1958

Investigation of some physical and mechanical properties of reconstituted wood particle boards of sandwich type when using different types of resin in core and faces

Joe Yao

The University of Montana

Recommended Citation

Yao, Joe, "Investigation of some physical and mechanical properties of reconstituted wood particle boards of sandwich type when using different types of resin in core and faces" (1958). *Graduate Student Theses, Dissertations, & Professional Papers*. 2752.
https://scholarworks.umt.edu/etd/2752

AN INVESTIGATION OF SOME PHYSICAL AND MECHANICAL PROPERTIES OF RECONSTITUTED WOOD PARTICLE BOARDS OF SANDWICH TYPE WHEN USING DIFFERENT TYPES OF RESIN IN CORE AND FACES

by

JOE YAO

B.S., Taiwan Provincial College of Agriculture, 1954

Presented in partial fulfillment of the requirements
for the degree of

Master of Science in Forestry

MONTANA STATE UNIVERSITY

1958

Approved by:

John P. Krier
Chairman, Board of Examiners

Ellis Waldron
Dean, Graduate School

MAY 29 1958
Date

8-25-58

ACKNOWLEDGEMENTS

The author wishes to express his heartfelt gratitude to Dr. John P. Krier for his valuable advice and his constant guidance throughout the entire work. The author is also grateful to Mr. George A. Schultz for reading the manuscript. Grateful thanks should also go to the Lumber Department of The Anaconda Company, at Bonner, Montana for their help in supplying the wood raw material for this research, and to the Adhesive, Resin & Chemical Division of American-Marietta Company for their contribution and supply of both gluing materials (resins) and information on particle board manufacturing.

TABLE OF CONTENTS

PAGE

LIST OF TABLES v

LIST OF FIGURES vi

INTRODUCTION 1

PREPARATION OF SAMPLE BOARDS 4

Wood Raw Materials 5

Type of Resins 5

Other Factors 6

Percentage of resin, 6
Moisture content of mat prior to press, 6
Pressures applied, 6

Processes and Board Making Procedures 7

Urea resin bonded particle boards, 7
Phenolic resin bonded particle boards, 8
Sandwich type particle boards, 8

PREPARATION FOR TESTING AND TESTING PROCEDURES . . . 11

Conditioning of Boards Prior to Tests 11

Method of Cutting Specimens 11

Testing Procedures for Static Bending 13

Conditioned specimens, 13
Soaked specimens, 14

Other Testing Procedures and Formulas Used 17

Specific gravity, 17
Moisture content, 18
Water absorption, 18
Thickness swelling, 19

CALCULATING AND ANALYSIS OF VARIANCE 20

PAGE

The Form of the Tables Designed to Represent the Data 20

Calculated Results of Boards at Time of Tests . . 20

Specific gravity, 20
Moisture content at time of tests, 20
Bending strength tests, 23

Calculated Results of Boards after Soaking 25

Water absorption, 26
Thickness swelling, 29
Reduction of bending strength after soaking, 32

RESULTS AND DISCUSSION 37

Comparison of water absorption, 38
Comparison of thickness swelling, 38
Comparison of the reduction of bending strength, 39

CONCLUSIONS 42

BIBLIOGRAPHY 47

APPENDIX 50

The Form of the Tables Designed to Represent the Data 50

Total Data Recorded and Calculated from the Urea-formaldehyde Resin Bonded Boards 53

Total Data Recorded and Calculated from the Phenol-urea Resin Bonded Boards 57

Total Data Recorded and Calculated from the Phenol-formaldehyde Resin Bonded Boards 61

LIST OF TABLES

TABLE PAGE

I. Comparison of water absorption and thickness swelling between paraffin edge coated and uncoated boards 16

II. Average specific gravity of boards for this study 21

III. Average moisture content of boards for this study 24

IV. Average water absorption of boards after soaking 27

V. The analysis of variance of the data in Table IV 28

VI. Average thickness swelling of boards after soaking 30

VII. The analysis of variance of the data in Table VI 31

VIII. Average reduction of bending strength of boards after soaking, represented by percent of its unsoaked bending strength . . . 34

IX. The analysis of variance of the data in Table VIII 35

X. Average values of the water absorption, the thickness swelling and the reduction of bending strength 40

LIST OF FIGURES

FIGURE PAGE

1. Cutting plan for test specimens 12
2. Comparison of water absorption 44
3. Comparison of thickness swelling 45
4. Comparison of the reduction of bending strength 46

INTRODUCTION

The fact that all types of wood particle boards and natural wood are subject to a certain amount of dimensional change due to a change in moisture content is well established. To compensate for this shortcoming, numerous experiments have been or are being conducted in order to find a way to increase the dimensional stability of wood particle boards. Generally, an increase in resin content, an elevation of curing pressures, and the addition of water repellents are the three most common methods of reducing the dimensional change of boards. Of course, these practices increase the cost of production. In addition to these three common methods, an increase in dimensional stability of wood particle board can possibly be attained by using different types of resins in face layers and the core. This latter is the approach that this thesis aims to establish.

For the face layers of a sandwich-type board, a waterproof resin (Phenol-formaldehyde) was used. For the core, a less expensive, water resistant (Urea-formaldehyde) resin was used. Since the cost of resin binder is a major item in producing wood particle board, usually 35 to 60 percent of the total manufacturing cost, any reduction in resin cost would constitute a considerable saving to the manufacturer.[1]

Thus, the purpose of this study was to try to increase the dimensional stability of a Urea-formaldehyde board by using a waterproof resin in the two face layers of the board. Presumably this would give the resultant product a much higher dimensional stability, but with a comparatively small increase in cost due to the low cost of Urea-formaldehyde resin (about half the price of Phenol-formaldehyde resin at the present time) used in the core layer. The reason this stability was expected was due to the fact that the faces of a board play the most important role in making the board water resistant. Therefore, a more water resistant face, not only should increase the dimensional stability of itself, but should also retard the contact of water with the core layer.

To illustrate this principle, let us assume a piece of sponge enclosed in a tightly covered glass bottle; no matter how strongly the sponge might tend to absorb moisture, it would not get a chance to be in contact with the outside moisture. This is because of the protecting and isolating function of the bottle.

Of course, this analogy of a sponge and a bottle cannot be rigidly applied to a wood particle board since

---

[1] E. S. Johnson (ed.), Wood Particle Board Handbook (North Carolina: The Industrial Experimental Program, 1956), p. 52.

the waterproof resin faces do not make the board completely water proof (except with excessive amounts of resin). In addition, the edges of the board are usually unprotected because sawing will expose the core to the atmosphere and moisture.

PREPARATION OF SAMPLE BOARDS

Three batches of sample boards were made under approximately the same conditions. These conditions were resin content, moisture content of mat prior to hot pressing, and pressure. There were differences in temperature and pressing cycles depending on the necessary curing temperature required by the different types of resins and the adjustment of pressing cycles which were necessary in order to produce boards of the same density under different curing temperatures.

These three different batches of boards were as follows: (1) boards using 6% Urea-formaldehyde resin as a binder throughout; (2) boards using 6% Phenol-formaldehyde resin as a binder throughout; and (3) boards using 6% Phenol-formaldehyde resin as a binder in the face layers and 6% Urea-formaldehyde resin in the core. The total thickness of the two faces of the sandwich type board was equal to the thickness of core. Ten boards were made of each type so that they could be statistically compared.

The first letter of each type of board is capitalized throughout this paper to represent those made for this study. For example, the term "Urea resin bonded board" means the urea resin bonded board specific to this study. Otherwise, the term "urea resin bonded board" used in the paper is just a common name or term for this general type of board. This distinction is also valid for the Phenol-urea resin and Phenolic resin bonded boards.

Wood Raw Materials

Splinter type particles were obtained from The Anaconda Co., Lumber Dept., at Bonner, Montana. They were a mixture of Douglas fir, western larch, and ponderosa pine, (the "fines" residue from their chip screening operation), with a small percent of bark. The particle size was coarse, ranging from 4 to 8 mesh. These particles were dried to 5.6 percent moisture content before they were sprayed with the resins.

Type of Resins

Phenol-formaldehyde and Urea-formaldehyde resins are the two resins most commonly used as binders for wood composition boards. These are usually supplied to the industry in liquid form, however, powdered resins are available and they are sometimes used instead. The amount of resin required is dependent upon the type of board, the manufacturing process, and the intended use of the board.

The resins used in this study were AMRES 6120A Phenol-formaldehyde and AMRES 7500 Urea-formaldehyde. Both of them were in a liquid form but contained differing solids content (44.8% solids for AMRES 6120A and 66.8% solids for AMRES 7500). The curing temperatures were applied in accordance to the suggestions of the manufacturer, the American-Marietta Company.[2]

Other Factors

Percentage of resin. The recommended resin content for particle board advised by the Adhesive, Resin & Chemical Division of American-Marietta Company is 3% to 6% for both urea and phenolic resins. In order to get better comparative results between different types of boards, the highest percent, 6%, was used for all boards in this study.

