324 pieces had been weighed and placed in water to soak.

When two hours had elapsed, from the time the first batch was placed in the pan of water, this first batch of 27 soak specimens was removed and the pieces were taken from the brass rods and placed upright on paper towels to drain for 10 minutes. The surfaces of each molding were carefully wiped with a paper towel to remove any excess surface moisture. Then this group of specimens was wrapped in aluminum foil and taken from the "12 percent room" to be weighed wet on the Toledo balance. Again, the specimens were taken back to the "12 percent room" and secured to the brass rods. When 20 minutes had elapsed, this group was again immersed and the next group of specimens was removed from the

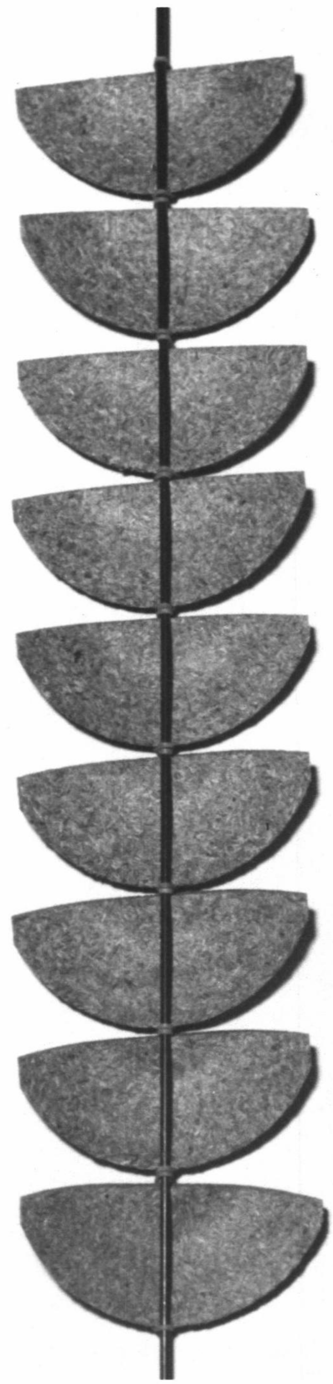

Figure 11. Water soak pieces secured to a brass rod with elastic bands.

water bath, blotted and weighed. This procedure was repeated until the 324 moldings had been weighed.

The same procedure was followed after the moldings had been immersed for 24 hours. Thus, three weights were recorded for each specimen; (a) the 12 percent conditioned weight, (b) the weight after two hours of water soaking, and (c) the weight after 24 hours of water soaking.

The percentage of water absorbed in two hours and in 24 hours, based on the 12 percent conditioned weight of each molding, was calculated by using the following formula:

$$\text{Moisture Content Percent} = \frac{\text{Wet Weight} - \text{Conditioned Weight} \times 100}{\text{Conditioned Weight}}$$

(d) Specific Gravity Determination.

Each of the 972 specific gravity wafers was marked with an identifying number, and a piece of sandpaper was used to remove any loose material from its edges. The pieces were placed in a Dispatch oven until repeated weighings indicated they had been oven-dried. Complete drying took approximately 12 hours. The wafers were removed from the oven and placed in a desiccator to cool. The oven-dry weight of each piece was obtained by weighing it to the nearest 1/1000 of a gram on a Mettler direct reading balance.

The volume of each wafer was determined by immersion in distilled water maintained at a temperature between 63 and 66 degrees. The Mettler direct reading balance, Figure 12, was used for this purpose. The immersion apparatus was tared while in the water. Then a specific gravity wafer was attached to the clip of the apparatus and the apparatus plus the wafer was reimmersed in the water. The change in weight from the tared weight was recorded. An increase in weight was subtracted from the oven-dry weight, while a decrease in weight was added to the oven-dry weight of the wafer. This calculation resulted in the volume of the piece. The oven-dry weight of each wafer was divided by its volume to obtain its specific gravity.

(e) Rockwell Superficial Hardness.

The specific gravity wafers were used in the Rockwell superficial hardness tests after they had been redried in an oven and cooled in a desiccator.

These pieces were tested in a Rockwell superficial hardness tester with its indicator set to the "deep" position. A half-inch ball was affixed to the test head of the device and a 15-kilogram weight was used on the weight holder. The gage readings indicated the net indentation made by the ball when it

