RELATION OF SEVERAL FORMATION VARIABLES TO PROPERTIES OF PHENOLIC-RESIN-BONDED WOOD-WASTE HARDBOARDS

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RELATION OF SEVERAL FORMATION VARIABLES TO PROPERTIES OF PHENOLIC-RESIN-BONDED WOOD-WASTE HARDBOARDS[1]

By

H. DALE TURNER, Chemical Engineer
and
JOHN D. KERN, Collaborator[2]

Forest Products Laboratory,[3] Forest Service
U. S. Department of Agriculture

Abstract

This paper presents the results of a Forest Products Laboratory study regarding the effects of resin content, particle size, and molding pressure upon specific gravity, strength, and water absorption of hardboard products made of wood waste treated with powdered phenolic resin. Modulus of rupture in bending was found to vary approximately as the cube of specific gravity, whereas water absorption varied inversely with increasing density.

Minor changes in resin content within the range of 5 to 20 percent were shown to be of secondary importance, as compared to density, in their effect on properties.

Introduction

In the formation of a resin-bound hardboard, many variables are known to have a significant effect upon the qualities of the final product. Using a board prepared from mixed species and types of wood waste, the effect of some of these variables was investigated so that information could be made available for general use in the development of this type of material.

The experimental work was done on laboratory-size equipment, and no attempt was made to correlate the data with production-size equipment. The relations

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[1]Presented to the Midwest Section, Forest Products Research Society, April 24-25, 1950, at Madison, Wis.

[2]Much of the work here reported was done by Mr. Kern as a student collaborator for thesis work while at the University of Wisconsin. He is now a chemical engineer at The Richardson Company, Melrose Park, Ill.

[3]Maintained at Madison 5, Wis., in cooperation with the University of Wisconsin.

developed are useful in that they do lead to a clearer understanding of the relative significance of particle size, resin content, and curing pressure with respect to the final quality of the board.

Experimental Procedure

Preparation of Wood Waste

Approximately 100 pounds of mixed shop waste produced principally from circular saws, joiners, and planers was reduced in a small hammer mill to pass an 8-mesh screen.

The air-dry ground material was then fractionated in a continuous-type laboratory sifter into the following grades:

Fine — Through 40-mesh screen
Medium — Through 20- and retained on a 40-mesh screen
Coarse -- Through an 8- and retained on a 20-mesh screen

Preparation of Molding Composition

The sawdust was dried at 105° C. (221° F.) in a forced-air-circulation oven for 15 hours preceding the molding operation. Six hundred grams of the oven-dry sawdust were measured out and mixed with the required weight of finely pulverized phenolic resin in an improvised tumbling cylinder containing internal baffles. All batches were mixed for 5 minutes at a drum speed of 40 revolutions per minute. The complete experimental scheme may be followed by referring to the flow sheet (fig. 1).

Molding Procedure

Molding was done in a 100-ton hydraulic press equipped with 20-inch, steam-heated platens. The temperature of the platens was held constant at 195° C. (383° F.) for all test panels. The hardened tool steel mold used is illustrated in figure 2. The diameter of the circle is 8-1/2 inches and the depth of the mold is 0.75 inch. The faces have zero clearance when the mold is empty.

For each particle size and resin content 150-gram lots of the oven-dry mixture were weighed out, charged into the mold, and cured for 15 minutes at 195° C. at pressures of 400, 600, 1,000, and 2,000 pounds per square inch. The mold was preheated before the first disc was molded. Duplicates were made, so that 8 discs were produced for each specific particle size and resin content. A suspension of zinc stearate in kerosene applied to the mold faces was found to be an effective parting agent. Sticking was encountered primarily when making discs at low pressures and low resin contents.

The complete series consisted of 36 combinations of particle size, resin content, and curing pressure.

Preparation of Specimens

From the central portion of each circular plate three rectangular pieces were cut; two 1-1/2- by 7-1/2-inch sections for modulus of rupture tests and one 1- by 3-inch section for moisture-absorption determination. The modulus of rupture specimens were conditioned for 10 days at 75° F. and 65 percent relative humidity.