Moisture content of mat prior to press. The boards for this research were made by the dry process, which means that the moisture content of the mat prior to press was less than 15 per cent.[3] The actual moisture content of the mats in this study was 12%, which again followed the suggestion of American-Marietta Company.[4]

Pressures applied. All boards in this project were consolidated under the same initial squeeze of 500 psi and a subsequent holding pressure of 200 psi. Though the total

---

[2] General Information on Particle Board Manufacturing Testing & Bibliography (Washington: American-Marietta Company, 1955), p. 1.

[3] Wood Composition Boards (Oregon: Pacific Power & Light Company, 1955), p. 20.

[4] General Information on Particle Board Manufacturing Testing & Bibliography (Washington: American-Marietta Company, 1955), p. 1.

time under pressure was the same, the different types varied in the time period for each of the two stages--the squeeze and holding stages. When higher temperatures are applied to boards during hot pressing, higher densities are produced. Therefore, in this study, an adjustment in pressing cycle was necessary to produce boards of three different groups having the same density.

Processes and Board Making Procedures

All boards were pressed in a single-opening hydraulic hot press. The boards were all 1/4" by 8" by 10" in dimension and about 0.85 in specific gravity. Procedures of board making were necessarily varied somewhat among the three groups.

Urea resin bonded particle boards. Splinter type particles were screened to 4 to 8 mesh and dried to 5.6% moisture content. Then, in a drum type mixer with a speed of approximately 20 rotations per minute, the particles were evenly coated with liquid Urea-formaldehyde resin by spraying. A quantity of liquid resin, weighing 6% resin solids by oven dry wood particle weight, was mixed with 6.4% of additional water to make a mat having 12% moisture content by oven dry wood particle weight.

The mat was formed by hand. Before hot pressing a pre-press with a forming frame was applied. This practice was applied to partially form the board and to reduce its thickness before curing. The pressure used for pre-pressing was 200 psi and it was maintained for 30 seconds without heat. The process following the pre-pressing was hot pressing. All the boards of this category were consolidated under a 2-minute initial squeeze at 500 psi followed by a holding period of 8 minutes at 200 psi. The platen temperature was 285°F.

<u>Phenolic resin bonded particle boards</u>. Most parts of the procedure in this category were as same as that of the Urea resin bonded particle boards except that the temperature and pressing cycle were changed. The new platen temperature was 320°F and the new pressing cycle was: (1) 30-second initial squeeze at 500 psi; (2) 20-second breathing period, free from pressure ; and (3) 9-minute 30-second holding pressure at 200 psi. Since a higher temperature was applied to the mat, the breathing period for moisture escape was found necessary to avoid blistering. Also, the shorter initial squeezing time was necessary to avoid producing a higher density board than desired.

<u>Sandwich type particle boards</u>. Usually so-called sandwich type particle boards are boards made from different sizes or species of particles in different layers. But here, different from the others, the sandwich type particle boards were made of the same size and species in the face layers as in the core. The reason that these are here called sandwich type boards is that different resins have been used in the face layers and in the core.

In making boards of this type, urea resin coated particles and phenolic resin coated particles were prepared separately. The mixing of the resins and the mechanics of spraying were the same as in the other two batches.

Before mat forming, equal weights of urea resin coated particles and phenolic resin coated particles, on a pure wood particle weight basis, were weighed. Because of the lower solids percent in the phenolic resin in its liquid form, the actual weight of phenolic resin coated particles was a little higher than that of the urea resin coated particles. When forming the mat, half the quantity of phenolic resin coated particles was placed on the caul to make a bottom layer. Next, all the urea resin coated particles were placed on top of the bottom layer. Then on top of the core layer, the remaining half part of phenolic resin coated particles was placed. After the mat forming was completed, a pre-pressing at 200 psi was used before hot pressing. For this sandwich type board the platen temperature was 320°F and the pressing cycle was: (1) 40-second initial squeeze at 500 psi; (2) 20-second breathing period free from pressure; and (3) 9-minute 20-second holding pressure at 200 psi.

The reason for using a longer initial squeeze for this type of board than for the Phenolic resin bonded board was that the lower moisture content in the urea resin coated particles of the core layer made the total moisture content of the mat of this type lower than that of the phenol type. It was found from an exploratory experiment that the density of Phenolic resin bonded board was higher than the sandwich board when the same time of initial squeeze was applied. This result was interpreted to mean that the higher moisture content of the mat of Phenolic resin bonded board increased its compressibility during the hot pressing.

The total thickness of the two face layers of this type of board was equal to the thickness of core. The total thickness of the board = face layer + core + face layer = 1/16"+2/16"+1/16" = 1/4".

The temperature applied to boards of this category should be elaborated. The same 320°F temperature as was used in making Phenolic resin bonded particle board was used rather than that which was used in the Urea resin bonded particle board. This was dictated because of the higher curing temperature needed for phenolic resin.

PREPARATION FOR TESTING AND TESTING PROCEDURES

All of the boards were tested for the values of moisture content, specific gravity, bending strength (represented by modulus of rupture), water absorption and thickness swelling. Before the actual testing, all boards were conditioned to constant weight and moisture content, then cut to test-specimen size.

Conditioning of Boards Prior to Tests

According to ASTM Designation: D 1037 - 56 T all boards were conditioned to constant weight and moisture content in a conditioning chamber maintained at a relative humidity of 65±1 percent and a temperature of 68±6°F.[5]

Method of Cutting Specimens

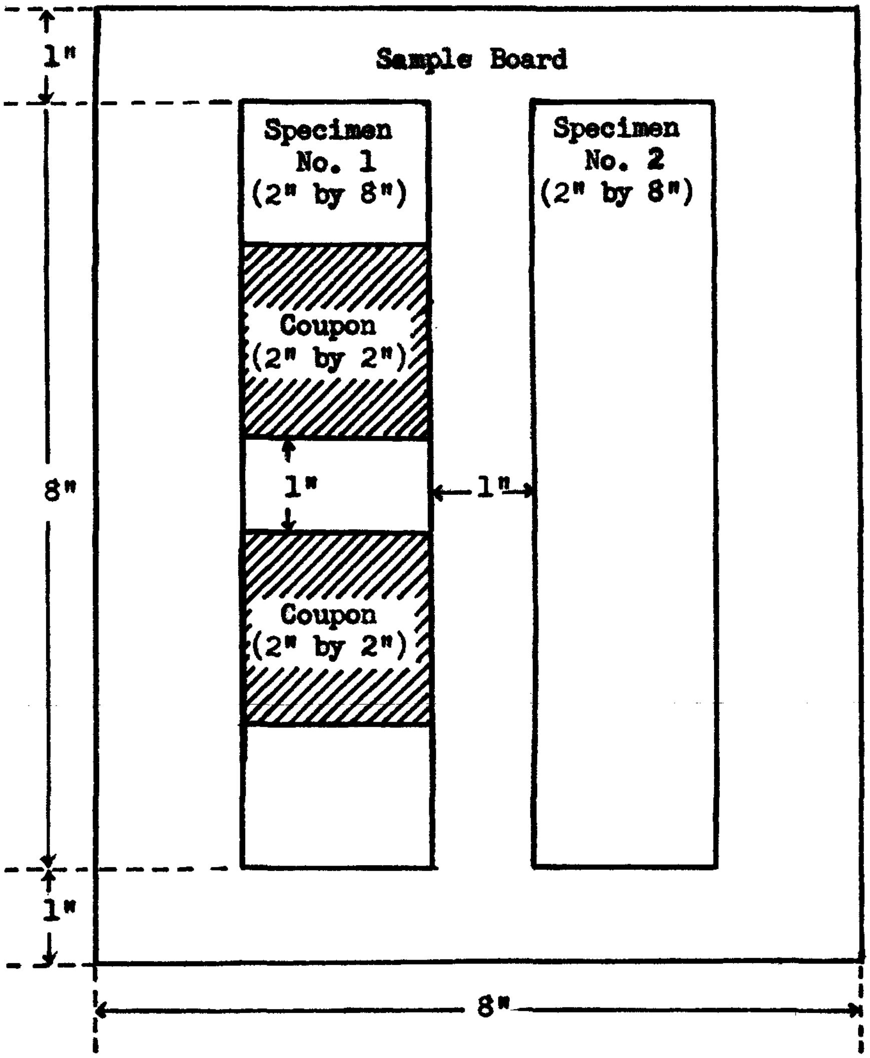
The cutting method for testing specimens from each 1/4" by 8" by 10" board is shown in Figure 1. As shown, two specimens were cut from each of the sample boards for the modulus of rupture (M.O.R.) test. Specimens for the M.O.R. test were 1/4" by 2" by 8".

One of these two was prepared for testing of M.O.R. under normal condition, and from this specimen two coupons

---

[5] Tentative Methods of Test for EVALUATING THE PROPERTIES OF BUILDING FIBERBOARDS (Philadelphia: American Society for Testing Material, 1956), p. 123.

FIGURE 1. CUTTING PLAN FOR TEST SPECIMENS AND COUPONS



of 2" by 2" dimension were cut following the M.O.R. test, for further study of specific gravity and moisture content of board at test.

The other specimen was prepared for the tests of water absorption, thickness swelling and the reduction of M.O.R. after soaking. No coupons were cut from this specimen.