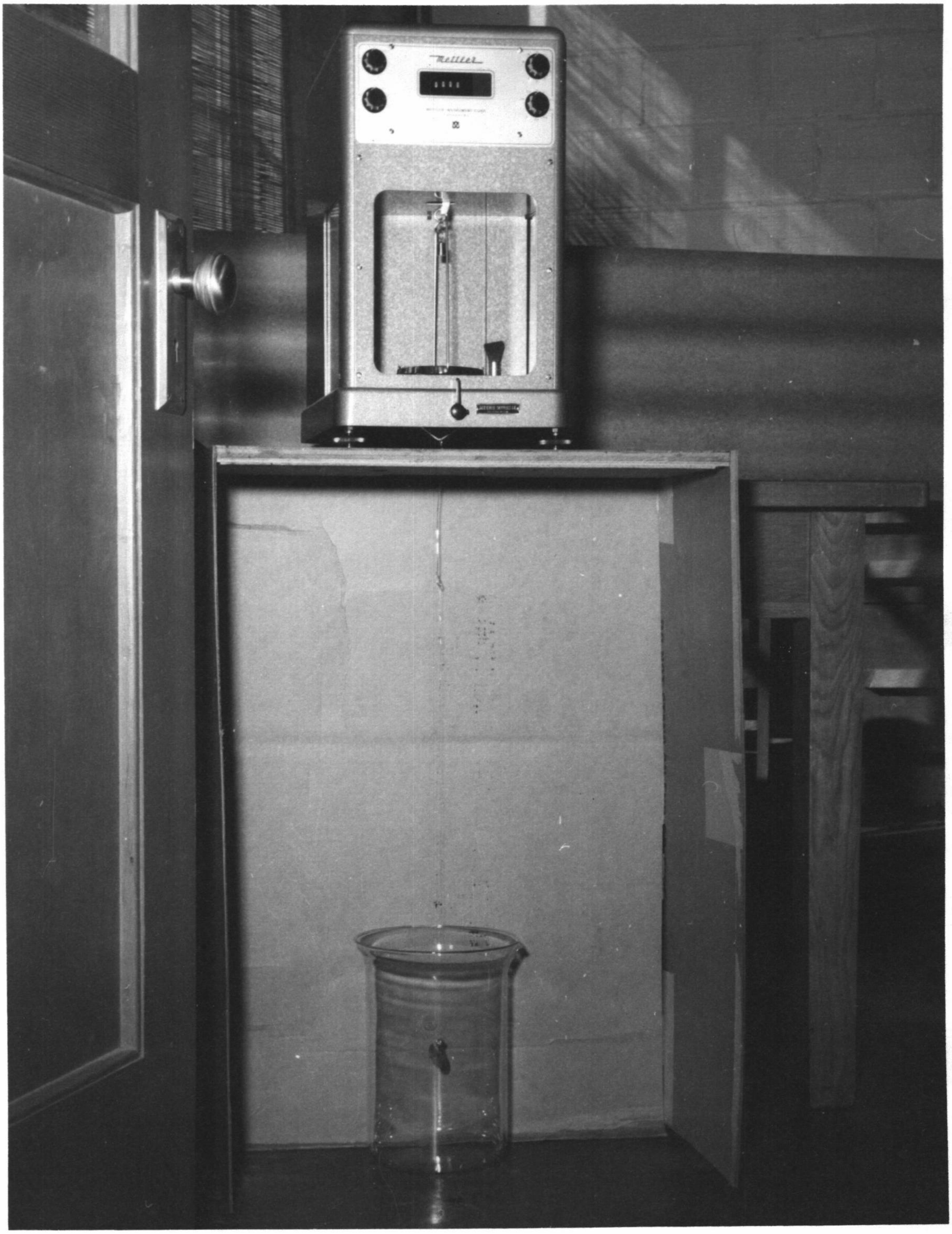

Figure 12. Mettler balance and immersion jig for determining the volume of specific gravity wafers.

was pressed into the surface of the wafer by the machine. The higher the reading, the smaller the indentation made by the ball.

When these tests were completed, a total of 2268 observations were recorded. A complete series consisted of 81 combinations of four variables. Each combination was repeated four times so a total of 324 moldings were made. These moldings were cut into five test pieces. One was used for a bending test, one was used for the two-hour and twenty-four hour water absorption test and three were used for specific gravity tests. One of the specific gravity pieces was used again in the hardness test.

IV STATISTICAL ANALYSIS

This study was designed as a factorial experiment to be analyzed by an analysis of variance. In this case a 3 x 3 x 3 x 3 randomized[15] block, factorial experiment with four replicates was used. Randomization was carried out in order to eliminate the influence of variations in technique and/or bias on the part of the experimenter.

In the present experiment there were 81 combinations of the four factors investigated, since there were three levels of each factor - particle size, resin content, moisture content and pressure. The 81 treatment combinations were randomized by blocks within each of the four replicates.

Since it was possible to manufacture only 27 moldings each day, complete randomization of the 81 combinations was achieved in the following manner. The particle size to be molded in a given day was selected at random (7, p. 422) from the three particle sizes. Then the order of mixing, and subsequent pressing, of the different resin contents with wood particles was randomized. When the mixture of particles and resin had been humidified to the required moisture contents, the

15 The order in which factors were combined was established by consulting a table of random numbers.

order in which moisture content and pressure were combined was randomized in groups of nine. The order in which replicates were made was not randomized. See Table 4 for a tabular presentation of the complete randomization of the 81 combinations of factors.

Details of the procedure followed in an analysis of variance of this kind are complex. The reader is referred to any standard statistical text.

A factorial experiment was used, in this case, to study the simultaneous effect of four variables upon the properties of a small dish-shaped molding. The advantages of a factorial experiment lie in its efficiency and in the revelation of the presence or absence of interactions. Efficiency is achieved through each observation supplying information on each of the four factors dealt with. In this case, one factorial experiment supplies information equivalent to four separate experiments of the same size used to study one factor at a time. A series of four simple experiments would reveal no information at all about the interactions which take place between factors. An interaction occurs when two or more factors act together to influence a given property more or less than when they act separately.

Throughout the following section the reader will see repeatedly the comments "significant" or "not significant". In an analysis of variance, a test is made of the hypothesis that the means are all equal. When this hypothesis is rejected as a result of statistical tests, the conclusion is reached that there is a significant difference between the means. When there is a significant difference between means it can be concluded that a given factor or combination of factors when used in varying amounts has a varying effect on a given property.

When significant differences are found between means these differences may be classified as significant or as highly significant. For significant differences, a true hypothesis may be rejected five percent of the time due to chance. Thus, it may be wrongly concluded that there is a significant difference between means five percent of the time. For highly significant differences, a true hypothesis may be rejected one percent of the time due to chance.

Once significant differences are found between sample means, individual means can be examined, differences between them calculated and compared to computed least significant differences at the five percent and one percent levels. In this way, the differences between individual means are classified as

TABLE 4

COMPLETE RANDOMIZATION OF THE 81 COMBINATIONS OF FACTORS

RANDOM SELECTION OF PARTICLE SIZE

Particle Size (mesh)	10-20	20-40	40-pan
Random Order of Use	3	1	2

PARTICLE SIZE 20-40

(Molding Material For One Day)

Resin Content (per cent)					5				
Random Order					1				
Moisture Content (per cent)		5			10			15	
Pressure (100 p.s.i.)	5	10	15	5	10	15	5	10	15
Random Order	4	1	2	5	6	9	7	8	3
Consecutive Random Order	4	1	2	5	6	9	7	8	3

Resin Content (per cent)					10				
Random Order					3				
Moisture Content (per cent)		5			10			15	
Pressure (100 p.s.i.)	5	10	15	5	10	15	5	10	15
Random Order	5	1	7	2	9	6	4	3	8
Consecutive Random Order	23	19	25	20	27	24	22	21	26

Resin Content (per cent)					15				
Random Order					2				
Moisture Content (per cent)		5			10			15	
Pressure (100 p.s.i.)	5	10	15	5	10	15	5	10	15
Random Order	2	3	1	6	9	8	7	5	4
Consecutive Random Order	11	12	10	15	18	17	16	14	13

significant (five percent) or highly significant (one percent).