Method of Test

The test specimens were measured and weighed for specific gravity data and then tested to failure in static bending on 3/8-inch-radius reactions by a center loading head.

Since the modulus of rupture is influenced by the ratio of span to depth of the test sections, this ratio was maintained approximately constant for all test specimens. The rate of head movement of the testing machine was also varied for the different specimens to produce approximately equal rates of stress development in the sections. Four strength values were determined for each of the 36 different boards.

The moisture-absorption specimens were oven dried at 105° C. for 15 hours, cooled in a desiccator, then measured and weighed for specific gravity determination. The samples were then submerged in distilled water for 24 hours at an average temperature of 23° C. (73° F.). The sections were racked on wire net so that maximum surface area was directly exposed to the water. Upon removal from the water, the samples were lightly blotted and again weighed and measured.

Results of Tests

Effect of Molding Pressure on Specific Gravity

The relationship of specific gravity to molding pressure is shown in figure 3. The data at 400 pounds per square inch were given less weight than those at higher pressures in establishing the slope of this curve and those following, because it was difficult to reproduce this pressure with as high a degree of precision as the higher pressures.

The data approximate a straight line on semilogarithmic coordinates and indicate that the curves are of the form

$$Y = m \log X + \text{constant}$$

The factor $\underline{m}$ is the slope of the line and when evaluated was found to be approximately the same for all of the curves. This indicates that the rate of increase of the specific gravity with increase in molding pressure is little affected by resin content or particle size. The effect upon specific gravity of a two-fold increase in pressure is roughly four times as great as the effect of a two-fold increase in the resin content.

Extrapolation of this or any of the following relationships beyond the upper or lower limits of the experimental pressures or resin contents, or at another curing temperature, is not recommended. Conditions other than those used in this experiment could conceivably lead to a change in the relationships discussed herein. The conditions used were fixed arbitrarily.

To obtain a board with a specific gravity of 1.00, the required molding pressures are tabulated in table 1 for each particle size and resin content.

The pressure required progressively decreases as the resin content is increased. Changing the particle size at one resin content shows that higher pressures are required to produce a comparably dense board with the medium-size particles in all cases. The board produced from medium particles exhibits distinctly different properties in this comparison.

Strength Tests

The relation of specific gravity to the modulus of rupture is shown in figure 4. These curves were found to approximate straight lines when plotted on log-log coordinates and indicate a relationship of the form

$$\text{Log } Y = m \log X + \text{constant}$$

A solution of the equation for the factor m in all nine cases presented, shows the slope of each curve to be very close to three. This indicates that the modulus of rupture varies as the cube of the specific gravity.

In an investigation[4] with wet-formed pulp-based hardboards, it was found that the modulus of rupture varied according to the square of the specific gravity. The fiberboards contained no added bonding or chemical agents and were tested under similar experimental conditions.

The pronounced difference between these types of materials in the rate of strength change with changes in density presents an interesting problem. The distinct difference in type of particle, interparticle adhesive or combinations of these may be the cause of the observed differences. There are, however, no experimental data available at this time which give a better understanding of the relationship of particle shape to the strength and strength-density relationship in a composition of resin-bonded wood waste.

The effect of the moisture content of the samples at the time of the breaking tests was not investigated in this work. The moisture content may have a significant effect upon ease of molding, strength, and the development of panels of higher specific gravity. The study of moisture-content variables was contemplated in this investigation but the nature of the mold design did not permit controlled venting during molding. It was noted that even a low moisture content (3 to 5 percent) in the wood caused pronounced blisters to

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[4] Turner, H. D., Hohf, J. P., and Schwartz, S. L., "Effect of Some Manufacturing Variables on the Properties of Fiberboard Prepared from Milled Douglas-fir," Forest Products Research Society Proceedings, 1948.

appear on the finished panel when removed from the mold immediately after completion of the press cycle.

Table 2 indicates the effect of particle size and resin content on the strength of boards having a specific gravity of 1.00. The table was derived from figure 4.

The boards of medium particle size had somewhat greater strength than the others at each resin content.

