THE INFLUENCE OF SPECIFIC GRAVITY AND RESIN CONTENT ON THE PROPERTIES OF PARTICLE BOARD MADE WITH SPECIES OF WIDELY DIFFERENT SPECIFIC GRAVITY

Thesis for the Degree of M. S.
MICHIGAN STATE UNIVERSITY
Frederick Dale Larmore

1958

THE INFLUENCE OF SPECIFIC GRAVITY AND RESIN CONTENT ON THE PROPERTIES OF PARTICLE BOARD MADE WITH SPECIES OF WIDELY DIFFERENT SPECIFIC GRAVITY

By

FREDERICK DALE LARMORE

AN ABSTRACT

Submitted to the College of Agriculture
Michigan State University of Agriculture and
Applied Science in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE

Department of Forest Products

1958

Approved: Aubrey E. Wylie

ABSTRACT

Aspen, Populus tremuloides, and yellow birch, Betula alleghanensis, flake boards were fabricated and tested to determine the effects of wood specific gravity, resin content, and board density on the strength and dimensional stability properties. The variables were: (1) wood specific gravity, 0.37 and 0.65, (2) resin content, percent solids, 4 and 8 percent, (3) board specific gravities, 0.56 and 0.72. A static bending test and a tension test perpendicular to the surface were run according to Tentative A.S.T.M. Standards *(1). The modulus of rupture, proportional limit stress, modulus of elasticity, and the work to maximum load were calculated from the static bending test. Dimensional stability measurements for the boards were taken first at equilibrium in constant conditions of 80° F.-30 percent relative humidity and then in constant conditions of 80° F.-80 percent relative humidity. The percent change in thickness and in linear expansion was calculated, based on the dimensions at equilibrium in 80° F.-30 percent relative humidity. A statistical analysis of variance was performed on the data for each test to determine significance for the fabrication variables in question.

Aspen flake boards had higher modulus of elasticity, higher work to maximum load, and lower linear expansion, as compared to yellow birch flake boards. The higher resin content boards had lower thickness expansion as compared to the lower resin content boards.

The boards of high specific gravity had higher modulus of elasticity than the low specific gravity boards. From the data it appears as though aspen flake boards have higher modulus of rupture values than the birch boards, but the statistics do not indicate this. High resin content also appears to produce high modulus of rupture, but again this is not statistically substantiated.

THE INFLUENCE OF SPECIFIC GRAVITY AND RESIN CONTENT

ON THE PROPERTIES OF PARTICLE BOARD MADE WITH

SPECIES OF WIDELY DIFFERENT

SPECIFIC GRAVITY

By

FREDERICK DALE LARMORE

A THESIS

Submitted to the College of Agriculture
Michigan State University of Agriculture and
Applied Science in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE

Department of Forest Products

1958

Acknowledgments

Without the full cooperation of the United States Forest Products Laboratory, this investigation could not have been carried out. The author wishes to express his appreciation for the help and guidance in the pursuit of this investigation by Dr. Herbert Fleischer, Chief of the Division of Timber Processing, and Mr. Bruce Heebink.

Sincere thanks are also due Dr. Aubrey Wylie and Dr. Otto Suchsland, Department of Forest Products, and Dr. William Baten, Experiment Station Statistician, Michigan State University, for their assistance in writing this thesis.

The author wishes to express his deepest appreciation to his wife for the many long hours that she spent in assisting with testing and writing.

Table of Contents

List of Tables

List of Illustrations

I. Introduction

A wood particle board is composed of essentially dry wood particles which have been coated with a resin binder and pressed into shape. Particle board was first introduced as a commercial product in Germany, in 1948. It was originally produced to utilize wood waste. Now, in many situations, particle board manufacturers are using wood from the tree, rather than from some waste source. With this occurring, it is evident that a product has been developed, not solely as a utilizer of waste, but as a new product for new uses.

There are several basically different methods of production and many variables within each method. It is not within the scope of this paper to outline these methods or all of the variables. An effort will be made to investigate some of the basic variables that are always present. These basic variables influence the mechanical properties of particle board. At the present time there is little or no standardization of mechanical properties. A prospective user of particle board can not consult a simple table to determine the mechanical properties, as he could with steel or aluminum or even with wood. In most cases it would be difficult to determine these properties, even from the manufacturers, and in some cases the only source of such information would be through a series of tests made privately.

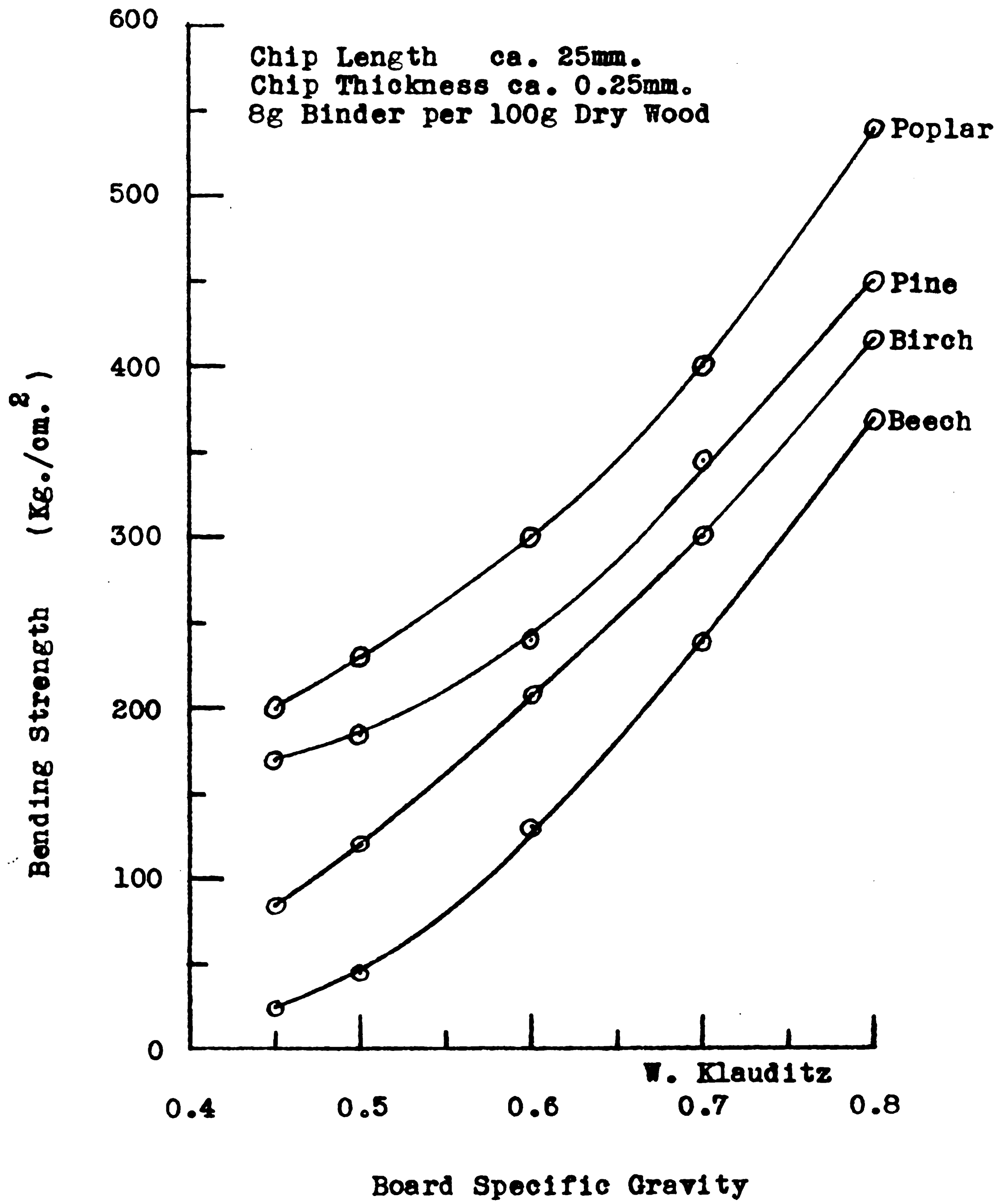
W. Klauditz *(5) carried out research investigating the modulus of rupture in bending for varied board specific gravities and for different species. Figure 1 shows the results of his work. Actually the work involves the difference in species which have many variables in themselves. The average specific gravities for each wood could be assigned, and a comparison might then be made between wood specific gravity, board specific gravity, and strength, but such factors as wood specific gravity and board resin content were not varied. The work that has been done on the interrelationship of fabricating variables and mechanical properties is not conclusive.