Least significant differences were computed using the formula, L.S.D. = $t\sqrt{\frac{2S^2}{N}}$ where:

t = a value obtained from the statistical table of "t"

N = the number of observations used in calculating the means.

S^2 = the error mean square in the analysis of variance table.

V RESULTS AND DISCUSSION OF ANALYSES

Information presented in this section is as detailed as practical. Tables 7, 10, 13, 16 and 19 are included to permit the reader to make as many comparisons as he desires. However, it should be noted the differences between means in these tables are significant only in the case of Table 10.

In the following discussion reference is made to symbols in order to facilitate the presentation of results:

P = particle size

R = resin content

M = moisture content

Pr = pressure

Pi = piece number

NS = differences between means are not significant

* = differences between means are significant (5%)

** = differences between means are highly significant (1%)

Combinations of factors, i.e. R x M, are tests for the significance of interactions. In this case the effect of the combination of resin content and moisture content on a given property is tested. Should the effect be significant or highly significant an interaction exists between resin content and moisture content.

Significant differences at the five and one percent levels are denoted by * and **, respectively.

A. Formation Variables' Influence on Bending Strength

The master table (Table 5) of the analysis of variance shows resin content, moisture content and pressure are all highly significant. Particle size is not significant. The interactions resin content x pressure, moisture content x pressure and resin content x moisture content x pressure are all highly significant.

When tables 6a, 6b and 6c are examined it is evident that bending strength increases as resin content, moisture content and pressure increase. Conversely, the lowest level of each of these factors produced the lowest bending strength. It is interesting to note the greatest increases in strength occur between the first and second level of the significant variables.

When least significant differences were calculated, it was found the differences between individual means were highly significant in all cases.

Table 7 presents the average values for bending strength of the 81 combinations of four variables. When this table is examined it should be noted that the

TABLE 5

FORMATION VARIABLES' INFLUENCE ON BENDING STRENGTH

Master Table - Analysis of Variance

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	Variance Ratio (F)	Remarks
Total	323	169,793,076			
Reps	3	1,277,826	425,942	1.25	
P	2	2,635,918	1,317,959	3.86	
Error (a)	6	2,047,508	341,251		
R	2	43,643,076	21,821,538	222.79	**
P x R	4	575,952	143,988	1.47	
Error (b)	18	1,763,006	97,945		
M	2	20,720,359	10,360,180	110.76	**
P x M	4	353,112	88,278	.94	
R x M	4	523,645	130,911	1.40	
P x R x M	8	354,260	44,282	.47	
Error (c)	54	5,050,773	93,533		
Pr	2	75,768,797	37,884,398	829.34	**
P x Pr	4	439,155	109,789	2.40	
R x Pr	4	2,790,516	697,629	15.27	**
M x Pr	4	1,385,875	346,469	7.58	**
P x M x Pr	8	509,951	63,744	1.40	
P x R x Pr	8	378,051	47,256	1.03	
R x M x Pr	8	1,278,952	159,869	3.50	**
Pr x M x R x P	16	896,234	56,015	1.23	
Error (d)	162	7,400,110	45,680		

differences between particle sizes are not significant while the interaction resin content x moisture content x pressure is highly significant.

From the above discussion it is apparent the strength of a molding can be increased by increasing any one of the three significant variables. When table 7 is examined it can be seen that if moisture content and resin content are held constant and pressure is increased pronounced increases in strength take place. By holding moisture content and pressure constant and increasing resin content, changes in strength take place that about equal increases created when resin content and pressure are held constant and moisture content is increased. Since particle size and its interactions with the other three variables are not significant, no comparison need be made. Individual means for bending strength vary from 236.55 psi to 2647.82 psi.

B. Formation Variables' Influence on Water Absorption

1. Two hours of soaking

Particle size, resin content, moisture content and pressure were found to have a highly significant influence upon the amount of moisture absorbed during a two hour soaking period (Table 8). The interactions

TABLES OF MEANS SHOWING THE EFFECTS OF FOUR FACTORS ON THE BENDING STRENGTH. EACH OF THE FACTOR MEANS HAS BEEN AVERAGED OVER THE EFFECTS OF THE OTHER THREE FACTORS

TABLE 6a

Resin Content Means

Resin Percent	Mean P.S.I.	Difference	Remarks:		L.S.D.
5	841.96				
		511.42	**	: 5%	89.479
10	1353.38				
		384.59	**	: 1%	122.570
15	1737.97				

TABLE 6b

Moisture Content Means

Moisture Percent	Mean P.S.I.	Difference	Remarks:		L.S.D.
5	990.20				
		344.63	**	: 5%	83.445
10	1334.83				
		273.45	**	: 1%	111.163
15	1608.28				

TABLE 6c

Pressure Means

Pressure P.S.I.	Mean P.S.I.	Difference	Remarks:		L.S.D.
500	693.12				
		673.30	**	: 5%	57.501
1000	1366.42				
		507.35	**	: 1%	75.911
1500	1873.77				

TABLE 7

TABLE OF MEANS SHOWING THE EFFECT OF 81 COMBINATIONS OF FOUR VARIABLES ON THE BENDING STRENGTH IN POUNDS PER SQUARE INCH

P x R		10-20			20-40			40-pan		
		5	10	15	5	10	15	5	10	15
M x	Pr									
5	500	236.55	401.90	606.05	242.82	404.50	650.90	280.02	877.82	678.50
	1000	545.40	956.68	1233.15	531.62	879.10	1410.18	613.38	1216.78	1569.12
	1500	955.92	1537.17	1851.00	686.72	1433.02	2178.52	1025.00	1589.92	2143.65
10	500	280.68	611.62	873.92	345.72	739.52	978.02	614.18	623.30	1155.18
	1000	880.45	1234.18	1888.85	778.72	1245.78	1871.68	987.60	1502.80	1859.35
	1500	1317.70	1961.58	2468.30	1203.60	2048.70	2618.68	1327.70	1974.85	2647.82
15	500	412.00	816.95	1000.18	615.42	761.42	1328.88	497.88	1106.70	1573.52
	1000	903.10	1720.25	1807.58	996.98	1806.05	2356.72	1401.08	2294.00	2402.88
	1500	1719.92	2258.00	2614.95	1475.00	2165.80	2583.05	1857.75	2372.78	2574.72