With the fine series of boards, a two-fold increase in resin content from 5 to 10 percent produced a 44 percent increase in strength. The two-fold increase from 10 to 20 percent resin produced only a 6 percent increase in strength. Both the percentage increases are based on the strength at the lower of the two resin contents compared.

By a similar analogy, the boards of medium particle size showed each increase to be 16 percent. In the coarse series the first increase was 46 percent and the the second 27 percent. From these results the feasibility of adjusting resin contents and particle size can be predicted in a general way, on an economic basis, to attain a board with desired properties.

The particles appeared, when examined under a low-power microscope, to have approximately similar geometrical shapes through each of the three fractions. Until a definite investigation of this factor is made, however, the effect of particle shape is a variable of indeterminate influence.

Moisture Absorption Tests

Figure 5 presents the results of a 24-hour moisture-absorption test plotted against the specific gravity of the samples. A straight line is obtained using linear coordinates and indicates a relationship of the form

$$Y = m X + \text{constant}$$

where m is the slope of the lines.

The effects of doubling the resin content twice in each particle-size series of boards are presented in table 3 for boards of a specific gravity of 1.00.

The effects of a decrease in the particle size at one given resin content are indicated in table 4 for boards of a specific gravity of 1.00.

The relationship between moisture absorption, resin content, and particle size is not obvious, as is indicated by tables 3 and 4. The moisture-absorption data are not equilibrium values.

The moisture-absorbing ability of a board of this type would be a complex function of:

(a) The volume of the voids which will mechanically hold water.

(b) The capillary passages to the voids.

(c) The surface area of the particles.

(d) The densification of each wood particle by the molding pressure.

(e) The ratio of resin-covered particle surface area to that which is not covered.

(f) The permeability of the resin binder.

(g) The depth of impregnation of each wood particle by resin.

(h) The original moisture content of the wood particles.

(i) The viscosity and surface tension of the water, which is, in turn, a function of the temperature at which the test was made.

The differences indicated by the slopes of the curves appear to be a function of particle size when the curve families of the coarse and medium boards are compared; that is, slopes are identical within the families, indicating no resin-content effect, but are different between the families, indicating a particle-size influence. A comparison of the fine and medium series finds five of the six curves with the same slope. The general trend, however, seems to indicate a decreasing slope as the particle size is increased.

The curves of figure 5 show that the fine-particle board of 5 percent resin content lost moisture-absorbing ability more rapidly with increase in curing pressure than any of the others made. It was also the only board which, at low specific gravities, absorbed enough water to more than double its weight.

Another factor to consider when attempting to analyze the moisture-absorption data is the surface condition of each rectangular test specimen. The two greatest areas are those which were in contact with the mold and thus have fiber orientation to some extent and possibly a higher concentration of resin than is found in the interior of each board. The end and edge areas of the section were exposed when sections were sawed from the molded plate. The ratio of the area which was in contact with the mold to the rough areas caused by sawing ranged from 3.33 for the low-pressure boards to 5.35 for the high-pressure boards, or 1.6 times as large. This holds true for boards of each particle size. The rate of diffusion of water into the board through each of these types of surface is probably different.

Theories could be proposed in an attempt to explain the curves, but without broader and more intensive research any discussion is purely speculative. The results presented in this report are useful in the empirical form and may be used to compare and predict the properties of similarly constituted boards.

Table 1.--Molding pressure required to form boards of a specific gravity of 1.00 from wood waste of three particle sizes

Particle size	Molding pressures required at		
	5 percent resin	10 percent resin	20 percent resin
	P.s.i.	P.s.i.	P.s.i.
Fine (40-100)	1,200	980	730
Medium (20-40)	1,700	1,400	1,000
Coarse (8-20)	1,400	1,300	950

Table 2.--Effect of particle size and resin content on hardboards with a specific gravity of 1.00

Resin content	Strength with particle size of		
	Fine (40-100)	Medium (20-40)	Coarse (8-20)
Percent	P.s.i.	P.s.i.	P.s.i.
5	3,400	4,300	2,800
10	4,900	5,000	4,100
20	5,200	5,800	5,200

Table 3.--Decrease in moisture absorption of waste-wood hardboards with increase in resin content