H. Dale Turner *(8) carried out further basic research on the effect of particle size and shape on the strength and dimensional stability of wood particle boards. In this work, Turner tested boards of various specific gravities made up with different percentages of synthetic resins. Different species of wood having varying specific gravities were also used in the study. Turner made no attempt to correlate the strength properties with all three factors of varying wood specific gravity, resin content, and board specific gravity. Turner's work was primarily an investigation on particle shape. He did find, however, that board density was of primary influence and that resin content was of secondary influence in controlling strength properties.

The simple relationships between strength and resin content, strength and board density, and strength and species are known.

Without more detailed basic research in the particle board field, it will be difficult to predict and establish any kind of standardization as concerns the physical properties of particle board.

Fig. 1 Effects of Species on Chipboard Bending Strength Relative to Specific Gravity.[1]



The majority of particle boards made in the United States utilize softwoods because there has been more softwood waste available. Some manufacturers are making boards from hardwoods now, and consequently it is important to learn more about the use of these woods in particle board.

Objective

The objective of this thesis is to determine the character of the relationships between the three factors: (1) specific gravity of the wood, (2) specific gravity of the particle board, (3) resin content of the board, and the strength and dimensional stability of flake boards made from hardwoods. This study should reveal whether the specific gravity of the wood used in fabricating particle board has a significant effect on the strength of the derived board when interrelated with the factors of board specific gravity and resin or glue content. If the specific gravity of the wood causes significant variations in the strength of the resulting panels, then it should be possible in the future to predict more reliably the relative mechanical properties of boards made from woods of different specific gravities, with different resin contents, and with different board specific gravities.

Part of the work for this problem was carried out by the author as an employee of the United States Forest Products Laboratory. The problem was carried on as an approved Forest Products Laboratory project.

II. Materials and Methods

A. Selection of Variables

Wood material requirements for the study dictated the choice of two species of widely different specific gravity. It was desirable that the species have similar structures. Aspen, Populus tremuloides, and yellow birch, Betula alleghanensis, were selected.

The board densities or specific gravities to be used were selected as representative of typical boards produced by the particle board industry. The densities and specific gravities used were 35 pounds per cubic foot, 0.56, and 45 pounds per cubic foot, 0.72. These specific gravities were based on ovendry weight and volume at equilibrium in constant conditions of 75° F. and 65 percent relative humidity.

Four percent resin solids and 8 percent resin solids, based on the weight of ovendry wood, were selected as the third variable. In this case an attempt was made to bracket the percentages used by industry.

In order to obtain a measure of the variation to be encountered, a series of replications were fabricated. The three tests described in the section detailing testing procedure were carried out. A statistical analysis of variance was run for the maximum load in static bending. There was no significant difference at either the 5 percent

or the 1 percent level. The analysis of variance is given in table 1. From these results it appeared that three replications of each board type would give sufficient data for a satisfactory analysis. The relationship of variables and replications in the experimental design for this study is indicated in table 2.

B. Material Procurement

Approximately 20 cubic feet of each species, in the green condition, were required. One yellow birch log provided a sufficient volume of material. Its average specific gravity, based on green volume and ovendry weight, was 0.65. Procurement of suitable aspen was more difficult. Three aspen logs were selected as matched material on the basis of specific gravity. The average specific gravity of each log was 0.36, 0.37, and 0.37. From this point on, the term wood specific gravity will replace the term wood species. There are other variations between species, but in this study they have been considered negligible.

C. Particle Generation

In any kind of scientific study of strength properties, it is desirable to obtain uniformity in the material being tested. Consequently it is essential that the particles generated for a study of this type have some uniformity. At the present time, the most easily generated uniform wood particle is the flake. A flake 1 inch along the grain, 0.5 inch across the grain, and 0.010 inch thick was

Table 1.--Analysis of variance for maximum loads in static bending for preliminary test boards

	DF	Sum Sq	Mn Sq	F	$F_{.05}$	$F_{.01}$
Total	11	1,761.27				
Between boards	2	294.53	147.26	0.90	19.4	99.4
Within boards	9	1,466.74	162.97			

Table 2.--Design of experiment

Species	Aspen				Yellow birch			
Resin content	4 percent resin		8 percent resin		4 percent resin		8 percent resin	
Board specific gravity	0.561	0.721	0.561	0.721	0.561	0.721	0.561	0.721
Replications	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3

produced on the disc flake cutter at the Forest Products Laboratory. This cutter is illustrated in figure 2. The lower picture shows the disc cutter head at rest with the knives and spur cutters in the face of the disc. The 0.5-inch-thick blocks on the lathe bed were fed into the disc as it revolved. The grain in the flakes, with respect to radial or tangential dimensions, was not controlled. The upper picture illustrates the cutter head in operation. Some difficulty was experienced in drying the flakes because they had a tendency to stick together. Drying was successfully carried out in a rotary drum, through which hot air was forced.

D. Resin Binder Application

Borden's WW-17 Urea Formaldehyde was used as a binder because it is a typical synthetic resin used in the particle board industry. This resin had a solids content of 65 percent and was applied to the flakes in the form of a mist or fine spray. The flakes were placed in a rotary drum illustrated in figure 3. As the drum rotated, the flakes tumbled and the resin was applied through a paint sprayer at 45 pounds per square inch air pressure.

A technique was used by the author for photographing individual flakes after they had been resin-coated. A yellow fluorescent dye was added to the resin in very minute quantities. The resin was then sprayed on the flakes in the usual manner, and a 1-quart sample of flakes was selected from several places in the mixing drum. This large sample was spread out under an ultraviolet floodlight, where the presence of glue was evidenced by yellow spots on the deep purple