TABLE 8

FORMATION VARIABLES' INFLUENCE ON MOISTURE ABSORPTION
TWO HOUR SOAK

Master Table - Analysis of Variance

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	Variance Ratio (F)	Remarks
Total	322	6,950.1463			
Reps	3	195.5275	65.1758	4.58	
P	2	712.4097	356.2048	25.01	**
Error (a)	6	85.4535	14.2422		
R	2	1,949.8412	974.9206	73.36	**
P x R	4	72.9001	18.2250	1.37	
Error (b)	18	239.1987	13.2888		
M	2	563.5531	281.7766	64.59	**
P x M	4	19.9927	4.9982	1.15	
R x M	4	136.3356	34.0839	7.81	**
P x R x M	8	36.0147	4.5018	1.03	
Error (c)	54	235.5728	4.3625		
Pr	2	1,507.3982	753.6991	193.20	**
P x Pr	4	25.8581	6.4645	1.66	
R x Pr	4	78.0644	19.5161	5.00	**
M x Pr	4	35.5592	8.8898	2.28	
P x M x Pr	8	100.3395	12.5424	3.22	**
P x R x Pr	8	139.4121	17.4265	4.47	**
R x M x Pr	8	75.2354	9.4044	2.41	*
Pr x M x R x P	16	113.3098	7.0819	1.82	*
Error (d)	161	628.0800	3.9011		

resin content x moisture content x pressure and pressure x moisture content x resin content x particle size have a significant effect on the amount of water absorbed in two hours. The interactions resin content x moisture content, resin content x pressure, particle size x moisture content x pressure, particle size x resin content x pressure have a highly significant effect on the percentage of moisture absorbed in two hours.

The amount of moisture absorbed by a molding decreased as resin content, moisture content and pressure increased, and it decreased as particle size decreased (Tables 9a, 9b, 9c and 9d).

The greatest decrease in water absorption occurs between the first and second level of each of the variables except in the case of moisture content. Here the greatest decrease occurs between the second and third level of this variable.

The least significant differences were computed for the four variables. From an examination of Tables 9a, 9b, 9c and 9d, it was found that the differences between means were highly significant in all cases except the difference between particle size 20-40 and 40-pan. In this case, the difference was significant. The third level of each variable produced the smallest

TABLES OF MEANS SHOWING THE EFFECTS OF FOUR FACTORS EACH AVERAGED OVER THE EFFECTS OF THE OTHER THREE FACTORS ON THE PERCENTAGE OF WATER ABSORBED IN TWO HOURS OF SOAKING

TABLE 9a

Particle Size Means

Particle Mesh	Mean Percent	Difference	Remarks :		L.S.D.
10-20	10.29				
		2.03	**	: 5%	1.257
20-40	8.26				
		1.59	*	: 1%	1.904
40-pan	6.67				

TABLE 9b

Resin Content Means

Resin Percent	Mean Percent	Difference	Remarks :		L.S.D.
5	11.63				
		3.74	**	: 5%	1.042
10	7.89				
		2.20	**	: 1%	1.428
15	5.69				

TABLES OF MEANS SHOWING THE EFFECTS OF FOUR FACTORS EACH AVERAGED OVER THE EFFECTS OF THE OTHER THREE FACTORS ON THE PERCENTAGE OF WATER ABSORBED IN TWO HOURS OF SOAKING

TABLE 9c

Moisture Content Means

Moisture Percent	Mean Percent	Difference	Remarks	:	L.S.D.
5	9.84				
		1.13	**	: 5%	0.570
10	8.71				
		2.03	**	: 1%	0.759
15	6.68				

TABLE 9d

Pressure Means

P.S.I.	Mean Percent	Difference	Remarks	:	L.S.D.
500	11.15				
		2.97	**	: 5%	0.531
1000	8.18				
		2.30	**	: 1%	0.702
1500	5.88				

water absorption.

The water absorption results for two hours of soaking for the 81 combinations of variables are presented in Table 10. These results vary from 17.95 percent to 2.10 percent moisture absorbed in two hours, depending on the combination of variables.

From the foregoing discussion it appears that, although particle size is highly significant, it does not have as pronounced an effect on moisture absorption as the other variables. None of the first order interactions containing particle size are significant. Moisture content and resin content are highly significant and approximately equal in their effect on the moisture absorption properties, but the interactions of these variables with particle size are not significant. Highly significant interactions take place involving particle size, and moisture content and/or resin content when pressure is part of the interaction.

2. Twenty-four hours of soaking

The amount of moisture absorbed by a molding in twenty-four hours of soaking was influenced to a highly significant degree by particle size, resin content, moisture content and pressure (Table 11).

TABLE 10

TABLE OF MEANS SHOWING THE EFFECT OF 81 COMBINATIONS OF FOUR VARIABLES ON THE PERCENTAGE OF WATER ABSORBED IN TWO HOURS OF SOAKING

P x R		10-20			20-40			40-pan		
		5	10	15	5	10	15	5	10	15
M x	Pr									
5	500	17.02	14.90	11.12	17.95	9.28	7.92	16.58	17.92	5.60
	1000	15.15	11.15	7.42	14.48	7.75	5.70	11.40	5.85	4.20
	1500	12.50	9.08	5.78	12.02	6.50	4.35	6.65	4.45	3.08
10	500	15.55	14.18	10.72	16.45	9.08	7.48	13.22	10.40	6.48
	1000	14.05	9.38	6.72	12.95	7.38	6.98	11.85	4.70	3.30
	1500	10.78	6.68	5.05	8.82	5.52	3.95	6.48	4.22	2.78
15	500	14.52	11.88	10.48	12.42	6.60	6.90	9.40	5.65	4.58
	1000	10.92	8.98	6.08	8.98	5.72	4.80	5.65	3.40	2.72
	1500	8.05	5.82	3.85	5.70	3.80	3.42	4.48	2.85	2.10