Testing Procedures for Static Bending
(M.O.R. test)

Conditioned specimens. The M.O.R. tests were performed in accordance with the ASTM Designation: D 1037 - 56 T. Each test specimen was 2" in width and 8" in length.[6] The span for each test was 24 times the nominal thickness, in other words, 1/4" x 24 = 6", for our boards.[7]

The supports were rounded to a radius of 1 1/2 times the thickness (1/4"x1.5) of the material being tested, which is equal to 0.375".[8] The load was applied continuously throughout the test at a uniform rate of motion of the movable cross head of the testing machine of 0.1" per minute. The measurements of thickness were read to the

---

[6] Tentative Methods of Test for EVALUATING THE PROPERTIES OF BUILDING FIBERBOARDS (Philadelphia: American Society for Testing Material, 1956), p. 125.

[7] Ibid., p. 125.

[8] Ibid., p. 125.

nearest 0.001", and loads to the nearest one pound.

The formula used for calculating the M.O.R. was:

$$R = \frac{3PL}{2bd^2}$$

where:

R = modulus of rupture, psi.

P = maximum load, lbs.

L = length of span, in.

b = width of specimen, in.

d = thickness (depth) of specimen, in.

Soaked specimens. The edges of specimens will absorb more water than the faces, and this will vary the percentage of water absorption appreciably according to size. For example, a smaller size specimen has a higher percentage of edge surface, so more water per unit volume will be absorbed and more swelling will result. All boards prepared for testing under soaked condition were edge sealed with a paraffin which had a melting range of 140° to 143.6°F (60° to 62°C). The reason for using a paraffin with this melting range was that it would not be melted at the soaking temperature. The sealing of edges in this test was done to increase the comparison values of properties of boards after soaking.

As a matter of fact, this practice did not make the edges of specimens fully waterproof, since openings occured after swelling. However, as an exploratory experiment shows (Table I), this practice did show effective results.

In accordance with ASTM Designation: D 1037-56T, the specimens to be tested in the soaked condition should be submerged in water at 68±2°F for 24 hrs. before the test.[9] In order to amplify results, the temperature used in this study was higher than standard. After the edges of the specimens were sealed with paraffin, they were submerged in water at 113°F for 24 hr. Since data was to be comparative, it was deemed that this departure from standards would not reduce the effectiveness of this study. Upon removal from the water, specimens were set on edge and allowed to drain for 10 minutes before measuring their thickness, width, length and weight.

The methods of applying the load, such as head speed and length of span, were the same as those mentioned in the section, Conditioned specimens. According to the standards the head speed and length of span should have been adjusted according to the increased thickness. However, here the M.O.R. of soaked specimens was so much lower than that of conditioned specimens that the slightly higher value for M.O.R. (than standard), gained due to the using of same length of span (6"), and the same speed of head applied (0.1" per minute), was far below the point which could

---

[9] Tentative Methods of Test for EVALUATING THE PROPERTIES OF BUILDING FIBERBOARDS (Philadelphia: American Society for Testing Material, 1956), p. 137.

TABLE I

COMPARISON OF WATER ABSORPTION AND THICKNESS SWELLING BETWEEN PARAFFIN EDGE-COATED AND UNCOATED BOARDS (in per cent)

Item	Edge treatment	Type of Board		
		Urea	Phenol-urea	Phenol
Water Absorption %	Coated	112.0	96.5	65.0
	Uncoated	161.0	100.0	73.2
Thickness Swelling %	Coated	83.1	63.8	56.1
	Uncoated	90.9	77.0	67.2

possibly influence the accuracy of the compared results.

Other Testing Procedures and Formulas Used

Specific gravity. As discussed before, two 2" by 2" coupons were cut from each broken specimen after M.O.R. test. These were weighed and their thickness, width and length were measured. They were then oven-dried at 103±2°C for 24 hr.[10]

After taking them out from the electric-heated oven, the dry weights were recorded again. The dimensions were not measured after drying since the specific gravity values were calculated on the basis of oven-dry weight and volume at test.[11]

The formula used in calculating specific gravity was:

$$\text{Sp.gr} = \frac{Kw2}{Lbt}$$

where:

Sp.gr = specific gravity

K = 0.061, when metric units of weight and English units of measurement are used.

w2 = final weight when oven dry, grams.

---

[10] Tentative Methods of Test for EVALUATING THE PROPERTIES OF BUILDING FIBERBOARDS (Philadelphia: American Society for Testing Material, 1956), p. 141.

[11] Ibid., p. 141.

L = length of coupon, in.

b = width of coupon, in.

t = thickness of coupon, in.

Moisture content. The moisture content at time of test was calculated from the initial and oven-dry weights of each coupon. These weights were collected from the same coupons which were used for specific gravity testing.

The formula used in calculating moisture content was:

$$M = 100 \left(\frac{w1 - w2}{w2}\right)$$

where:

M = moisture content, in percent.

w1 = weight at time of test, grams.

w2 = final weight when oven-dry, grams.

Water absorption. From the conditioned and soaked weights that were recorded from the same specimens used for M.O.R. test in soaked condition, the water absorptions were calculated.

The formula used for water absorption was:

$$W.A. = 100 \left(\frac{W2 - W1}{W1}\right)$$

where:

W.A. = water absorption, in percent.

W1 = conditioned weight, grams.

W2 = weight after soaking, grams.

Thickness swelling. From the conditioned and the soaked thicknesses which also were recorded from the same specimens used for M.O.R. tests in soaked condition, the thickness swelling was calculated.

The formula used for thickness swelling was:

$$T.S. = 100\left(\frac{T2 - T1}{T1}\right)$$

where:

T.S. = thickness swelling, in percent.

T1 = conditioned thickness, in.

T2 = thickness after soaking, in.

CALCULATION AND ANALYSIS OF VARIANCE

The Form of the Tables Designed to Represent the Data

In order to contain all the data on a single sheet, the tables for recording of data and calculating of results were specially designed. They were arranged according to the order of testing and calculating procedures. In these tables, the data from this study are included in their entirety. These tables are included in the Appendix so as to be available for interested readers.

Calculated Results of Boards at Time of Tests

Specific gravity. As shown in Table II, the average specific gravity was 0.85 for Urea resin bonded boards, 0.84 for Phenol-urea resin bonded boards and 0.86 for Phenolic resin bonded boards. As all boards were made under control with the desire to produce an equal density in the three batches, the differences in density which occurred here were caused by chance or unavoidable experimental error. However, the differences were not statistically significant and they will not influence the results of comparison in dimensional stability.

Moisture content at time of tests. The equilibrium moisture content (E.M.C.) will be affected by many factors, among them, the type and amount of resin, curing

TABLE II

AVERAGE SPECIFIC GRAVITY OF BOARDS MADE FOR THIS STUDY

Sample Board No.	Type of Board		
	Urea	Phenol-urea	Phenol
1	0.87	0.82	0.85
2	0.85	0.83	0.89
3	0.86	0.84	0.84
4	0.85	0.83	0.87
5	0.88	0.86	0.85
6	0.84	0.84	0.86
7	0.87	0.84	0.84
8	0.86	0.84	0.85
9	0.82	0.83	0.84
10	0.82	0.84	0.87
Sum = Σ	8.52	8.37	8.56
Mean = $\bar{\bar{X}}$	0.85	0.84	0.86
Standard Deviation	0.021	0.010	0.016

temperature, pressure, and pressing cycle are considered most important. According to a laboratory survey the average E.M.C.'s found in this country are 12-13% in natural wood, 5-8% in Hardboard and 8-9% in Particle board.[12]

The reason for the lower E.M.C. represented by wood particle board when compared to natural wood is probably that (1) the average higher density decreased the space which otherwise would absorb the free water (this may only be true when comparing it with natural wood), (2) the cured resin binders partially sealed the openings of tracheids and filled voids between individual particles. Actually there are many factors involved which will influence the E.M.C. values of a wood particle board, and there is no way at the present time to estimate or predict the exact E.M.C. value. This can be accurately determined only by testing methods.

Generally, for boards conditioned in the same conditioning chamber for a definite length of time, less than equilibrium time, it will be found that a urea resin bonded board will contain a higher moisture content than a phenolic resin bonded board. This is due to the lower curing temperature used for urea resin, which leaves more moisture in a board just coming out of the press. In accordance

---

[12] E. S. Johnson (ed.), <u>Wood Particle Board Handbook</u> (North Carolina: The Industrial Experimental Program, 1956), p. 223.

with this, the average moisture content of Urea resin bonded boards (Table III) was 7.0%, higher than the other two types. However, it is not quite understood why the average moisture content of Phenol-urea resin bonded boards (6.4%) was higher than that of the Phenolic resin bonded boards (5.9%) since they were consolidated under the same curing temperature, and especially since the initial moisture content of the mat of Phenolic resin bonded board was higher. Perhaps this was caused by the early breathing in making Phenolic resin bonded board (after 30 sec. initial squeeze vs. after 40 sec. for Phenol-urea resin bonded boards) which increased the quantity of moisture (steam) that escaped during the period of breathing, or else the more completely cured resin, due to longer initial squeeze, retarded the escape of moisture (steam) from the Phenol-urea resin bonded board. This conclusion cannot be arbitrarily established without further study, since other factors such as the different types of resins used, etc., may be involved in causing such a result.