Figure 2

Disc flake cutter in operation

Disc flake cutter showing knives
and spur cutters in face of disc

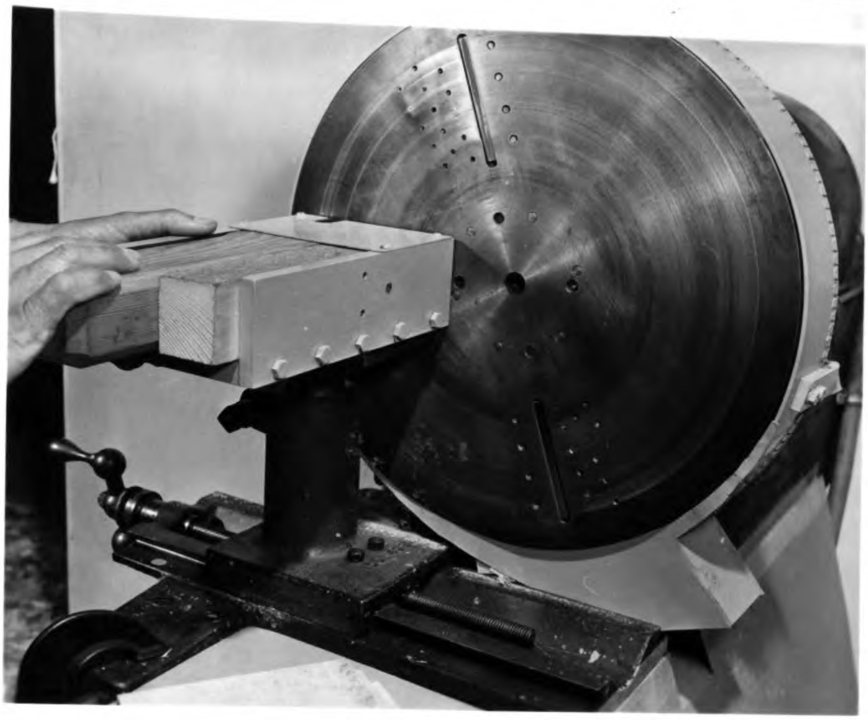
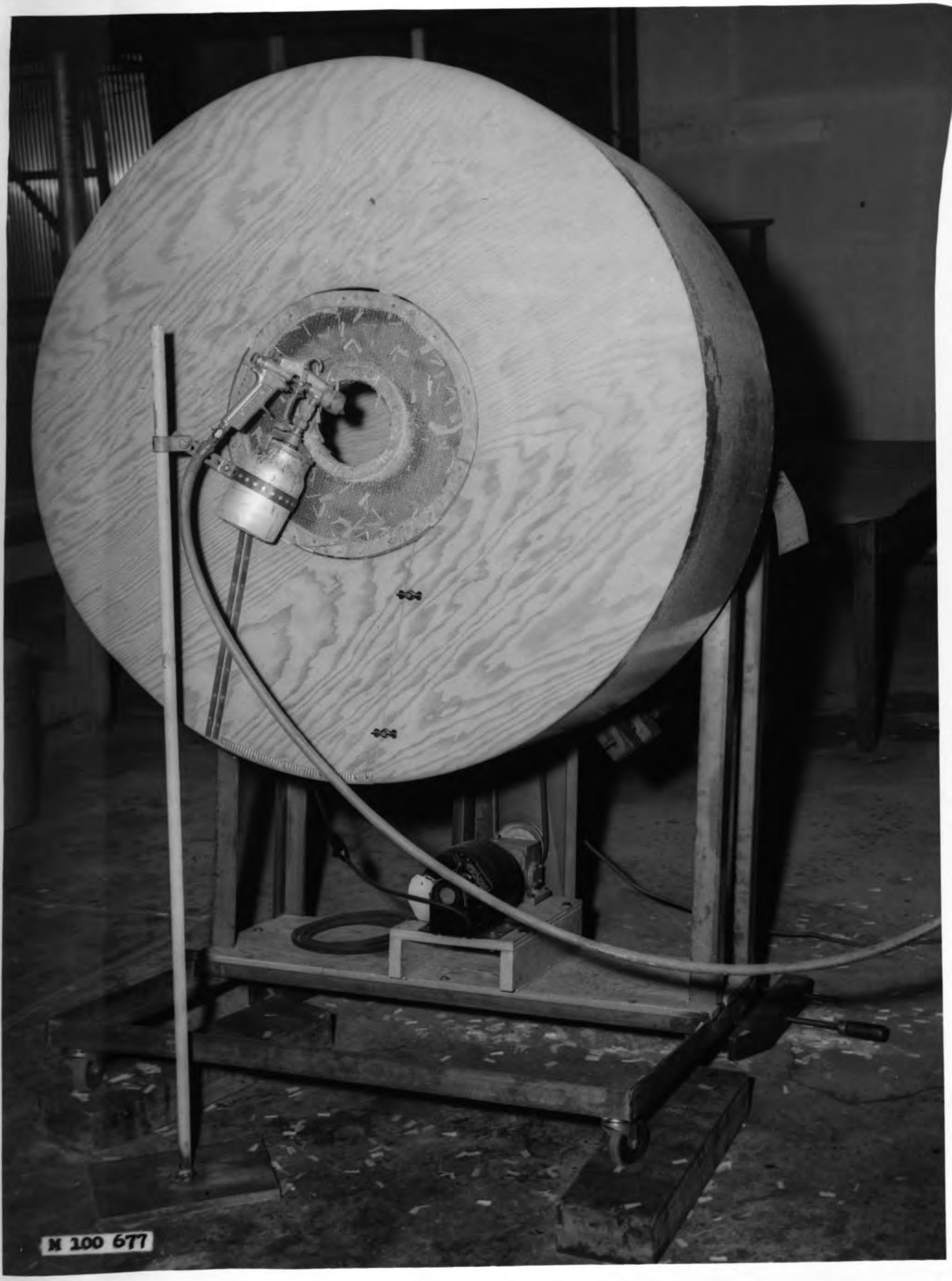


Figure 3.--Resin application equipment


M 100 677

background of wood. From this sample, 15 flakes were selected which represented the range from most glue present on a flake to least glue present on a flake. These 15 flakes were arranged in descending order from most to least glue present. Two ultraviolet floodlamps were used to illuminate these flakes and the representative sample was then photographed in black and white. The flakes were turned over in place and photographed again so that both sides of each flake could be seen. The resin present on each flake is evidenced by white areas or spots on the flakes in the photographs. Resin coverage for the 4 percent level on birch flakes is illustrated in figure 4, and for the 8 percent level in figure 5. One trial particle board was pressed using birch flakes coated with the fluorescent resin. A photograph of a 4- by 5-inch area on the board was made under ultraviolet light and is shown in figure 6. This board was of yellow birch, with 4 percent resin and having a specific gravity of 0.56. The uniformity of spread obtained was considered adequate.

In the flake-drying process the moisture content was held to 6 percent ± 1 percent. The urea formaldehyde was not diluted with water. It required from 5 to 8 minutes to apply the resin to the flakes, and the moisture content of the resin-coated flakes was 10 percent ± 1 percent. These moisture contents were recommended as typical of industrial practice.

E. Particle Board Fabrication

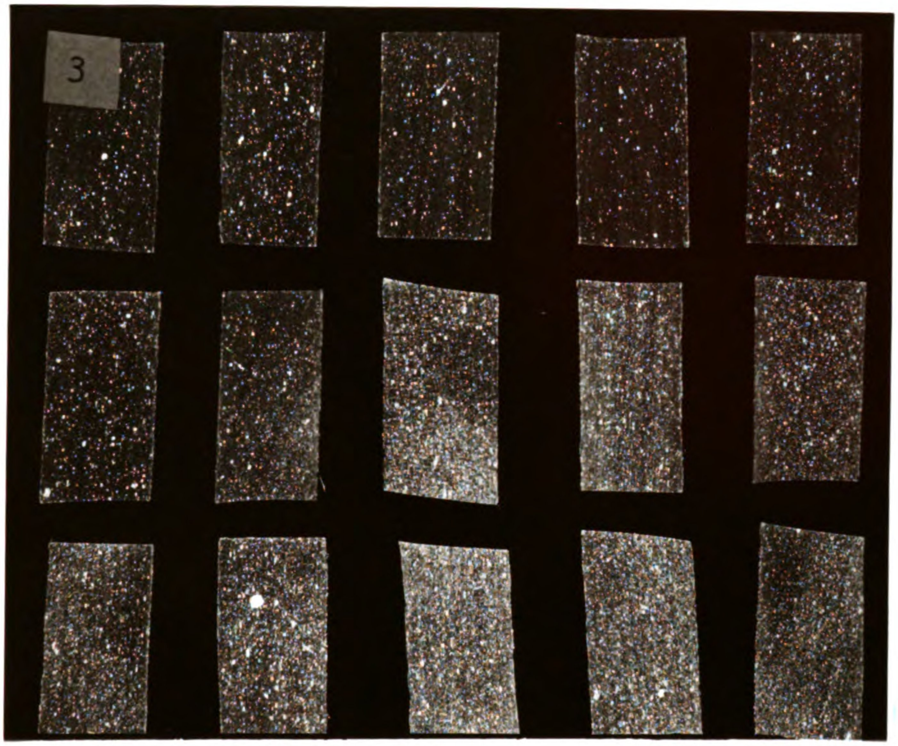
The boards were pressed in rough form, 28 inches by 24 inches by 1/2 inch. This was the size from which the static bending and the