Resin increase	Decrease for particle size of		
	Fine (40-100)	Medium (20-40)	Coarse (8-20)
Percent	Percent	Percent	Percent
5-10	12.5	7.5	12.5
10-20	8.0	7.0	14.5
5-20	20.5	14.5	27.0

Table 4.—Effect on moisture absorption by hardboards of changes in particle size of wood waste

Change in particle size	Moisture absorption by boards with		
	5 percent resin	10 percent resin	20 percent resin
	Percent	Percent	Percent
Coarse to medium.	4.8	10.0	7.0
Medium to fine...	12.0	7.0	7.0
Coarse to fine...	7.2	8.0	14.0

Figure 1.--Flow sheet of steps in preparation of phenolic-resin-bound waste-wood board.

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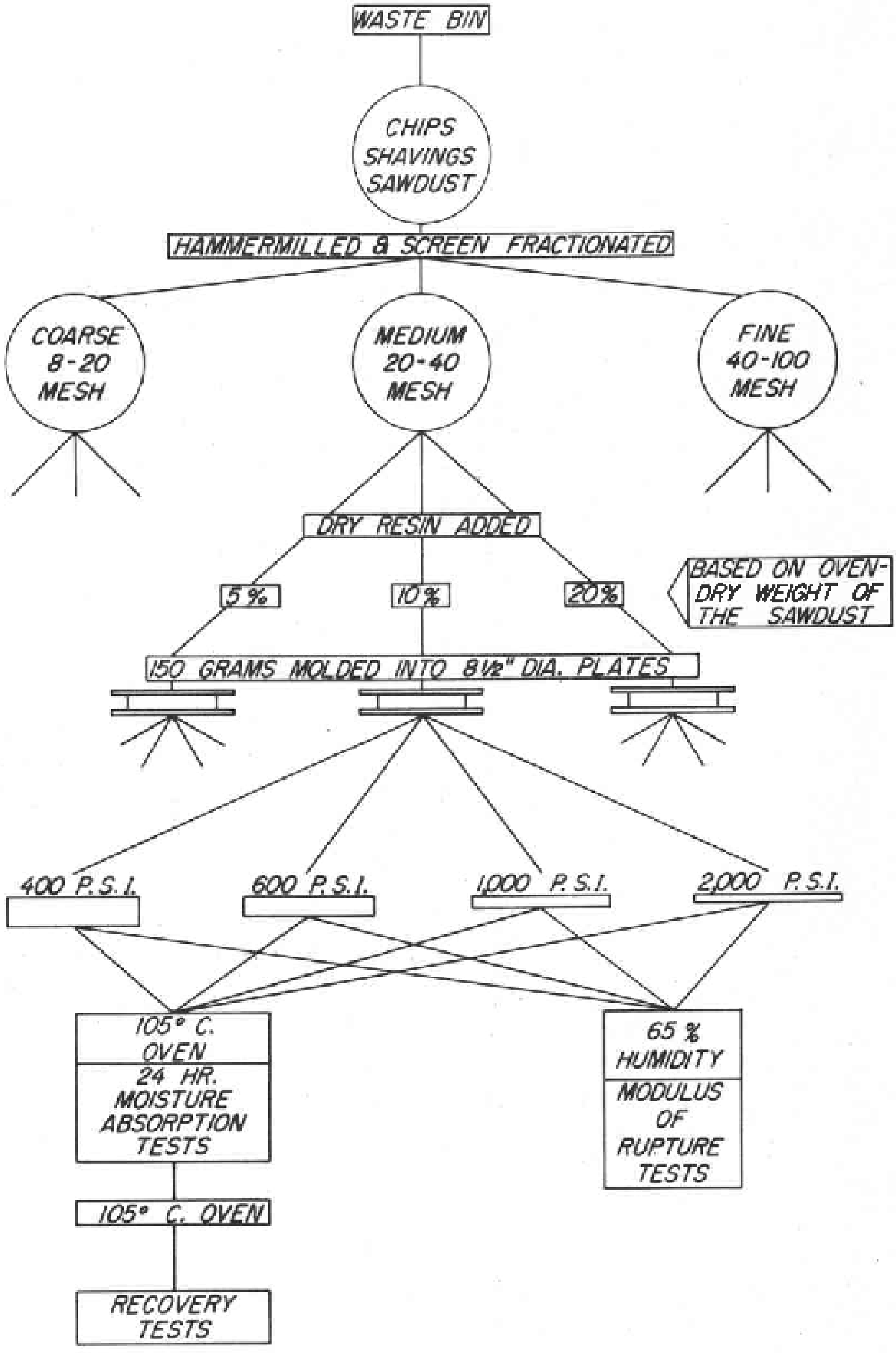
WASTE BIN
CHIPS SHAVINGS SAWDUST
HAMMERMILLED & SCREEN FRACTIONATED
COARSE 8-20 MESH
MEDIUM 20-40 MESH
FINE 40-100 MESH
DRY RESIN ADDED
BASED ON OVEN-DRY WEIGHT OF THE SAWDUST
5 %
10 %
20%
150 GRAMS MOLDED INTO 8½" DIA. PLATES
400 P.S.I.
600 P.S.I.
1,000 P.S.I.
2,000 P.S.I.
105° C. OVEN
24 HR. MOISTURE ABSORPTION TESTS
65 % HUMIDITY
MODULUS OF RUPTURE TESTS
105° C. OVEN
RECOVERY TESTS