<u>Bending strength tests</u>. The bending strength of particle board is affected by a good many factors, such as species of wood used, type and size of particles, amount of resin binders, moisture content of mat, density of board. Among all these, density and resin amount are considered to be the most important two. Here in this study, the bending strengths are represented by M.O.R. values.

TABLE III

AVERAGE MOISTURE CONTENT OF BOARDS MADE FOR THIS STUDY (in per cent)

Sample Board No.	Type of Board		
	Urea %	Phenol-urea %	Phenol %
1	7.3	5.6	5.8
2	7.0	6.2	6.1
3	6.8	6.4	5.9
4	6.3	6.4	5.9
5	6.6	6.0	6.2
6	6.8	6.7	5.9
7	7.1	6.7	5.5
8	7.1	6.7	6.0
9	7.4	6.6	5.9
10	7.4	6.7	6.1
Sum = Σ	69.8	64.3	59.3
Mean = $\bar{X}$	7.0	6.4	5.9
Standard Deviation	0.36	0.31	0.20

From the first table in the Appendix it can be seen that the average M.O.R. of Urea resin bonded boards was 3,742 psi, which was higher than either of the other two types. The cause of this greater M.O.R. is understandable since a lower curing temperature was used and there was no breathing period. Since the absence of a breathing period under a lower curing temperature allows moisture to remain in the board for a longer time, a better flowing of resin binder will result. Then, naturally, a better bonding and higher strength will be produced.

The matter of why the average M.O.R. of Phenol-urea resin bonded boards was (3,151 psi, see the second table in the Appendix) lower than Phenolic resin bonded boards (3,341 psi, see the third table in the Appendix) should be deduced from the fact that the high curing temperature used in pressing Phenolic-urea resin boards (320°F) produced excessive resin cure in the urea resin bonded core layer (actually only 285°F required). The producing of brittle and flaky resin is a general result of excessive curing temperature.

Calculated Results of Boards After Soaking

Beginning from this part of the discussion the real objects of this study are presented, therefore more details will be given in this part. An analysis of variance was employed to analyze the data to obtain the maximum information therefrom.

Water absorption. Reference to Table IV will show that the average water absorption of Urea resin bonded boards was 89.7%, higher than that Phenol-urea resin bonded boards (82.8%), and that the water absorption of Phenol-urea resin bonded boards was higher than Phenolic resin bonded boards (79.6%). These results were coincident with original, assumption.

From the data in Table V, analysis shows that the variance due to differences in treatments is sufficiently greater than that due to error to make a highly significant ($P = 0.01$ or 1%) contribution to the total variance. This means that there is less than a 1% chance that differences between treatments as great or greater than those shown could arise due to chance sampling.

The analysis of variance by F -value can only test the general significance of differences among groups. A supplementary test of significance must be applied in the form of a t-test. The equation used for this test was:

$$t = \frac{\bar{X}1 - \bar{X}2}{\sqrt{\text{Error M.S. } (1/n1+1/n2)}}$$

where:

Error M.S. = error variance or error mean square

$\bar{X}1$ and $\bar{X}2$ = the means of any two groups.

n1 and n2 = the number of items in each group being tested.

TABLE IV

AVERAGE WATER ABSORPTION OF BOARDS AFTER SOAKING
(in per cent)

Sample Board No.	Type of Board		
	Urea %	Phenol-urea %	Phenol %
1	90.1	83.7	86.9
2	92.7	80.4	76.2
3	88.4	80.2	83.3
4	87.9	80.2	74.4
5	87.8	81.2	83.9
6	92.5	83.4	81.7
7	90.3	87.3	78.9
8	85.2	82.9	79.5
9	87.7	84.4	78.1
10	94.8	84.3	72.6
Sum = Σ	897.4	828.0	795.5
Mean = $\bar{X}$	89.7	82.8	79.6
Standard Deviation	2.91	2.31	3.17

TABLE V

THE ANALYSIS OF VARIANCE OF THE DATA IN TABLE IV
(DATA OF WATER ABSORPTION)

Source of Variation	Sum of Squares	Degrees of Freedom	Variance	Sample F	F.05	F.01
Total	756.29	29				
Between Samples	541.88	2	270.94	34.1	3.35	5.49
Within Samples (Error)	214.41	27	7.94			

Thus, for our data (see Tables IV and V):

A. Test of significance of difference between Urea resin and Phenol-urea resin bonded boards:

$$t = \frac{89.7 - 82.8}{\sqrt{7.94\ (1/10+1/10)}} = \frac{6.9}{1.26} = 5.47$$

B. Test of significance of difference between Phenol-urea resin and Phenolic resin bonded boards:

$$t = \frac{82.8 - 79.6}{1.26} = 2.54$$

From the t-table, for 27 degrees of freedom (number of d.f. used to estimate the standard error term), a t-value equal to 2.77 at P = 0.01 and 2.47 at P = 0.02 is found. It can thus be seen that the difference in water absorption between Urea resin bonded board and Phenol-urea resin bonded board is definitely significant (above the P = 0.01 level). But the difference between Phenol-urea resin and Phenolic resin bonded boards is slightly lower than that above (between P = 0.02 and P = 0.01).

<u>Thickness swelling</u>. As Table VI shows, the average thickness swellings were 73.3% for Urea resin bonded board, 65.5% for Phenol-urea resin bonded board, and 61.8% for Phenolic resin bonded board. From Table VII, the F-value of 36.11 gained from our variance ratio test was much greater than the F-value found in the F-table, which is F = 5.49 at the level of P = 0.01 when a variance with 2

TABLE VI

AVERAGE THICKNESS SWELLING OF BOARDS AFTER SOAKING
(in per cent)

Sample Board No.	Type of Board		
	Urea %	Phenol-urea %	Phenol %
1	74.0	66.1	69.2
2	72.8	64.6	60.5
3	71.8	64.7	66.5
4	75.6	63.2	56.2
5	73.0	66.4	61.3
6	70.9	66.0	54.5
7	74.5	66.4	64.3
8	73.8	65.8	66.4
9	74.0	64.2	60.8
10	72.7	67.2	58.7
Sum = Σ	733.1	654.6	618.4
Mean = $\bar{X}$	73.3	65.5	61.8
Standard Deviation	1.32	1.23	4.70

TABLE VII

THE ANALYSIS OF VARIANCE OF THE DATA IN TABLE VI (DATA OF THICKNESS SWELLING)

Source of Variation	Sum of Squares	Degrees of Freedom	Variance	Sample F	F.05	F.01
Total	914.79	29				
Between Samples	665.95	2	332.95	36.11	3.35	5.49
Within Samples (Error)	248.90	27	9.22			

degrees of freedom is tested against an error variance having 27 degrees of freedom. So again, it is proved that the variance which is due to differences in treatments is sufficiently greater than that due to error that it makes a highly significant contribution to the total variance.

To discover if each treatment is significantly different from the others, a t-test the same as that used in the section Water absorption was used. Thus, for our data (see Tables VI and VII):

A. Test of significance of difference between Urea resin and Phenol-urea resin bonded boards:

$$t = \frac{73.3 - 65.5}{\sqrt{9.22\ (1/10+1/10)}} = \frac{7.8}{1.36} = 5.74$$

B. Test of significance of difference between Phenol-urea resin and Phenolic resin bonded boards:

$$t = \frac{65.5 - 61.8}{1.36} = 2.\ 72$$

From the t-table, for 27 degrees of freedom, a value equal to 2.47 at P = 0.02 and 2.77 at P = 0.01 was obtained. Therefore, the difference between Urea resin and Phenol-urea resin bonded boards is definitely significant (above P = 0.01 level). The difference between Phenol-urea resin and Phenolic resin bonded boards is above the P = 0.02 and slightly below P = 0.01 level.

Reduction of bending strength after soaking. Table

VIII shows that the average M.O.R. after soaking was 12.6% (percent of unsoaked bending strength) for Urea resin bonded boards, 16.6% for Phenol-urea resin bonded boards, and 16.2% for Phenolic resin bonded boards. Table IX shows that the variance due to differences in treatments is sufficiently greater than that due to error to make a highly significant (P = 0.01) contribution to the total variance. Further tests were:

A. Test of significance of difference between Urea resin and Phenol-urea resin bonded boards:

$$t = \frac{12.6 - 16.6}{\sqrt{4.81\ (1/10+1/10)}} = \frac{4.0}{0.97} = 4.12$$

B. Test of significance of difference between Phenol-urea resin and Phenolic resin bonded boards:

$$t = \frac{16.6 - 16.2}{0.97} = 0.41$$

C. Test of significance of difference between Urea resin and Phenolic resin bonded boards:

$$t = \frac{12.6 - 16.2}{0.97} = 3.71$$

From t-values calculated above, it is very clear that the differences in reduction of M.O.R. between Urea resin bonded board and Phenol-urea resin bonded and between Urea and Phenolic resin bonded board were definitely significant. The difference between Phenol-urea and Phenolic

TABLE VIII

AVERAGE REDUCTION OF BENDING STRENGTH OF BOARDS AFTER SOAKING, REPRESENTED BY PERCENT OF ITS UNSOAKED BENDING STRENGTH
(in per cent)

Sample Board No.	Type of Board		
	Urea %	Phenol-urea %	Phenol %
1	12.7	17.9	12.6
2	12.3	13.5	15.1
3	13.3	19.7	14.7
4	12.8	16.3	20.3
5	14.8	15.1	15.4
6	14.1	16.7	20.6
7	12.1	16.8	20.3
8	11.8	19.0	13.7
9	11.4	17.3	14.9
10	10.9	14.1	14.4
Sum = Σ	126.2	166.4	162.0
Mean = $\bar{X}$	12.6	16.6	16.2
Standard Deviation	1.22	1.99	3.00

TABLE IX

THE ANALYSIS OF VARIANCE OF THE DATA IN TABLE VIII (DATA OF THE REDUCTION OF BENDING STRENGTH)

Source of Variation	Sum of Squares	Degrees of Freedom	Variance	Sample F	F.05	F.01
Total	227.17	29				
Between Samples	97.23	2	48.61	10.1	3.35	5.49
Within Samples (Error)	129.94	27	4.81			

resin bonded boards was not significant (below P = 0.50 level).