Figure 4

Resin coverage for the 4 percent level on birch flakes (1X)

Reverse side of flakes

(IX)



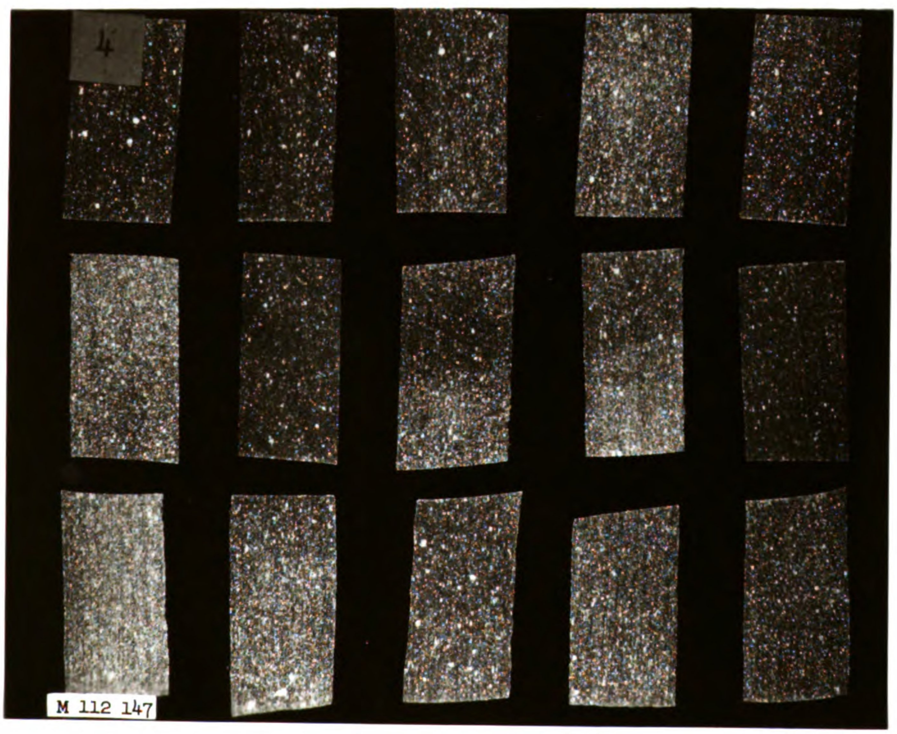
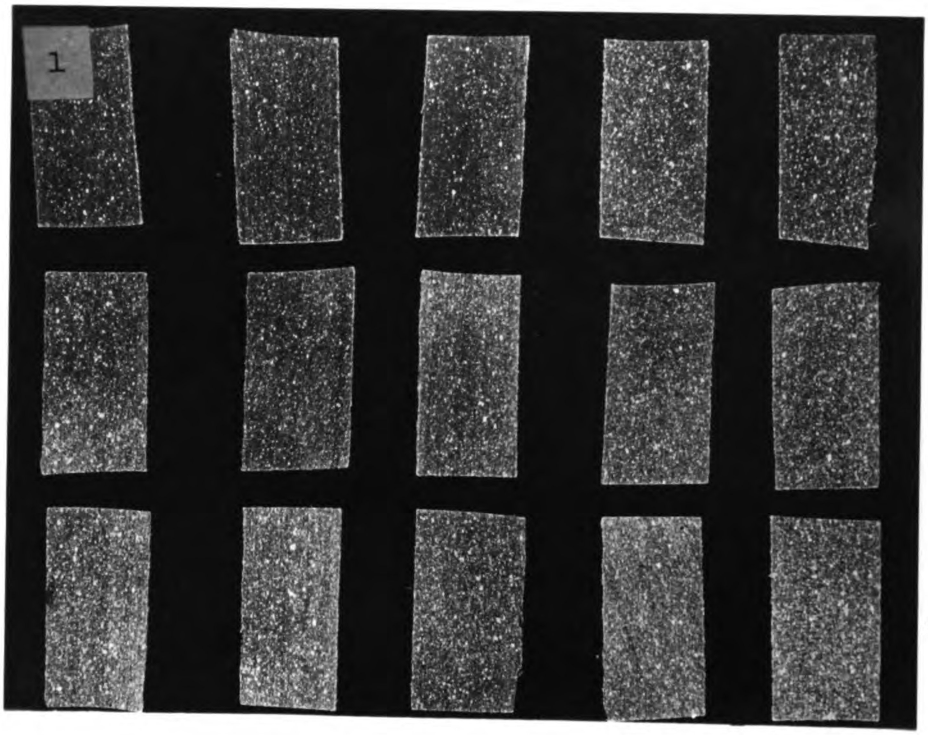


Figure 5

Resin coverage for the 8 percent level on birch flakes (1X)