TABLE 11

FORMATION VARIABLES' INFLUENCE ON MOISTURE ABSORPTION
24 HOUR SOAK

Master Table - Analysis of Variance

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	Variance Ratio (F)	Remarks
Total	320	67,477.8618			
Reps	3	4,600.8304	1,533.6101	9.16	*
P	2	6,283.0408	3,141.5204	18.76	**
Error (a)	6	1,004.9284	167.4881		
R	2	29,029.2000	14,514.6000	255.58	**
P x R	4	309.7446	77.4362	1.36	
Error (b)	18	1,022.2420	56.7912		
M	2	7,434.5949	3,717.2974	208.72	**
P x M	4	128.6325	32.1581	1.81	
R x M	4	1,609.7466	402.4366	22.60	**
P x R x M	8	149.4132	18.6766	1.05	
Error (c)	54	961.7551	17.8103		
Pr	2	11,450.8600	5,725.4300	536.47	**
P x Pr	4	237.6724	59.4181	5.57	**
R x Pr	4	379.8354	94.9588	8.90	**
M x Pr	4	106.1172	26.5293	2.49	*
P x M x Pr	8	547.4865	68.4358	6.41	**
P x R x Pr	8	189.7644	23.7206	2.22	*
R x M x Pr	8	167.6852	20.9606	1.96	
Pr x M x R x P	16	167.3906	10.4619	.98	
Error (d)	159	1,696.9216	10.6725		

In this analysis there is an instance where a significant difference appears between replicates or blocks. This would indicate a variation in technique. Most likely, the error occurred when the excess surface moisture was removed from the moldings by blotting. Some moldings had a rough surface texture and perhaps not all the excess surface moisture was removed. In other instances a certain amount of sloughing of particles from the surface of moldings occurred during handling after they had softened over a 24-hour soaking period. There is not a significant difference between replicates for the two-hour soaking analysis or for any of the other three analyses.

The significant interactions were moisture content x pressure and particle size x resin content x pressure. The highly significant interactions were resin content x moisture content, particle size x pressure, resin content x pressure and particle size x moisture content x pressure.

The amount of moisture absorbed by the moldings decreased as the particle size decreased and as the resin content, moisture content and pressure increased (Tables 12a, 12b, 12c and 12d).

The difference between the first and second level of the variables showed the greatest reduction in

TABLES OF MEANS SHOWING THE EFFECTS OF FOUR FACTORS EACH AVERAGED OVER THE EFFECTS OF THE OTHER THREE FACTORS ON THE PERCENTAGE OF WATER ABSORBED IN 24 HOURS OF SOAKING

TABLE 12a

Particle Size Means

Particle Mesh	Mean Percent	Difference	Remarks :		L.S.D.
10-20	33.60				
		6.61	**	: 5%	4.309
20-40	26.99				
		4.07	N.S.	: 1%	6.528
40-pan	22.92				

TABLE 12b

Resin Content Means

Resin Percent	Mean Percent	Difference	Remarks :		L.S.D.
5	40.61				
		15.69	**	: 5%	2.155
10	24.92				
		6.94	**	: 1%	2.951
15	17.98				

TABLES OF MEANS SHOWING THE EFFECTS OF FOUR FACTORS EACH AVERAGED OVER THE EFFECTS OF THE OTHER THREE FACTORS ON THE PERCENTAGE OF WATER ABSORBED IN 24 HOURS OF SOAKING

TABLE 12c

Moisture Content Means

Moisture Percent	Mean Percent	Difference	Remarks	:	L.S.D.
5	33.51				
		5.30	**	: 5%	1.151
10	28.21				
		6.42	**	: 1%	1.534
15	21.79				

TABLE 12d

Pressure Means

Pressure P.S.I.	Mean Percent	Difference	Remarks	:	L.S.D.
500	35.47				
		8.39	**	: 5%	.879
1000	27.08				
		6.12	**	: 1%	1.161
1500	20.96				

water absorption in all cases except that of moisture content. Here, the difference between the second and third level is the larger of the two. The third level of each variable produced the smallest water absorption.

Pursuing the analysis further, least significant differenses were computed and the means of Tables 12a, 12b, 12c and 12d were examined to see if the differences between means were significant. It was found that the differences between all main effects were highly significant except in the case of the difference between particle size 20-40 and 40-pan. This difference was not significant. This would indicate that the reduction in particle size in this instance has no effect on the absorption of moisture by the moldings.

Table 13 presents the average of four replicates for 81 combinations of factors. The amount of moisture absorbed in 24 hours varied from 59.08 percent to 7.62 percent.

Interactions containing particle size are not significant except where pressure is included in the interaction. In one case the interaction is significant and in the other two cases the interaction is highly significant.

Results of the 24 hour soaking period compared

TABLE 13

TABLE OF MEANS SHOWING THE EFFECT OF 81 COMBINATIONS OF FOUR VARIABLES ON THE PERCENTAGE OF WATER ABSORBED IN 24 HOURS OF SOAKING

P x R		10-20			20-40			40-pan		
		5	10	15	5	10	15	5	10	15
M x	Pr									
5	500	55.75	40.95	31.58	56.45	31.50	25.30	54.92	41.25	23.98
	1000	54.08	35.65	23.50	50.82	29.52	20.65	44.12	22.38	16.42
	1500	50.35	30.62	20.68	44.68	24.35	14.35	33.25	16.55	11.02
10	500	59.08	39.60	29.12	49.98	28.68	23.20	45.78	30.18	22.12
	1000	50.68	29.32	21.32	42.70	24.20	17.92	34.78	17.30	11.10
	1500	40.10	21.68	16.25	30.42	17.30	12.25	23.02	14.08	9.50
15	500	49.75	35.80	28.52	40.58	24.42	19.55	33.22	20.55	15.78
	1000	39.58	26.48	18.55	27.92	16.92	13.15	20.45	12.15	9.42
	1500	28.32	18.45	11.52	18.75	12.08	11.00	16.88	10.92	7.62

favorably with those obtained from two hour soaking. The exceptions were in the total moisture absorbed and the combination of molding factors giving a sample having high moisture absorption property values, i.e. 20-40 mesh, 5 percent resin, 5 percent moisture content pressed at 500 psi pressure gave the sample with highest moisture absorption after a two hour soak; for 24 hour soaking the sample made from 10-20 mesh particles, 5 percent resin, 10 percent moisture content and 500 psi pressure produced the highest moisture absorption.

The main effects were highly significant for both the two hour and 24 hour soak tests. Differences in the results of water absorption are presented in Table 20.