RESULTS AND DISCUSSION

It is commonly known that in similar boards soaked in water under the same conditions (such as temperature, time, etc), a board with a higher original moisture content before soaking will absorb a lesser percentage of water and consequently have a smaller percentage of thickness swelling. Thus, the water absorption and thickness swelling of Urea resin bonded board should have been less than Phenol-urea resin bonded board, and also the Phenol-urea resin bonded board should have been less than the Phenolic resin bonded board, since their original moisture contents were 7.0%, 6.4%, and 5.9% respectively.

However, the results show that these were just the opposite of this general rule when compared on the basis of their original moisture contents. This means these results were almost entirely ruled by the different treatments (different types of resins and construction of boards). Fortunately, this phenomenon served to justify confidence in comparing our results without further consideration of small differences in original moisture contents. An increase in pressing temperature may increase the dimensional stability of a board, but this was not shown to be the case in this study though different temperatures were used. As R. G. Frashour and G. D. Nixon have concluded in their paper:

> An increase in pressing temperature increased water resistance in the control boards (without addition of either resin or wax) and in boards containing resin and wax. There was no significant decrease in water absorption when resin alone was added.[13]

Thus, the increase in temperature when resin alone was added, as is the case here, should not be expected to significantly alter the results.

Comparison of water absorption. It was quite evident from results (Table X), that the water absorption of Urea resin bonded board was much greater than the other two types of boards. The difference between Urea resin and Phenol-urea resin bonded boards was 6.9% (89.7 - 82.8%) and between Phenol-urea resin and Phenolic resin bonded boards was 3.2% (82.8 - 79.6%). In other words, the difference in water absorption between Urea resin and Phenol-urea resin bonded boards was about twice as much as the difference between the Phenol-urea and the Phenolic types. Consequently, these figures proved that sandwich type boards had, not only higher water resistance than Urea resin bonded boards, but also had achieved such an improvement in water resistance that it was raised near to the Phenolic resin bonded board level.

Comparison of thickness swelling. Commensurate with

---

[13] R. G. Frashour and G. D. Nixon, Hardboard from Extracted Juniper Chips, (Vol. VI, No. 2. Forest Products Journal, 1956), p. 76.

higher water resistance of the Phenol-urea resin bonded board, its thickness swelling was relatively small. Its ability to resist thickness swelling was closer to that of the Phenolic resin bonded board than to the level of the Urea resin bonded board.

To put this in figures (see Table X), the difference in thickness swelling between Urea resin bonded board and Phenol-urea resin bonded board was 7.8% (73.3 - 65.5%) and between Phenol-urea resin and Phenolic resin bonded board was 3.7% (65.5 - 61.8%). Again the closer value of thickness swelling between the latter two indicates the success of this study.

<u>Comparison of the reduction of bending strength</u>. Figures for the reduction of M.O.R. in Table X are in percent bending strength of soaked boards compared to conditioned board (without soaking). Therefore a higher value of a percentage in Table X means a lesser reduction of M.O.R. after soaking.

The differences of reductions of M.O.R. were 4.0% (12.6 - 16.6%) between Urea resin and Phenol-urea resin bonded boards, 3.6% (12.6 - 16.2%) between Urea resin and Phenolic resin bonded boards, and only 0.4% (16.6 - 16.2%) between Phenol-urea resin and Phenolic resin bonded boards. The fact that there are almost the same values for reduction of M.O.R. of Phenol-urea resin bonded board and Phenolic resin bonded board indicated the excellent improvement in

TABLE X

AVERAGE VALUES OF THE WATER ABSORPTION, THE THICKNESS-SWELLING AND THE REDUCTION OF BENDING STRENGTH
(in per cent)

Item	Type of Board		
	Urea %	Phenol-urea %	Phenol %
Water Absorption	89.7	82.8	79.6
Thickness Swelling	73.3	65.5	61.8
Reduction of Bending Strength	12.6	16.6	16.2

board durability which was effected by the newly designed sandwich type construction.

Theoretically, there is no reason for Phenol-urea resin bonded board to produce a lesser reduction of M.O.R. when compared to the Phenolic resin bonded board. This is an unexpected result, probably caused by within-sample variation due to the inavoidable experimental error. With such a low level of significant difference, (below $P = 0.50$ level), it can only be concluded that this was due to chance alone.

CONCLUSIONS

It is natural to expect the Phenol-urea resin bonded boards to have higher dimensional stability than the Urea resin bonded boards due to the partial use of the better resin binder, but one cannot be satisfied merely with improvement without further consideration. For example, we could not necessarily consider it advantageous if the value of dimensional stability of a Phenol-urea board were just in between the others or below the average value of the other two. Because of the half and half of the two types of resins used, it would generally be thought that the resultant value would be midway between the other two types of boards. This was not the expected result of this study.

As expected, Figures 2, 3, and 4 shows that the values of water absorption, thickness swelling and reduction of M.O.R. of Phenol-urea resin bonded board were much nearer to Phenolic resin bonded board than to the Urea resin bonded board. They were above the average values of those from Urea resin and Phenolic resin bonded boards. The greatest achievement of the sandwich board was found in its ability to maintain bending strength (M.O.R.) in spite of the penetration of moisture, as evidenced by the fact that the value of the reduction of M.O.R. of Phenol-urea resin bonded board was approximately the same as the value of Phenolic resin bonded boards.

The final conclusions of this study is that the practice of using better resin binders in the face layers of a sandwich type board does improve its properties to such a level that it can be considered advantageous from the point of the cost of resin binders. That is, the sandwich type boards can approximate the properties of the boards made with the more expensive resin at a resin cost totalling considerably less since the cost of urea resin is only about half the cost of phenolic resin at the present time.

As mentioned in section INTRODUCTION the cost of resin binders is a major item in producing wood particle board, usually 35 to 60 percent of the total manufacturing cost, the low cost urea resin used in the core layer of the sandwich type board certainly would constitute a considerable saving to the manufacturer if it could be done without seriously reducing its properties. This study shows that it can be done in this case.