Z M 83904 F

Figure 2.--Hardened tool-steel mold. A 150-gram sample of the coarse particle composition is shown before and after molding.

(ZM83519F)

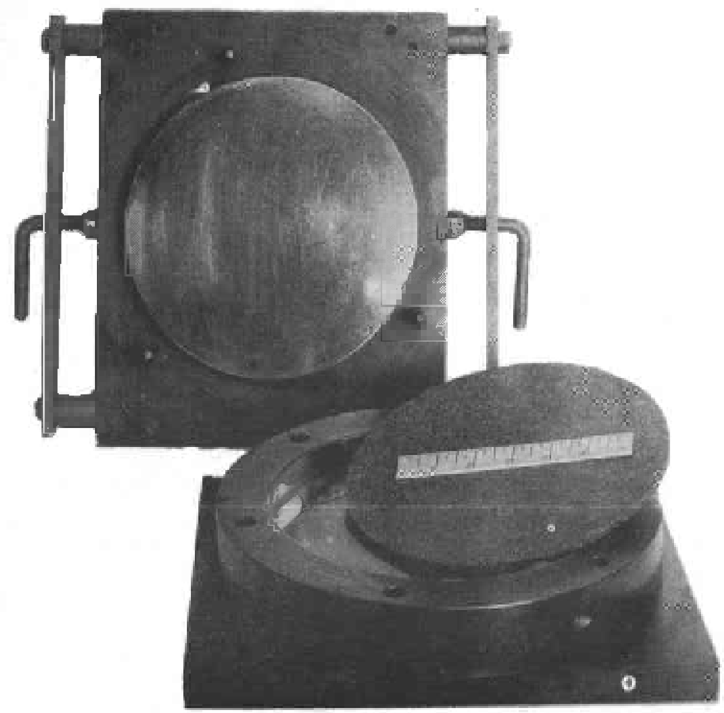

Figure 3.--Specific gravity versus molding pressure.