C. Formation Variables' Influence on Specific Gravity

The specific gravity of the moldings was influenced to a highly significant degree by particle size, resin content, moisture content, pressure and position in the molding from which the test piece was cut (Table 14). The interaction particle size x moisture content is significant while the interactions particle size x pressure, moisture content x pressure, piece x particle size, piece x resin content, piece x

TABLE 14

FORMATION VARIABLES' INFLUENCE ON THE SPECIFIC GRAVITY

Master Table - Analysis of Variance

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Squares	Variance Ratio (F)	Remarks
Total	961	30.778929			
Reps	3	.217392	.072464	2.72	
P	2	1.416773	.708386	26.59	**
Error (a)	6	.159837	.026640		
R	2	1.406984	.703492	302.58	**
P x R	4	.018187	.004547	1.96	
Error (b)	18	.041850	.002325		
M	2	3.786022	1.893011	238.75	**
P x M	4	.102726	.025682	3.24	*
R x M	4	.069354	.017338	2.19	
P x R x M	8	.046979	.005872	.74	
Error (c)	54	.428170	.007929		
Pr	2	13.512949	6.756474	2294.22	**
P x Pr	4	.090676	.022669	7.70	**
R x Pr	4	.008104	.002026	.69	
M x Pr	4	.126135	.031534	10.71	**
P x M x Pr	8	.029505	.003688	1.25	
P x R x Pr	8	.035008	.004376	1.49	
R x M x Pr	8	.038236	.004780	1.62	
Pr x M x R x P	16	.048437	.003027	1.03	
Error (d)	162	.477128	.002945		
Pl	2	7.074347	3.537174	2043.43	**
Pl x P	4	.253438	.063360	36.60	**
Pl x R	4	.119095	.029774	17.20	**
Pl x M	4	.044850	.011212	6.48	**
Pl x Pr	4	.139736	.034934	20.18	**
Pl x R x P	8	.018565	.002321	1.34	
Pl x M x P	8	.017487	.002186	1.26	
Pl x M x R	8	.025327	.003166	1.83	
Pl x Pr x P	8	.013521	.001690	.98	
Pl x Pr x R	8	.004349	.000544	.31	
Pl x Pr x M	8	.008917	.001115	.64	
Pl x M x R x P	16	.027506	.001719	.99	
Pl x Pr x M x P	16	.032489	.002031	1.17	
Pl x Pr x R x P	16	.035975	.002248	1.30	
Pl x Pr x M x R	16	.018059	.001129	.65	
Pl x Pr x M x R x P	32	.060985	.001906	1.10	
Error (e)	476	.823831	.001731		

moisture content and piece x pressure are highly significant.

Specific gravity increased as the particle size decreased and as resin content, moisture content and pressure increased (Tables 15a, 15b, 15c, 15d and 15e). Specific gravity decreased as the position changed from the outer edges to the center of the molding. The increase in the magnitude of resin content, moisture content and pressure from the first to the second level caused the greatest change in specific gravity. The change in specific gravity was greatest between the second and third level for pressure and piece.

The least significant differences were computed and the differences between means of the main effects were compared to these to determine if the differences were significant. In all cases the differences were highly significant except the difference between particle size 10-20 and 20-40 was not significant, while the difference between a pressure of 500 and 1000 psi was significant. The third level of each variable produced the highest specific gravity and the highest specific gravity was produced in most cases in piece number one, the outer edge of the molding.

Specific gravity within moldings was not

TABLES OF MEANS SHOWING THE EFFECTS OF FIVE FACTORS EACH AVERAGED OVER THE EFFECTS OF THE OTHER FOUR FACTORS ON THE SPECIFIC GRAVITY

TABLE 15a

Particle Size Means

Particle Mesh	Mean Specific Gravity	Difference	Remarks	:	L.S.D.
10-20	.9013				
		.0282	N.S.	:5%	.03138
20-40	.9295				
		.0631	**	:1%	.04754
40-pan	.9926				

TABLE 15b

Resin Content Means

Resin Percent	Mean Specific Gravity	Difference	Remarks	:	L.S.D.
5	.8927				
		.0524	**	:5%	.00796
10	.9451				
		.0405	**	:1%	.01090
15	.9856				

TABLE 15c

Moisture Content Means

Moisture Percent	Mean Specific Gravity	Difference	Remarks	:	L.S.D.
5	.8620				
		.0848	**	:5%	.01043
10	.9468				
		.0678	**	:1%	.01113
15	1.0146				

TABLES OF MEANS SHOWING THE EFFECTS OF FIVE FACTORS EACH AVERAGED OVER THE EFFECTS OF THE OTHER FOUR FACTORS ON THE SPECIFIC GRAVITY

TABLE 15d

Pressure Means

Pressure P.S.I.	Mean Specific Gravity	Difference	Remarks :		L.S.D.
500	.7838				
		.1881	*	:5%	.00843
1000	.9719				
		.0958	**	:1%	.01113
1500	1.0677				

TABLE 15e

Piece Means

Piece	Mean Specific Gravity	Difference	Remarks :		L.S.D.
1	1.0130				
		.0239	**	:5%	.00643
2	.9891				
		.1678	**	:1%	.00846
3	.8213				

uniform in all cases. It was originally thought that preforming would eliminate most of the variation within moldings. This was not true. At the highest level of resin content, moisture, pressure and the smallest particle size the greatest differences in specific gravity within a molding was found to occur. Perhaps this was caused by a migration of moisture in the form of steam and softened resin toward the outer lip of the molding during the breathing periods when steam was allowed to escape.

Table 16 is a table of means showing the effect of 243 combinations of four formation variables plus the effect of position on specific gravity. The specific gravity varied from .547 to 1.293.