FIGURE 2. COMPARISON OF WATER ABSORPTION

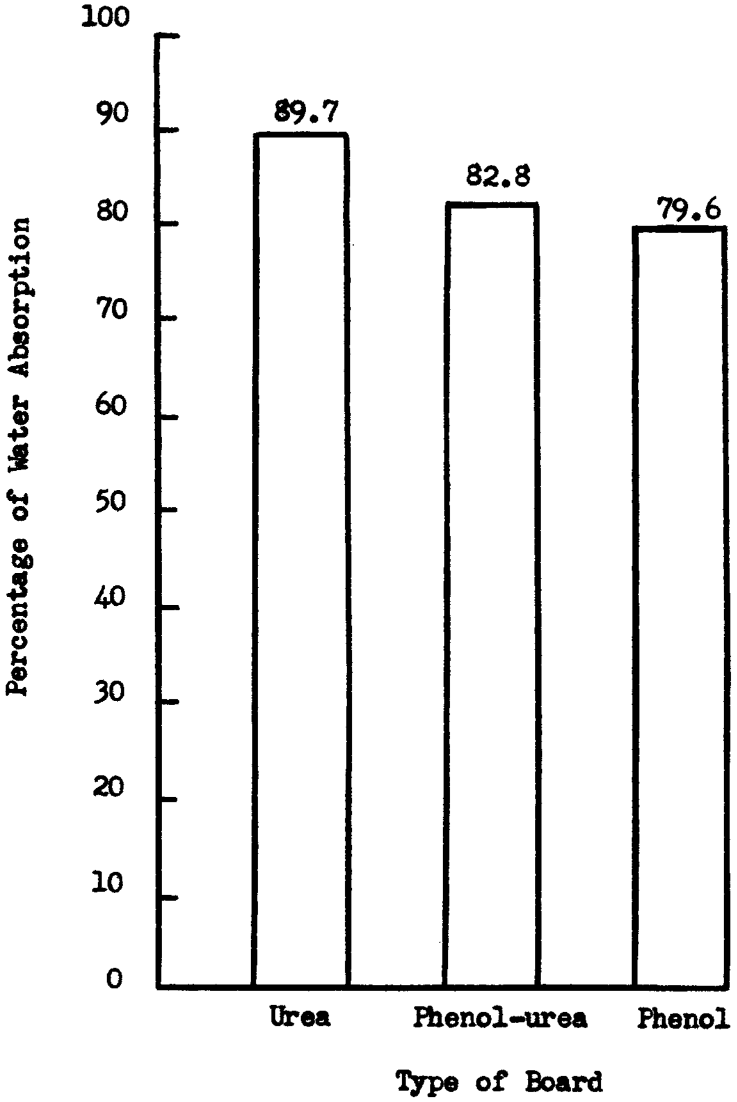


FIGURE 3. COMPARISON OF THICKNESS SWELLING

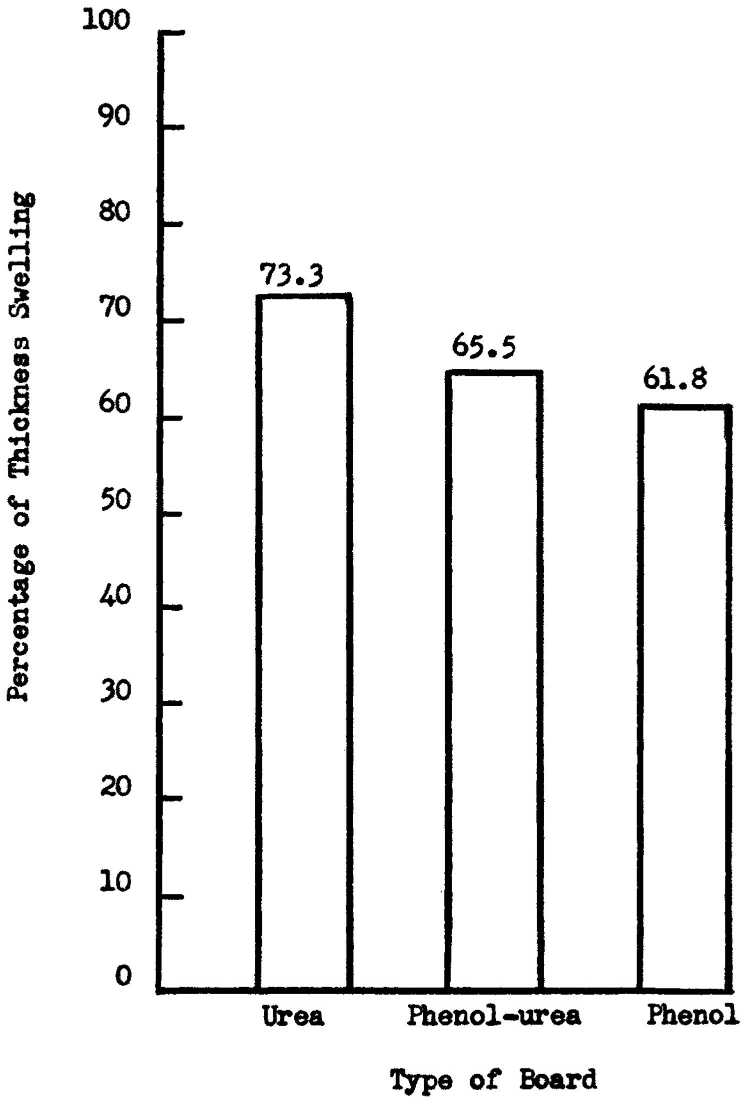
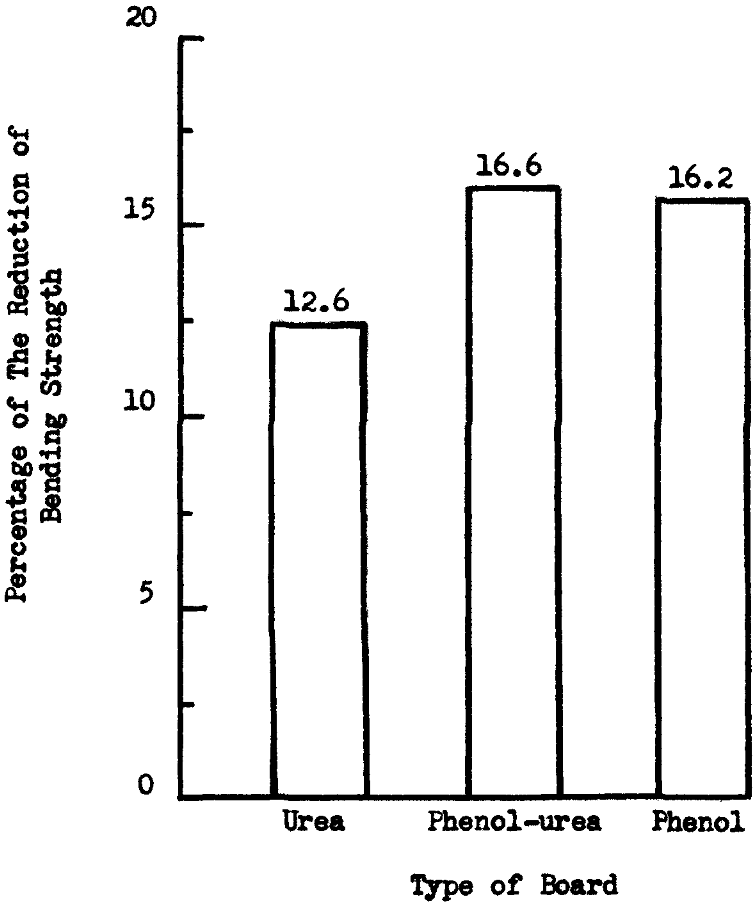


FIGURE 4. COMPARISON OF THE REDUCTION OF BENDING STRENGTH



BIBLIOGRAPHY

Bibby, R. D., "Manufacture and Use of Wood Particle Board," *Forest Products Journal*, Vol. VI, No. 55 (May, 1956), pp. 169-172.

Brouse, Don, "The Ideal Glue-How Close Are We?," *Forest Products Journal*, Vol. VII, No. 5 (May, 1957), pp. 163-167.

Brown, H. P., Panshin, A. J. and Forsaith, C. C. *Textbook of Wood Technology* 2 vols., McGraw-Hill Book Company, Inc., N. Y., 1952.

Bryant, Ben S. *Methods For Testing The Significance of Differences Between Sets Of Experimental Data*. Seattle, Washington: College of Forestry, University of Washington, 1952.

Clark, James d'A., "A New Dry-Process Multi-Ply Board," *Forest Products Journal*, Vol. V, No. 4 (August, 1955), pp. 209-213.

Consolidated Board Products Group Research Department. *American-Marietta Resin Binders For Particle Board*. Washington: American-Marietta Company, 1957.

Consolidated Board Products Group. *Effect of Pressing Temperatures on Urea and Phenolic Resin Bonded Particle Board*. Washington: American-Marietta Company, 1957.

Consolidated Board Products Group Research Department. *General Information on Particle Board Manufacturing Testing, & Bibliography*. Washington: American-Marietta Company, 1957.

Consolidated Board Products Group Research Laboratory. *The Use of Sodium Borate (Borax) As A Caul Releasing Agent in Wet Process Hardboard*. Washington: American-Marietta Company, 1957.

Cooke, William H. *Consolidated Products From Wood Residues*, Report No. L-2. Oregon: Forest Products Laboratory, 1953.

Cooke, W. H. and Frashour, R. G., "Resin Application in Attrition-Mill Type Particle Board," *Forest Products Journal*, Vol. V, No. 4 (August, 1955), pp. 214-218.

Currier, R. A., "Effect of Cyclic Humidification on Dimensional Stability of Commercial Hardboard," *Forest Products Journal*, Vol. VII, No. 3 (March, 1957), pp. 95-100.

De Bruyne, N. A. and Houwink, R. *Adhesion and Adhesives*. London: Elsevier Publishing Company, 1951.

Forest Service. *Wood Handbook*. Washington, D. C.: U. S. Government Printing Office, 1955.

FPRS Wood Technology Series. *No. 19*. *Fiber, Particle, and Hardboard*. Wisconsin: Forest Products Research Society, 1947-1953.

FPRS Wood Technology Series. *No. 21*. *Hardboard*. Wisconsin: Forest Products Research Society, 1956.

Frashour, R. G. and Nixon, G. D., "Hardboard from Extracted Juniper Chips," *Forest Products Journal*, Vol. VI, No. 2 (February, 1956), pp. 73-76.

Frashour, R. G., Cooke, W. H. and Morschouser, C. R. *Properties of Dry-Formed Hardboards With Various Resin Contents*. Report No. L-5. Oregon: Forest Products Laboratory, 1955.

Freas, A. D. and Selbo, M. L. *Fabrication and Design of Glued Laminated Wood Structural Timbers*. Washington, D. C.: U. S. Government Printing Office, 1954.

Gallaher, Juanita R. (ed). *Western Conservation Journal*. Vol. XIV, No. 2. March-April, 1957.

Johnson, E. S. (ed). *Wood Particle Board Handbook*. North Carolina: North Carolina State College, 1956.

Keaton, C. M. *Phenolic Resins In The Wet Process Hardboard*. Washington: American-Marietta Company, 1949.

Lewis, Wayne C., "Testing and Evaluating Procedures for Building Boards," *Forest Products Journal*, Vol. VI, No. 7 (July, 1956), pp. 241-246.

Lewis, Wayne C., "Use Development For Particle Board," *Forest Products Journal*, Vol. VIII, No. 2 (February, 1957), pp. 27A-30A.