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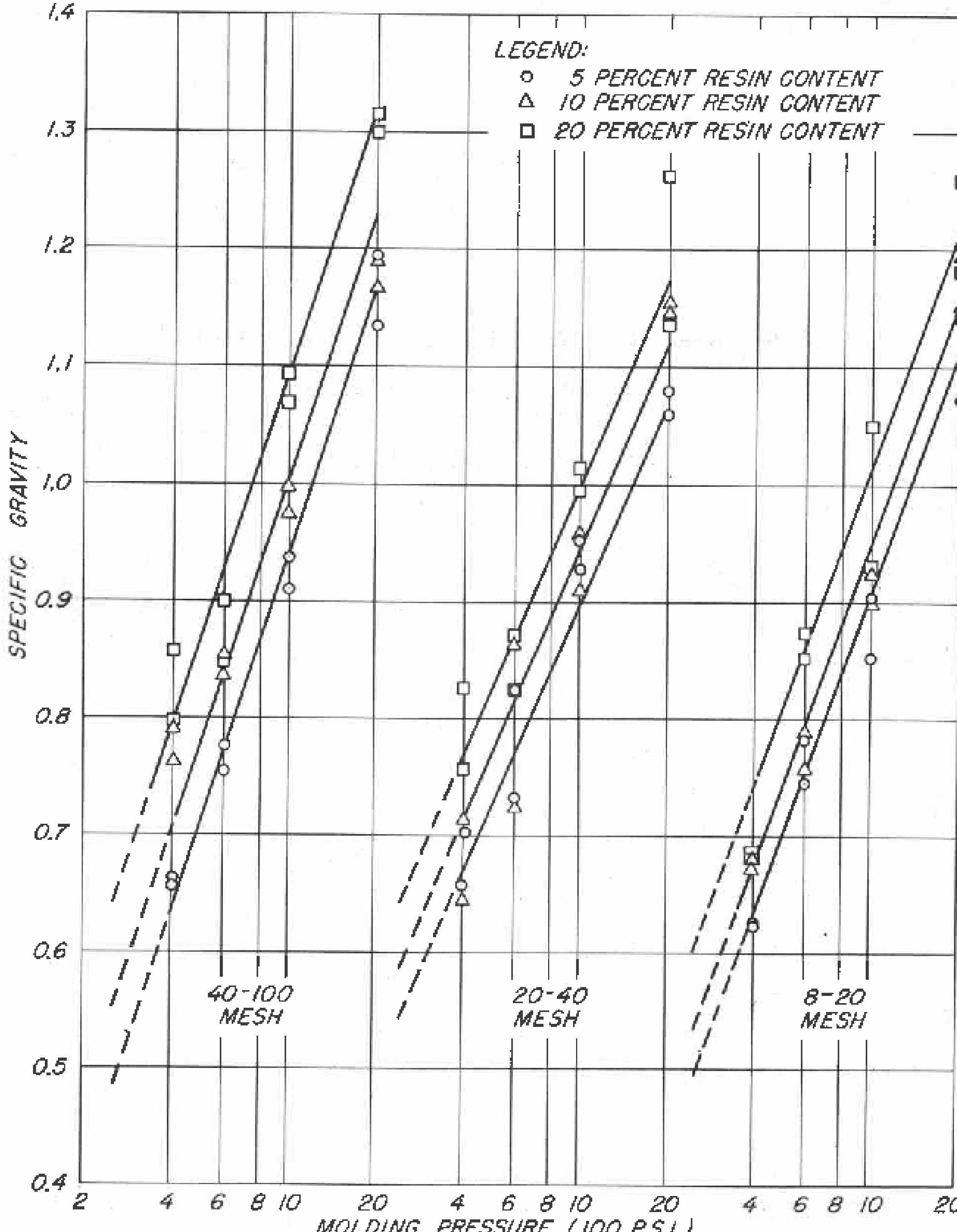

LEGEND:
○ 5 PERCENT RESIN CONTENT
△ 10 PERCENT RESIN CONTENT
□ 20 PERCENT RESIN CONTENT
SPECIFIC GRAVITY
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
40-100 MESH
20-40 MESH
8-20 MESH
2
4
6
8
10
20
MOLDING PRESSURE (100 P.S.I.)

Z M 84344 F

Figure 4.--Modulus of rupture of waste-wood hardboards as related to specific gravity.