Reverse side of flakes


1

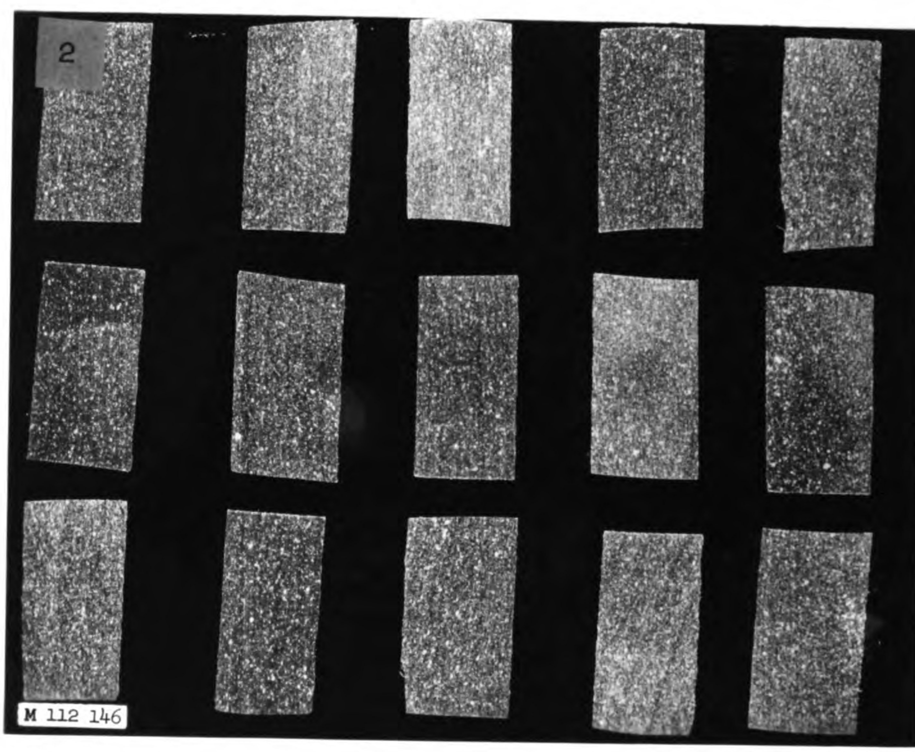
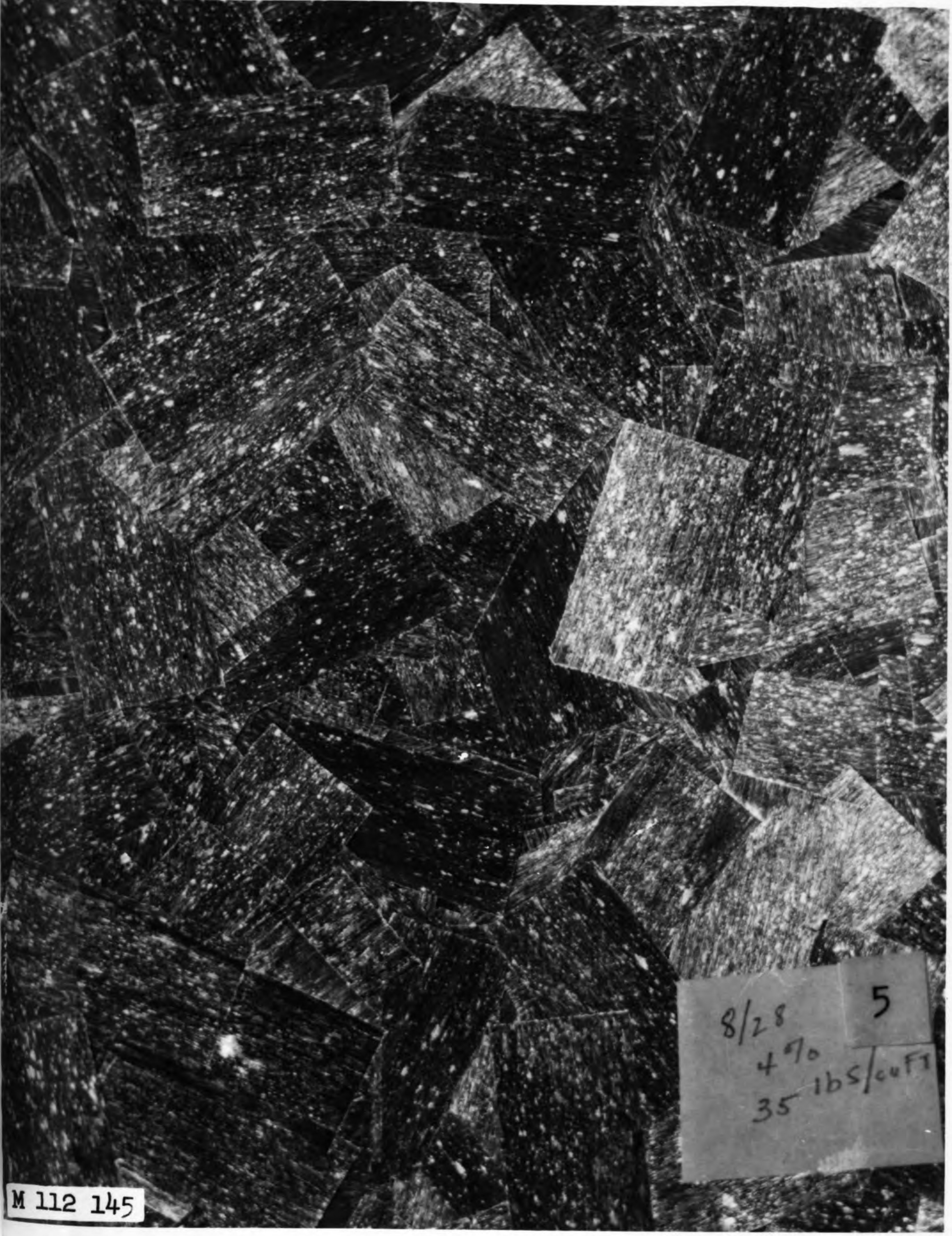

2
M 112 146

Figure 6.--Birch particle board showing resin coverage, 4 percent resin solids, specific gravity 0.56


8/28
4%
35 lbs/cu ft
5
M 112 145

dimensional stability specimens could be cut most conveniently. One-half-inch steel stops were placed between the 1/4-inch aluminum cauls to control the thickness of the board.

The specific gravity of the board was predetermined by placing a weighed quantity of resin-coated flakes into the forming box. The weighed charge of flakes was laid down in a mat inside the forming box by distributing them evenly over a screen which was vibrated by hand. The screen had 1-inch-square mesh. The forming box was set directly on the bottom caul. This felting procedure is illustrated in the photograph in figure 7. The forming box was then lifted free of the mat, the steel stops were placed on each side, and an identification tag was placed on the surface of the mat. The mat of flakes is illustrated in figure 8. After placement of the top caul, the assembly was slid into the press. The press was closed immediately, and pressure up to 750 pounds per square inch was applied to bring the upper caul down to the steel stops as rapidly as possible. Rapid closure was desired to avoid the possibility of precure in the glue lines. The press cycle, including closing time (40 seconds), was 15 minutes at 325° F. The finished board, as it came from the press, is illustrated in figure 9. The boards were allowed to cool, and then they were trimmed and cut into the required test specimens.

Four samples from each board fabricated were weighed and measured to determine whether the board actually was of the desired specific gravity. In two cases, boards were detected which did not meet the requirements and replacements were made. All the preceding fabrication work was carried out at the U. S. Forest Products Laboratory.