Although resin content acts alone to influence specific gravity, it does not react with any other variable except position. Particle size and moisture content each interact with pressure. The resistance to compression is reduced due to the plasticizing effect of moisture while the larger the particle size the greater will be the void spaces as well as the greater ability of a large particle to resist compressive forces. Particle size and moisture react together since the moisture content present under conditions of heat and pressure should reduce the ability of the particles

TABLE 16

TABLE OF MEANS SHOWING THE EFFECT OF 243 COMBINATIONS OF FIVE VARIABLES ON SPECIFIC GRAVITY

P x Pi			10-20			20-40			40-pan		
			1	2	3	1	2	3	1	2	3
R	x M	x Pr									
5	5	500	.635	.646	.547	.693	.690	.578	.736	.707	.619
		1000	.823	.829	.693	.876	.755	.708	.982	.941	.801
		1500	.960	.978	.806	.983	.946	.779	1.088	1.045	.891
	10	500	.746	.742	.615	.779	.751	.637	.804	.785	.711
		1000	.942	.951	.797	.952	.931	.780	1.079	1.018	.877
		1500	1.061	1.076	.914	1.100	1.079	.885	1.142	1.094	.909
	15	500	.804	.832	.682	.901	.895	.759	1.002	.894	.753
		1000	1.040	1.009	.852	1.093	1.045	.889	1.155	1.084	.926
		1500	1.119	1.149	.968	1.176	1.124	.867	1.237	1.174	1.015
10	5	500	.673	.692	.574	.766	.731	.598	.872	.827	.683
		1000	.854	.892	.731	.922	.920	.748	1.077	1.014	.845
		1500	.990	1.052	.800	1.075	1.058	.882	1.165	1.105	.929
	10	500	.735	.726	.690	.837	.836	.692	.904	.902	.720
		1000	.988	1.001	.815	1.013	1.001	.836	1.128	1.093	.940
		1500	1.059	1.143	.922	1.156	1.153	.963	1.217	1.150	.977
	15	500	.860	.889	.766	.918	.894	.733	1.004	.904	.806
		1000	1.071	1.084	.901	1.144	1.108	.935	1.188	1.132	1.007
		1500	1.193	1.185	.987	1.230	1.178	1.017	1.268	1.153	1.028
15	5	500	.715	.756	.610	.836	.803	.619	.950	.827	.681
		1000	.856	.908	.756	.988	.992	.760	1.131	1.065	.854
		1500	1.074	1.118	.867	1.144	1.135	.912	1.256	1.154	.926
	10	500	.831	.863	.664	.866	.867	.700	.967	.964	.763
		1000	1.044	1.098	.870	1.199	1.100	.879	1.223	1.106	.920
		1500	1.177	1.199	.966	1.129	1.208	.962	1.277	1.216	1.010
	15	500	.912	.901	.745	1.019	.952	.767	1.016	.950	.822
		1000	1.146	1.155	.917	1.182	1.135	.956	1.275	1.147	.985
		1500	1.194	1.212	1.012	1.249	1.175	.904	1.293	1.168	.997

to resist compressive forces.

D. Formation Variables' Influence on Rockwell Superficial Hardness.

The superficial hardness of the moldings was highly significantly influenced by particle size, resin content, moisture content and pressure (Table 17). The interaction resin content x pressure was significant while the interactions resin content x moisture content, particle size x pressure and moisture content x pressure were highly significant.

By referring to Tables 18a, 18b, 18c and 18d it was found that the hardness of the moldings increased as the particle size decreased and as the resin content, moisture content and pressure increased.

It is interesting to note that the greatest increase in hardness occurs between level one and two for resin content and pressure. The greatest increase in hardness occurs between level two and three for particle size and moisture content. The third level of each variable produced the greatest hardness.

The least significant differences were computed for the main effects and it was found that the differences were highly significant in all cases except the difference between a particle size of 10-20 and 20-40 which

TABLE 17

FORMATION VARIABLES' INFLUENCE ON ROCKWELL SUPERFICIAL HARDNESS

Master Table - Analysis of Variance

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Squares	Variance Ratio (F)	Remarks
Total	321	179,052.0707			
Reps	3	3,754.5077	1,251.5026	3.22	
P	2	20,760.7215	10,380.3608	26.72	**
Error (a)	6	2,330.6682	388.4447		
R	2	21,382.0123	10,691.0062	87.92	**
P x R	4	623.5411	155.8853	1.28	
Error (b)	18	2,188.8043	121.6002		
M	2	7,991.3889	3,995.6944	51.61	**
P x M	4	354.9839	88.7460	1.15	
R x M	4	2,147.1376	536.7844	6.93	**
P x R x M	8	149.8079	18.7260	.24	
Error (c)	54	4,180.4440	77.4156		
Pr	2	91,203.6975	45,601.8487	507.34	**
P x Pr	4	1,661.8614	415.4654	4.62	**
R x Pr	4	1,108.6428	277.1607	3.08	*
M x Pr	4	1,680.9829	420.2457	4.68	**
P x M x Pr	8	425.0404	53.1300	.59	
P x R x Pr	8	1,028.1749	128.5219	1.43	
R x M x Pr	8	513.6562	64.2070	.71	
Pr x M x R x P	16	1,184.4989	74.0312	.82	
Error (d)	160	14,381.4783	89.8844		

TABLES OF MEANS SHOWING THE EFFECTS OF FOUR FACTORS EACH AVERAGED OVER THE EFFECTS OF THE OTHER THREE FACTORS ON ROCKWELL SUPERFICIAL HARDNESS

TABLE 18a

Particle Size Means

Particle Mesh	Mean Hardness	Difference	Remarks	:		L.S.D.
10-20	46.07					
		8.28	*	:	5%	6.563
20-40	54.35					
		11.25	**	:	1%	9.943
40-pan	65.60					

TABLE 18b

Resin Content Means

Resin Percent	Mean Hardness	Difference	Remarks	:		L.S.D.
5	44.79					
		11.90	**	:	5%	3.153
10	56.69					
		7.86	**	:	1%	4.319
15	64.55					

TABLES OF MEANS SHOWING THE EFFECTS OF FOUR FACTORS EACH AVERAGED OVER THE EFFECTS OF THE OTHER THREE FACTORS ON ROCKWELL SUPERFICIAL HARDNESS

TABLE 18c

Moisture Content Means

Moisture Percent	Mean Hardness	Difference	Remarks :		L.S.D.
5	49.62				
		5.06	**	: 5%	2.401
10	54.68				
		7.05	**	: 1%	3.198
15	61.73				

TABLE 18d

Pressure Means

Pressure P.S.I.	Mean Hardness	Difference	Remarks :		L.S.D.
500	32.23				
		30.01	**	: 5%	2.551
1000	62.24				
		9.32	**	: 1%	3.369
1500	71.56				

was significant.