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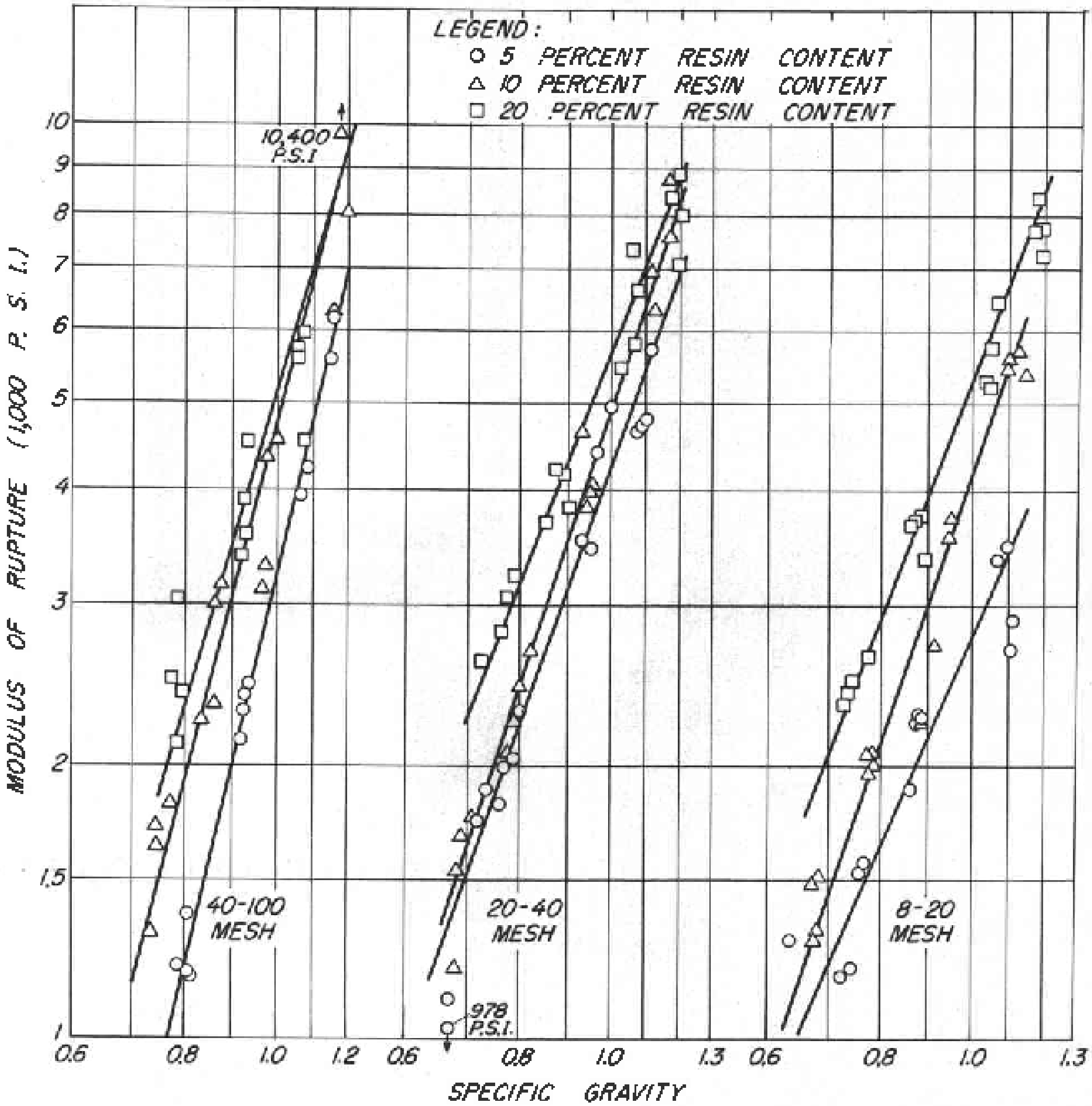
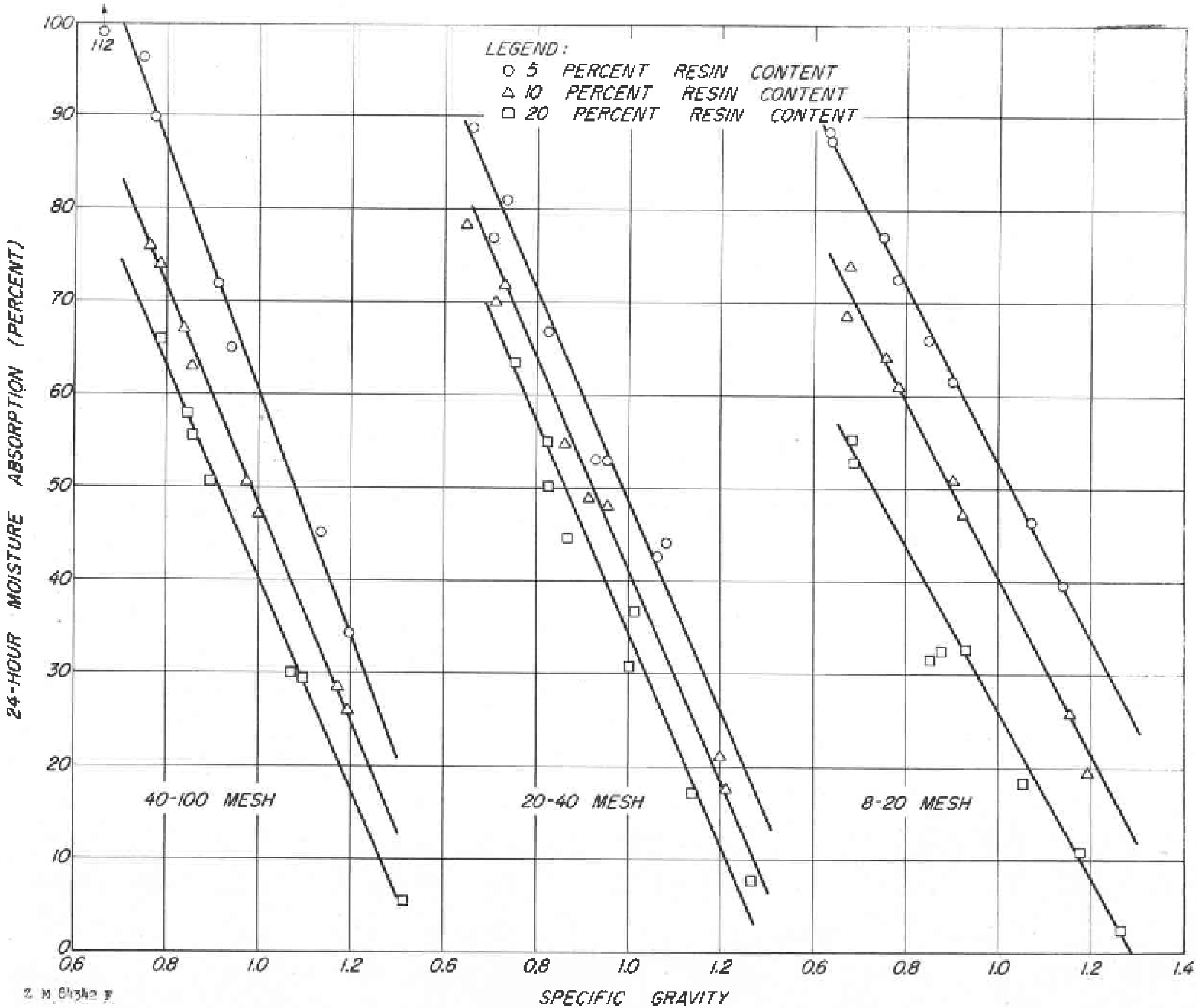

LEGEND:
○ 5 PERCENT RESIN CONTENT
△ 10 PERCENT RESIN CONTENT
□ 20 PERCENT RESIN CONTENT
10,400 P.S.I.
978 P.S.I.
40-100 MESH
20-40 MESH
8-20 MESH
MODULUS OF RUPTURE (1,000 P. S. I.)
SPECIFIC GRAVITY

Z M 84343 F

Figure 5.—Moisture absorption versus specific gravity.

(ZM84342F)


LEGEND:
○ 5 PERCENT RESIN CONTENT
△ 10 PERCENT RESIN CONTENT
□ 20 PERCENT RESIN CONTENT
24-HOUR MOISTURE ABSORPTION (PERCENT)
SPECIFIC GRAVITY
40-100 MESH
20-40 MESH
8-20 MESH
112

Z M 64342 F