Figure 7.--Hand felting methods used in board lay-up


WILLIAMS-WHITE
MOLINE
SAVE
M 100 678

Figure 8.--Mat of flakes ready for pressing, 1/2-inch steel stops in place

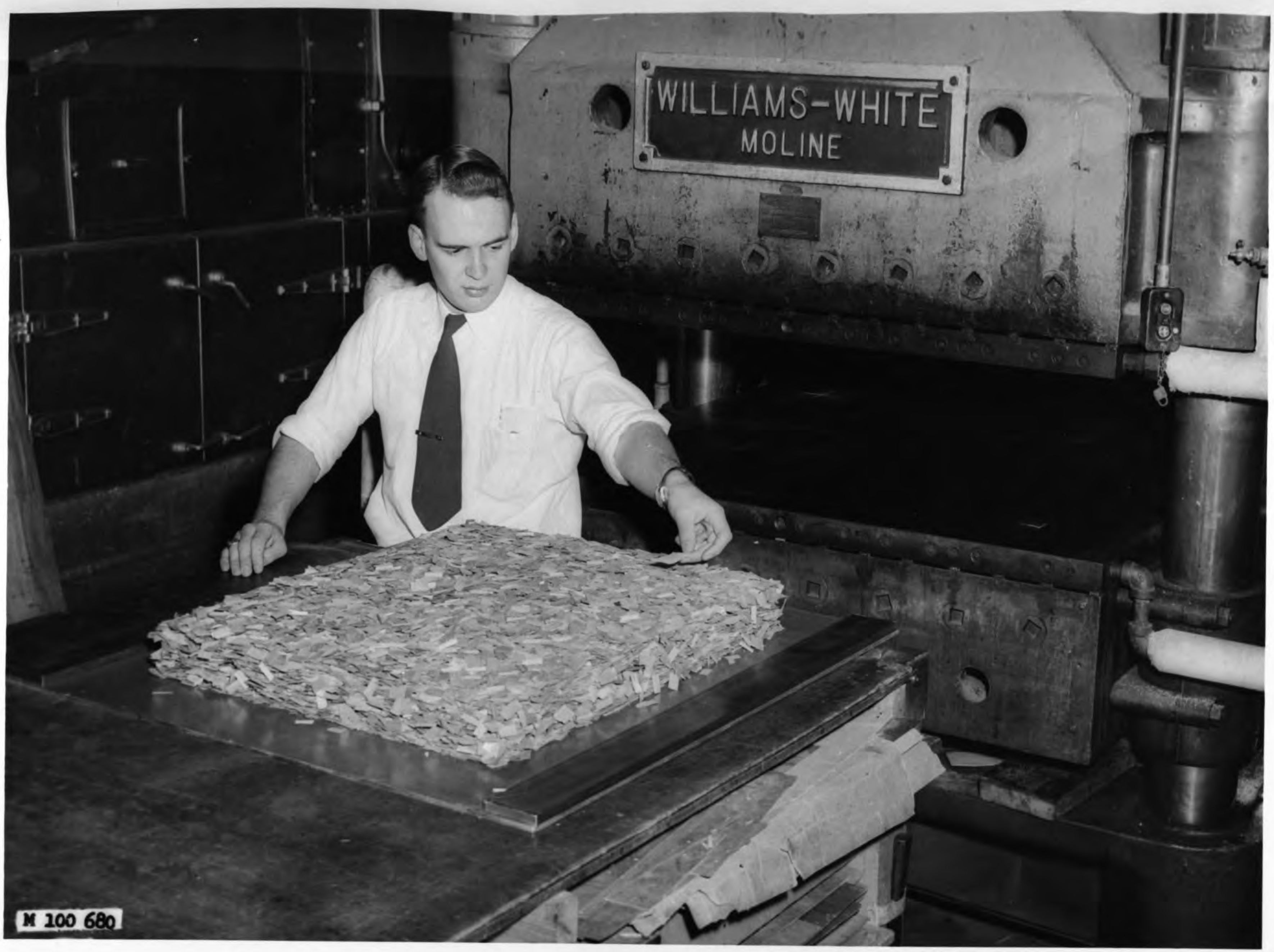

WILLIAMS-WHITE
MOLINE
M 100 680

Figure 9.--Finished board after removal from press


MOLINE
M 100 681

F. Testing Procedure

The static bending test and the tension test perpendicular to the surface were carried out according to the accepted tentative standards *(1). The specimens for these tests were stored at constant relative humidity conditions for a period of 1 month prior to testing. The average moisture content of the boards as they came from the press was about 2 percent.

The average moisture content for the aspen boards was 6.6 percent, while that for the yellow birch was 7.4 percent. The percentage resin content present in the boards appeared to have little or no effect on these moisture contents. It is a known fact that the strength of the wood varies as the moisture content varies. The slight difference in the moisture content undoubtedly makes some difference in the strength values determined and acts as another variable. As the moisture content difference is less than 1 percent, it will be assumed that this variable is negligible.

The test specimens were brought to equilibrium and tested at Michigan State University. A <u>Baldwin Emery Testing Machine</u> was used. There were four replications of each of the aforementioned tests within each board replication.

Dimensional stability was measured by determining the percent change in length and thickness. The test specimens were first brought to equilibrium by placing them in a controlled room at 80° F. and 30 percent relative humidity for 1 month. An 18-inch length was measured to the nearest 0.001 inch, and the thickness was measured to the nearest 0.001 inch. The test specimens were then placed in another

controlled room at 80° F. and 80 percent relative humidity for 1 month. At the end of this period the specimens were again measured and the percent change, based on the dimension at the first measurement, was calculated. There were two test specimens taken from each board. The dimensional stability measurements were made at the U. S. Forest Products Laboratory.

III. Results

A. Data Discussion

Several strength characteristics were calculated from the strength tests. The averages of these data for each board type are summarized in table 3.

The dimensional stability data are included in table 3. The change in thickness was considerable compared to the change in length. The change for thickness ranged from 6 to 11 percent, while the change in length was consistently below 0.2 percent.

The average property values for each board type were plotted in graphic form. A visual inspection of the graphic results suggests certain relationships. For the five strength properties tested, graphs appearing in figure 10 through figure 14, it appears that boards made with aspen, the wood of low specific gravity, have consistently higher strength values. For the percent change in length graph, figure 15, it appears that aspen has a smaller dimensional change. The graph for the percent change in thickness, figure 16, shows no apparent relationships. Comparing the percent change in strength properties between boards of different specific gravity indicates another relationship which bears out Klauditz's work. That is, as the board density is increased, the strength properties of boards made with woods of different specific gravity have a tendency

Table 3.--Summary of average strength and dimensional stability values determined in testing

Board type	Moisture content	Specific gravity[1]	Modulus of rupture	Proportional limit stress	E	Work to maximum load	Tension perpendicular surface	Change thickness	Change length
	Percent		P.s.i.	P.s.i.	P.s.i.	In.-lb. per $in.^3$	P.s.i.	Percent	Percent
Aspen 4 percent, 35 lbs.	6.8	0.56	4,760	1,930	788,000	2.28	44.4	10.1	0.11
Aspen 8 percent, 35 lbs.	6.6	.56	5,370	2,390	765,000	2.71	129.7	7.8	.12
Aspen 4 percent, 45 lbs.	6.5	.72	6,150	2,920	993,500	3.00	49.5	9.1	.12
Aspen 8 percent, 45 lbs.	6.6	.73	7,850	2,770	1,057,000	4.01	156.5	7.5	.12
Yellow birch 4 percent, 35 lbs.	7.6	.56	1,940	1,220	579,000	.70	16.2	8.4	.17
Yellow birch 8 percent, 35 lbs.	7.5	.57	2,370	1,390	635,500	.91	38.5	7.6	.16
Yellow birch 4 percent, 45 lbs.	7.3	.72	4,510	2,200	868,500	1.74	43.4	10.8	.16
Yellow birch 8 percent, 45 lbs.	7.4	.73	5,960	2,810	955,000	2.67	131.4	8.0	.16

[1]Specific gravity of board based on ovendry weight and volume at equilibrium in constant conditions of 75° F. and 65 percent relative humidity.

Fig. 10 Effects of Resin Content and Board Density on the Modulus of Rupture for Particle Board Relative to the Specific Gravity of the Wood Used.