Proposed Revision of Federal Specification LLL-F-311 For Fiber-Board; Hard-Pressed, Structural. Washington: Lumber Committee, 1952.

Rishell, Carl A., "Fundamental Economics of the Particle Board Industry," *Forest Products Journal*, Vol. VII, No. 1 (January, 1957), pp. 6-9.

Schwartz, S. L., Pew J. C. and Schafer, E. R., *Experiments on the Production of Insulating Board and Hardboard From Western Sawmill and Logging Waste*. Wisconsin: Forest Products Laboratory, 1947.

Stillinger, J. R. and Currier, R. A. *Relative Humidity, Moisture Content, and Dimensional Stability Relationships in Hardboard of Three Manufacturers*. Report No. T-7. Oregon: Forest Products Laboratory, 1954.

Talbott, J. W. and Maloney, D. E., "Effect of Several Production Variables on Modulus of Rupture and Internal Bond Strength of Boards Made of Green Douglas-Fir Planer Shavings," *Forest Products Journal*, Vol. VII, No. 10 (October, 1957), pp. 295-398.

Tentative Methods of Test for Evaluating The Properties of Building Fiberboards. (ASTM Designation: D 1037-56 T), Philadelphia 3, Pa.: American Society For Test-Materials, 1956.

The Company & Its Products. Washington: American-Marietta Company, 1955.

Wood Composition Boards. Oregon: Pacific Power & Light Company, 1955.

Urling, Gerard P., "Wood Particle Board-A Giant in the Making," *Forest Products Journal*, Vol. VI, No. 10 (October, 1956), pp. 363-365.

APPENDIX

The Form of the Tables Designed to Represent the Data

In order to contain all the data on a single sheet, the tables were specially designed. They were arranged according to the order of testing and calculating procedures.

Abbreviations used in the first table of the Appendix are:

U01, U02..........U10 = Urea resin bonded sample boards No. 1 through No. 10

Specimens for tests of conditioned board:

U011, U021..........U101 = specimen No. 1 (1/4" by 2" by 8") from U01 through U10

U0111, U0211........U1011 = coupon No. 1 (1/4" by 2" by 2") from U011 through U101

U0112, U0212........U1012 = coupon No. 2 (1/4" by 2" by 2") from U011 through U101

Specimens for tests of soaked board:

U012, U022........U102 = specimen No. 2 (1/4" by 2" by 8") from U01 through U10

Other abbreviations:

M. L. = maximum load, lbs.

t. = thickness of coupon, in.

a. t. = average thickness of coupon, in.

wl. = weight of conditioned coupon, grams.

w2. = weight of oven dried coupon, grams.

D. of w. = difference of weights between w1. and w2., grams.

S. G. = specific gravity of coupon.

M. C. = moisture content of coupon, %.

A. T. = average thickness of conditioned specimen, in.

A. S. G. = average specific gravity of conditioned specimen.

A. M. C. = average moisture content of conditioned specimen, %.

M. R1. = modulus of rupture of conditioned specimen, psi.

T1. = thickness of conditioned specimen (before soaking), in.

a. T1. = average thickness of T1., in.

T2. = thickness of soaked specimen, in.

a. T2. = average thickness of T2., in.

D. of T. = difference of thickness between a. T1. and a. T2., in.

W1. = weight of conditioned specimen, grams.

W2. = weight of soaked specimen, grams.

D. of W. = difference of weights between W1. and W2., grams.

T. S. = thickness swelling of specimen after soaking, %.

W. A. = water absorption of specimen after soaking, %.

M. R2. = modulus of rupture of specimen after soaking, psi.

R. M. R. = reduction of modulus of rupture, (M. R. of soaked specimen)/(M. R. of conditioned specimen), %.

All the thicknesses were measured at four points near the corners and one at the center of each coupon or specimen. Therefore, within each t or T category in this table five measurements were recorded. Figures used for thickness are thousandths of an inch. For example, a figure of 540 in t or T category means .540 inch.

The same arrangement and order was also used for the second and third tables of the Appendix. In addition to the abbreviations as mentioned above, PU and P are the abbreviations of Phenol-urea resin bonded board and Phenolic resin bonded board.

TOTAL DATA RECORDED AND CALCULATED FROM THE UREA-FORMALDEHYDE RESIN BONDED BOARDS

Item	Type of Board										Average
	U01	U02	U03	U04	U05	U06	U07	U08	U09	U10	
	U011	U021	U031	U041	U051	U061	U071	U081	U091	U101	
M.L.	58	54	56	55	55	55	52	42	51	54	
	U0111	U0211	U0311	U0411	U0511	U0611	U0711	U0811	U0911	U1011	
t.	251	252	247	248	248	253	251	254	257	264	
	251	250	247	246	244	258	250	256	257	264	
	248	251	249	252	245	255	251	257	258	260	
	249	253	248	249	248	254	253	256	258	261	
	250	251	248	246	247	254	251	257	258	262	
a.t.	250	251	248	248	246	255	251	256	258	262	253
w1.	15.53	15.01	15.27	15.23	15.45	15.01	15.48	15.26	14.33	14.83	15.14
w2.	14.46	14.01	14.30	14.34	14.47	14.07	14.46	14.24	13.33	13.82	14.15
D.of w.	1.07	1.00	0.97	0.89	0.96	0.94	1.02	1.02	1.00	1.01	0.99
S.G.	0.88	0.70	0.88	0.88	0.89	0.84	0.88	0.85	0.79	0.80	0.84
M.C.	7.4	7.1	6.8	6.2	6.6	6.7	7.0	7.0	7.5	7.4	7.0

(Continued)

	U0112	U0212	U0312	U0412	U0512	U0612	U0712	U0812	U0912	U1012	
t.	249	246	253	259	253	256	256	254	261	261	
	249	248	253	256	250	256	256	251	258	260	
	250	248	252	260	253	257	259	252	261	259	
	249	247	254	256	254	255	259	255	263	260	
	249	247	253	255	251	258	258	253	262	259	
a.t.	249	247	253	257	252	256	258	253	261	260	255
w1.	15.00	15.65	14.93	15.03	15.12	15.06	15.58	15.44	15.11	15.42	15.23
w2.	14.01	14.66	13.99	14.14	14.19	14.09	14.53	14.40	14.10	14.37	14.25
D.of w.	0.99	0.99	0.94	0.89	0.93	0.96	1.05	1.04	1.01	1.05	0.99
S.G.	0.85	0.90	0.84	0.82	0.86	0.83	0.86	0.87	0.83	0.84	0.85
M.C.	7.1	6.8	6.7	6.3	6.6	6.8	7.2	7.2	7.2	7.3	6.9
A.t.	250	249	251	253	249	255	254	254	255	261	253
A.S.G.	0.87	0.85	0.86	0.85	0.88	0.84	0.87	0.86	0.82	0.82	0.85
A.M.C.	7.3	7.0	6.8	6.3	6.6	6.8	7.1	7.1	7.4	7.4	7.0
M.Rl.	4176.0	3919.5	3996.0	3865.5	3991.5	3807.7	3634.9	2930.2	3530.8	3568.3	3742.0

(Continued)

	U012	U022	U032	U042	U052	U062	U072	U082	U092	U102	
M.L.	23	20	21	22	24	23	20	16	18	18	
T1.	253 255 256 252 252	251 248 251 251 250	250 251 248 245 245	257 257 257 250 254	244 243 252 250 246	257 257 261 260 255	256 257 258 264 262	251 251 254 254 250	262 263 255 255 257	266 265 264 266 261	
a.T1.	254	250	248	255	247	258	259	252	259	264	255
W1.	60.84	61.40	61.14	62.00	58.84	61.18	61.25	61.51	61.00	61.35	61.05
T2.	438 444 444 446 439	433 428 435 433 430	426 427 427 415 415	451 449 450 442 446	425 427 432 429 426	435 454 448 449 418	459 460 461 455 427	430 440 440 456 426	464 442 449 448 441	454 460 450 468 454	
a.T2.	442	432	422	448	428	441	452	438	449	457	441
W2.	115.68	118.32	115.20	116.49	110.54	117.75	116.55	113.92	114.54	119.56	115.86
D.of T.	188	182	178	193	181	183	193	186	190	193	187
D.of W.	54.84	56.92	54.06	54.49	51.70	56.57	55.30	52.41	53.54	58.21	54.80
T.S.	74.0	72.8	71.8	75.6	73.0	70.9	74.5	73.8	74.0	72.7	73.3

(Continued)

W.A.	90.1	92.7	88.4	87.9	87.8	92.5	90.3	85.2	87.7	94.8	89.7
M.R2.	530.5	480.5	531.0	495.0	589.9	535.5	441.2	374.9	401.0	387.5	476.7
R.M.R.	12.7	12.3	13.3	12.8	14.8	14.1	12.1	11.8	11.4	10.9	12.6