Table 19 is a table of means showing the variations in hardness produced by the 81 combinations of variables. The lowest hardness was − 7.25 while the greatest hardness was 87.88.

Particle size only forms one highly significant interaction. This is with pressure. Resin content appears two times in significant or highly significant interactions. The former is with pressure and the latter is with moisture and particle size. Moisture content is part of two highly significant interactions, one with pressure and one with resin content.

E. Summary of Formation Variables' Influence on Properties.

The change in properties of the moldings as the magnitude of the variables change was as follows: bending strength, specific gravity, and hardness increased, while moisture absorption decreased, when particle size decreased and resin content, moisture content and pressure increased. This does not mean to say that the smallest particle size, the highest resin content, moisture content and pressure will unite to influence the various properties in such a way as to produce the best result. By inspecting the analysis of

TABLE 19

TABLE OF MEANS SHOWING THE EFFECT OF 81 COMBINATIONS OF FOUR VARIABLES ON ROCKWELL SUPERFICIAL HARDNESS

P x R		10-20			20-40			40-pan		
		5	10	15	5	10	15	5	10	15
M x	Pr									
5	500	-7.25	13.25	19.12	11.62	24.88	36.12	16.00	48.75	54.88
	1000	32.88	47.88	55.75	49.88	53.88	65.88	53.00	70.50	80.50
	1500	50.38	58.62	76.75	49.12	68.50	78.12	66.62	78.88	85.25
10	500	- .38	17.00	38.75	16.88	34.00	40.62	18.88	50.00	54.00
	1000	44.88	56.88	62.00	44.75	54.88	70.00	65.50	72.50	81.75
	1500	60.88	68.50	70.62	64.25	70.50	82.38	69.00	79.38	87.88
15	500	23.75	26.92	41.25	41.38	43.12	48.25	41.38	62.50	54.62
	1000	56.12	60.38	60.38	61.00	69.62	73.75	70.38	80.62	84.88
	1500	61.25	68.00	79.38	68.62	67.50	78.00	78.55	83.12	82.00

variance tables, it can be seen that the interaction, particle size x resin content x moisture content x pressure is significant in one out of five analyses. What is meant is, the variables acting primarily alone influence the change in properties described above.

Table 20 shows the variables and interactions found to be significant and highly significant as a result of five statistical analyses. The variables are highly significant in 20 out of 21 tests. Particle size does not have an effect on strength. Six interactions were significant and 19 interactions were highly significant of a total of 69 interactions present in five analyses.

TABLE 20

SIGNIFICANT AND HIGHLY SIGNIFICANT VARIABLES
AND THEIR INTERACTIONS

	STRENGTH INDEX	WATER SOAK 2 HOUR	WATER SOAK 24 HOUR	SPECIFIC GRAVITY	ROCKWELL
P		**	**	**	**
R	**	**	**	**	**
M	**	**	**	**	**
Pr	**	**	**	**	**
Pi				**	
P x M				*	
R x M		**	**		
P x Pr			**	**	**
R x Pr	**	**	**		*
M x Pr	**		*	**	**
P x M x Pr		**	**		
P x R x Pr		**	*		
R x M x Pr	**	*			
Pr x M x R x P		*			
Pi x P				**	
Pi x R				**	
Pi x M				**	
Pi x Pr				**	

VI CONCLUSIONS

Within the limits of the variables studied in this experiment, it may be concluded that pressure exerted on the molding mix in heated dies has a highly significant effect on bending strength, water absorption, specific gravity and superficial hardness of the finished moldings.

Powdered synthetic resin adhesive mixed with wood particles has a highly significant effect on bending strength, water absorption, specific gravity and superficial hardness of the moldings.

Moisture content of the wood particle and synthetic resin adhesive mixture at the time of pressing in heated dies has a highly significant influence on bending strength, water absorption, specific gravity and superficial hardness of the moldings.

Particle size used in this experiment have no effect on bending strength. Particle size has a highly significant effect on water absorption, specific gravity and superficial hardness.

Bending strength, specific gravity and hardness increased when resin content, moisture content and pressure increased and particle size decreased. Moisture absorption decreased with an increase in resin content, moisture content, and pressure and a decrease in particle size.

The particle size that can be successfully used to make moldings varies as the complexity of the shape to be produced. Very coarse particles (6-mesh) can be used if the particle shape is granular rather than stick-like and if a relatively simple shape is made. Fine wood particles must be used with more complex shapes.

The resin content must be increased to prevent voids from developing as a result of limited flow when the shape to be molded is complex. In order to make complex shapes while using a low resin content, a preform must be used which closely matches the finished molding.

Unless some form of an expanding die or a bag molding technique is used, pressure will not be equal and normal to all surfaces of a molding of complex shape. Uniform pressure is required if uniformity of the product is to be achieved at resin contents as low as 15 percent.

By preforming, it is possible to achieve a more uniform density throughout the molding over a rather wide range of resin content and particle size combinations.

Preforming also makes it possible to vary the specific gravity from place to place in the molding. Thus, the molding can be strengthened at critical points if this is desired.

The preforming technique used in this experiment did not produce the anticipated uniformity of specific gravity within moldings over the complete range of variables studied. At the lower levels of the variables uniform specific gravity was achieved, but at the higher levels considerable variation of specific gravity occurred within the moldings.

Blisters resulted when the molding mix produced a large amount of vapors that were effectively trapped in the mold either through high pressure or through the shape of the dies. Unless a breathing technique is used, blisters will develop with high pressures, high moisture contents, high natural volatile content of the wood and high synthetic resin contents.

The manipulation of variables to achieve given properties will depend upon economics and the feasibility of using a given combination of variables.

The total force that a press is capable of exerting will determine the number of moldings that can be made at one time with a given specific pressure.

When the maximum force of the press is reached it means reducing the number of moldings that can be made at one time in a multiple die press with a given pressure or building a press capable of producing sufficient total force.

The resin content can only be increased so much before an economic limit is reached due to the cost of resin.

Moisture content can only be increased to the fiber saturation point. Above this point, moisture will be present as free water in the cell cavities. It is thought that free water will not contribute to further reduction in the wood particles' resistance to compressive forces. Also, more heat is required to raise the internal temperature of a molding mix saturated with water than to raise the temperature of a molding mix of low moisture content.

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