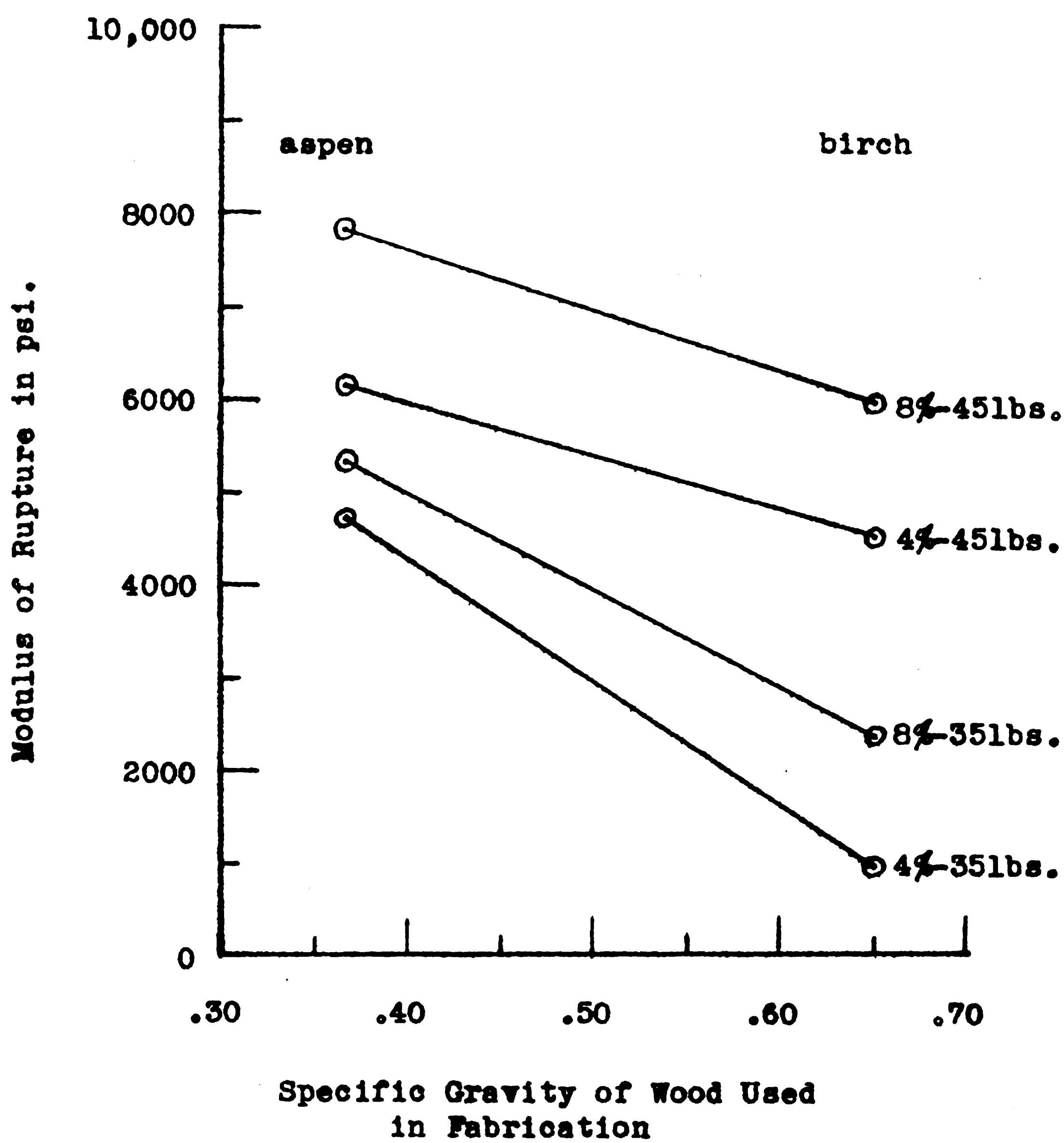


Fig. 11 Effects of Resin Content and Board Density on the Proportional Limit Stress for Particle Board Relative to the Specific Gravity of the Wood Used.

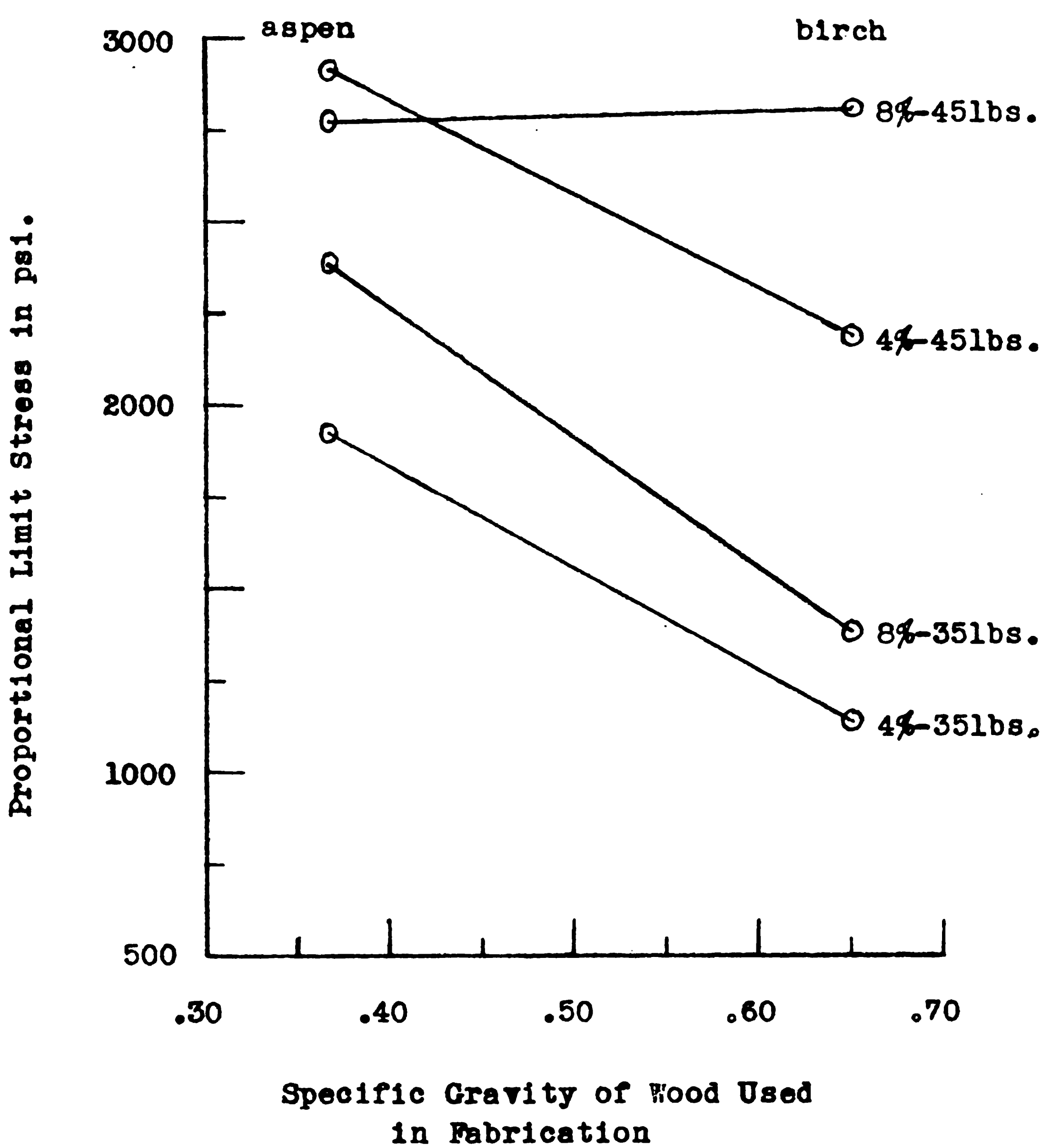


Fig. 12 Effects of Resin Content and Board Density on the Modulus of Elasticity for Particle Board Relative to the Specific Gravity of the Wood Used.