TOTAL DATA RECORDED AND CALCULATED FROM THE PHENOL-UREA RESIN BONDED BOARDS

Item	Type of Board										Average
	PU01	PU02	PU03	PU04	PU05	PU06	PU07	PU08	PU09	PU10	
	PU011	PU021	PU031	PU041	PU051	PU061	PU071	PU081	PU091	PU101	
M.L.	54	54	45	54	53	45	43	45	53	48	
	PU0111	PU0211	PU0311	PU0411	PU0511	PU0611	PU0711	PU0811	PU0911	PU1011	
t.	265 269 269 267 267	258 258 256 258 258	269 270 269 267 269	270 268 270 271 271	258 260 256 256 258	262 262 263 262 262	266 267 263 263 264	265 265 267 264 263	266 262 260 262 262	261 259 260 262 260	
a.t.	267	258	269	270	258	262	264	265	262	260	264
w1.	15.07	15.01	16.04	15.58	15.62	15.43	15.72	15.58	15.35	15.36	15.48
w2.	14.18	14.12	15.10	14.63	14.74	14.45	14.75	14.61	14.38	14.42	14.54
D.of w.	0.89	0.89	0.94	0.95	0.88	0.98	0.97	0.97	0.97	0.94	0.94
S.G.	0.81	0.83	0.85	0.82	0.87	0.84	0.85	0.84	0.83	0.84	0.84
M.C.	6.3	6.3	6.2	6.5	6.0	6.7	6.6	6.6	6.7	6.5	6.4

(Continued)

	PU0112	PU0212	PU0312	PU0412	PU0512	PU0612	PU0712	PU0812	PU0912	PU1012	
t.	267 270 271 269 269	256 257 258 258 258	268 266 267 269 268	263 264 263 264 263	254 256 257 258 255	264 263 264 265 263	264 265 268 270 268	265 264 265 269 265	276 280 277 272 276	273 271 266 270 268	
a.t.	269	257	268	263	256	264	267	266	276	270	266
w1.	15.47	14.89	15.66	15.34	15.13	15.62	15.32	15.68	16.14	15.74	15.50
w2.	14.68	14.03	14.70	14.45	14.26	14.64	14.35	14.69	15.15	14.74	14.57
D.of w.	0.79	0.86	0.96	0.89	0.87	0.89	0.97	0.99	0.99	1.00	0.93
S.G.	0.83	0.83	0.83	0.83	0.85	0.84	0.82	0.84	0.83	0.83	0.83
M.C.	5.4	6.1	6.5	6.2	5.9	6.7	6.8	6.7	6.5	6.8	6.4
A.t.	268	258	269	266	257	263	266	266	269	265	265
A.S.G.	0.82	0.83	0.84	0.83	0.86	0.84	0.84	0.84	0.83	0.84	0.84
A.M.C.	5.9	6.2	6.4	6.4	6.0	6.7	6.7	6.7	6.6	6.7	6.4
M.Rl.	3132.0	3649.5	2794.5	3433.5	3610.8	2926.4	2736.0	2863.4	3294.0	3073.5	3151.4

(Continued)

	PU012	PU022	PU032	PU042	PU052	PU062	PU072	PU082	PU092	PU102	
M.L.	24	20	24	24	23	21	19	23	24	20	
T1.	263	261	267	264	262	262	258	262	274	265	
	265	259	267	261	261	264	258	262	274	267	
	264	260	273	275	262	268	259	265	257	280	
	262	264	272	277	267	265	261	264	257	277	
	262	258	267	267	260	264	260	260	264	272	
a.T1.	263	260	269	269	262	265	259	263	265	272	265
W1.	62.22	62.26	63.34	63.40	62.04	62.22	62.32	62.00	62.04	63.73	62.56
T2.	439	441	440	431	420	441	433	431	444	450	
	434	428	442	421	419	450	437	434	450	451	
	445	420	442	450	437	437	431	450	438	460	
	448	420	443	446	451	438	420	433	427	459	
	420	430	447	449	446	435	433	430	428	455	
a.T2.	437	428	443	439	436	440	431	436	435	455	438
W2.	114.30	112.10	114.15	115.40	112.43	114.15	116.77	113.58	114.41	123.45	115.07
D.of T.	173	168	174	170	174	175	172	173	170	183	173
D.of W.	52.08	49.84	50.81	52.00	50.39	51.93	54.45	51.58	57.37	59.72	53.02
T.S.	66.1	64.6	64.7	63.2	66.4	66.0	66.4	65.8	64.2	67.2	65.5

(Continued)

W.A.	83.7	80.4	80.2	80.2	81.2	83.4	87.3	82.9	84.4	84.3	82.8
M.R2.	563.4	491.8	550.8	559.4	544.9	486.9	459.5	544.5	571.5	434.7	520.7
R.M.R.	17.9	13.5	19.7	16.3	15.1	16.7	16.8	19.0	17.3	14.1	16.6

TOTAL DATA RECORDED AND CALCULATED FROM THE
PHENOL-FORMALDEHYDE RESIN BONDED BOARDS

Item	Type of Board										Average
	F01	F02	F03	F04	F05	F06	F07	F08	F09	F10	
	F011	F021	F031	F041	F051	F061	F071	F081	F091	F101	
M.L.	55	50	53	48	48	44	45	53	54	50	
	F0111	F0211	F0311	F0411	F0511	F0611	F0711	F0811	F0911	F1011	
t.	269 272 274 272 272	251 254 253 251 252	270 267 271 274 270	259 260 259 256 257	257 256 254 257 255	271 266 265 271 271	258 257 261 259 257	263 266 263 264 265	255 254 257 257 255	253 253 250 250 251	
a.t.	272	252	270	258	256	269	258	264	256	251	261
w1.	15.36	15.79	15.51	15.54	15.19	15.99	15.44	15.26	15.22	15.31	15.46
w2.	14.55	14.89	14.69	14.66	14.31	15.10	14.65	14.39	14.39	14.44	14.61
D.of v.	0.81	0.90	0.92	0.88	0.88	0.89	0.79	0.87	0.83	0.87	0.86
S.G.	0.82	0.90	0.83	0.86	0.85	0.85	0.85	0.83	0.85	0.87	0.85
M.C.	5.6	6.0	6.3	6.0	6.2	5.9	5.4	6.1	5.8	6.0	5.9

(Continued)

	F0112	F0212	F0312	F0412	F0512	F0612	F0712	F0812	F0912	F1012	
t.	264	257	253	254	259	257	270	256	257	258	
	259	256	255	254	262	260	268	255	257	259	
	258	254	260	252	260	259	262	258	257	259	
	261	256	257	250	260	258	266	259	256	256	
	260	255	258	253	260	259	266	256	257	258	
a.t.	260	256	257	253	260	259	266	257	257	258	258
w1.	15.74	15.50	15.23	15.50	15.36	15.45	15.15	15.40	14.84	15.58	15.38
w2.	14.85	14.60	14.44	14.67	14.47	14.61	14.34	14.54	14.00	14.68	14.52
D.of w.	0.89	0.90	0.79	0.83	0.89	0.94	0.81	0.86	0.84	0.90	0.86
S.G.	0.87	0.87	0.85	0.88	0.85	0.86	0.82	0.86	0.83	0.86	0.86
M.C.	6.0	6.2	5.5	5.7	6.2	5.8	5.6	5.9	6.0	6.1	5.9
A.t.	266	254	264	255	258	264	262	260	257	255	260
A.S.G.	0.85	0.89	0.84	0.87	0.85	0.86	0.84	0.85	0.84	0.87	0.86
A.M.C.	5.8	6.1	5.9	5.9	6.2	5.9	5.5	6.0	5.9	6.1	5.9
M.Rl.	3496.5	3488.4	3421.8	3303.0	3243.2	2839.5	2952.0	3526.0	3681.5	3460.5	3341.2

(Continued)

	P012	P022	P032	P042	P052	P062	P072	P082	P092	P102	
M.L.	19	19	20	23	19	20	24	19	20	18	
T1.	267	249	246	256	259	256	263	251	257	248	
	266	250	248	255	259	254	261	250	255	251	
	255	253	263	247	253	257	253	256	254	260	
	254	253	263	248	251	250	254	256	253	257	
	258	251	252	250	256	252	257	252	254	254	
a.T1.	260	251	254	251	256	254	258	253	255	254	254
W1.	63.48	64.00	62.24	63.77	61.26	62.70	61.85	62.92	61.78	62.78	62.67
T2.	452	400	413	387	417	397	445	445	399	393	
	448	404	415	412	411	396	425	416	397	409	
	440	401	435	384	414	407	425	423	414	415	
	422	405	424	388	412	383	407	423	400	393	
	439	405	426	388	412	380	419	400	412	407	
a.T2.	440	403	423	392	413	393	424	421	405	403	412
W2.	118.65	112.77	114.10	111.45	112.66	112.95	110.64	112.77	110.05	108.35	112.44
D.of T.	180	152	169	141	157	139	166	168	155	149	158
D.of W.	55.17	48.77	51.86	47.68	51.40	50.25	48.79	49.85	48.27	45.57	49.76
T.S.	69.2	60.5	66.5	56.2	61.3	54.5	64.3	66.4	60.8	58.7	61.8

(Continued)

W.A.	86.9	76.2	83.3	74.4	83.9	81.7	78.9	79.5	78.1	72.6	79.6
M.R2.	440.6	527.4	503.2	670.5	499.5	584.1	598.5	482.9	549.0	499.5	535.5
R.M.R.	12.6	15.1	14.7	20.3	15.4	20.6	20.3	13.7	14.9	14.4	16.2