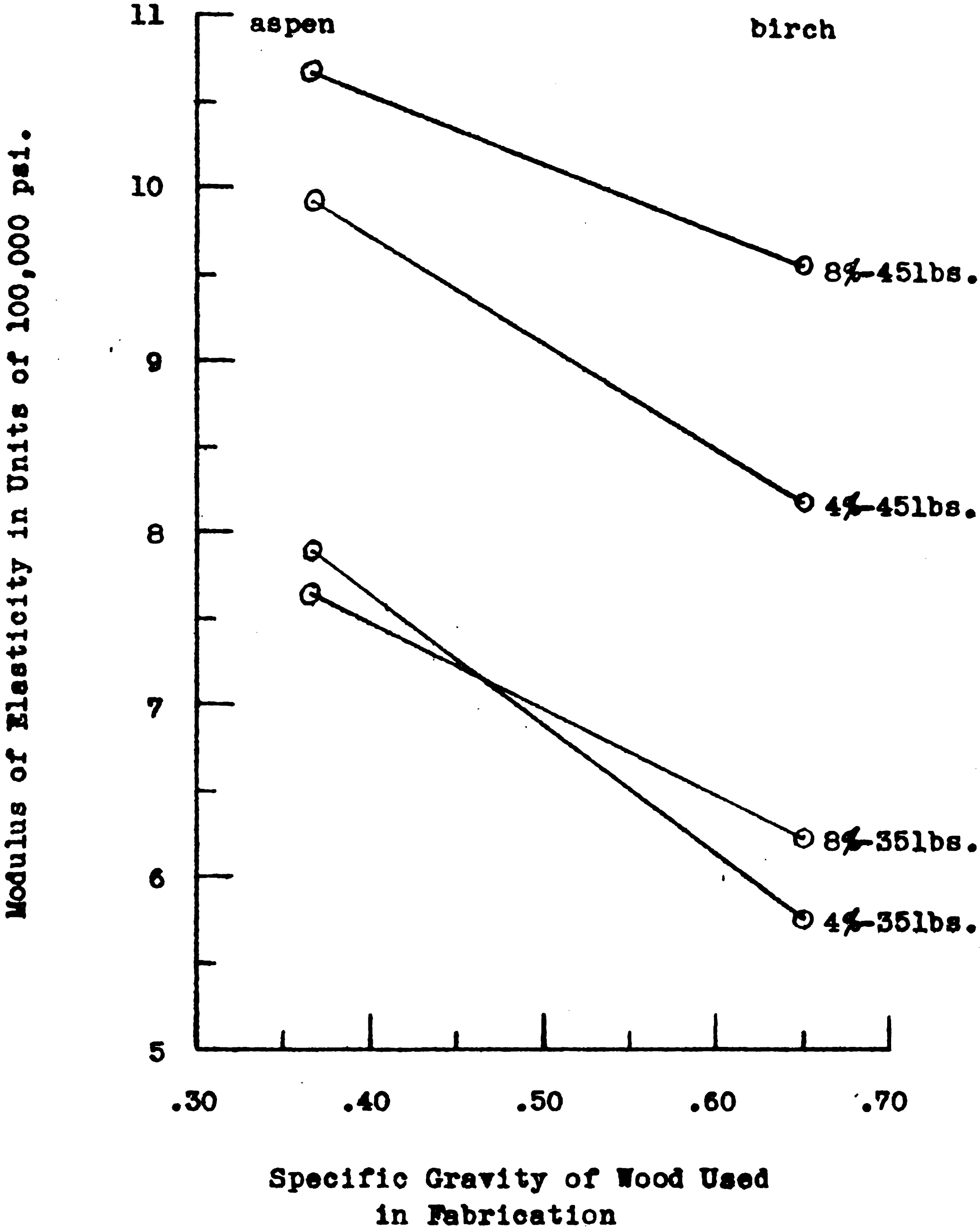


Fig. 13 Effects of Resin Content and Board Density on the Work to Maximum Load for Particle Board Relative to the Specific Gravity of the Wood Used.

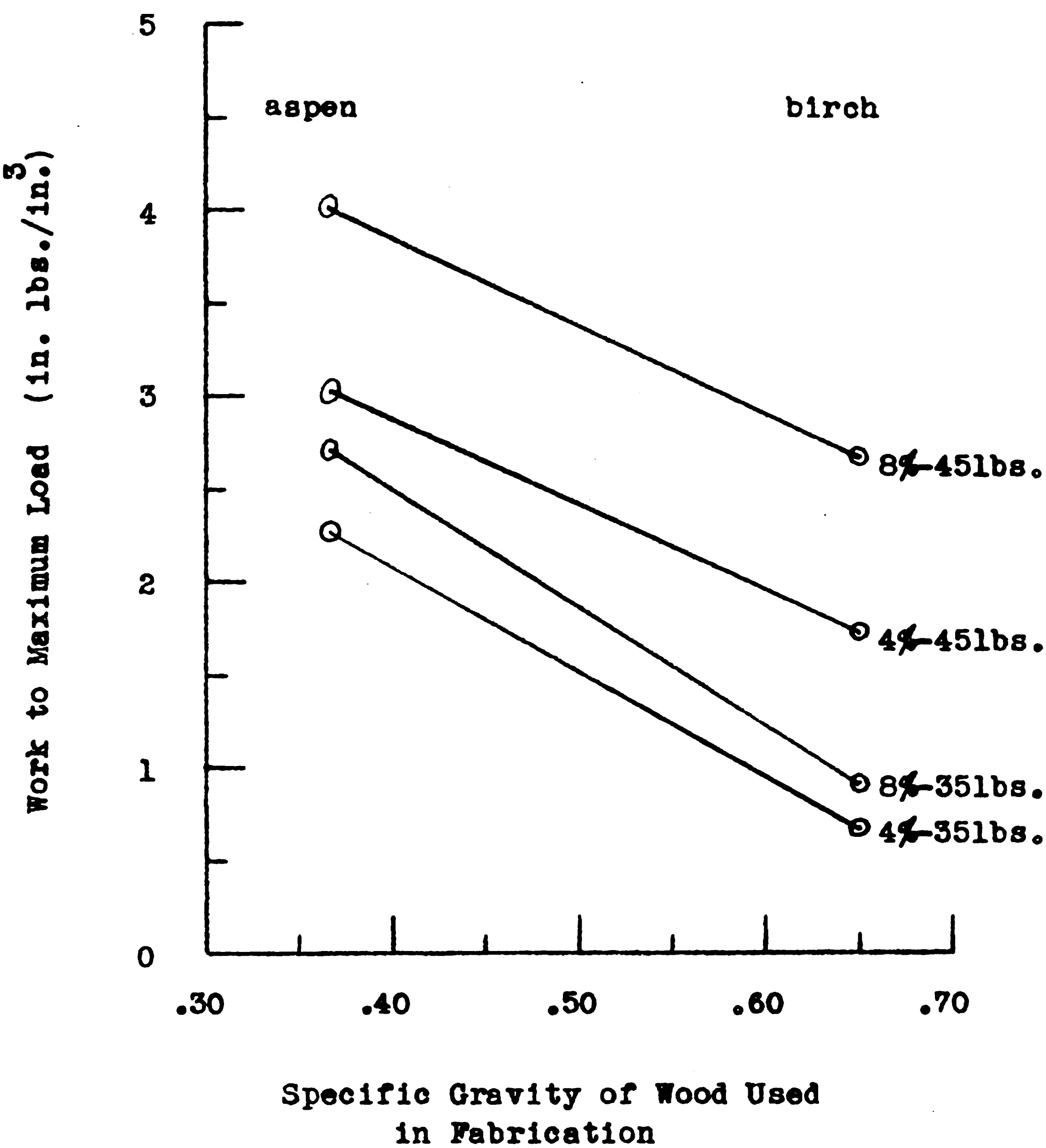


Fig. 14 Effects of Resin Content and Board Density on the Tension Perpendicular to the Surface for Particle Board Relative to the Specific Gravity of the Wood Used.

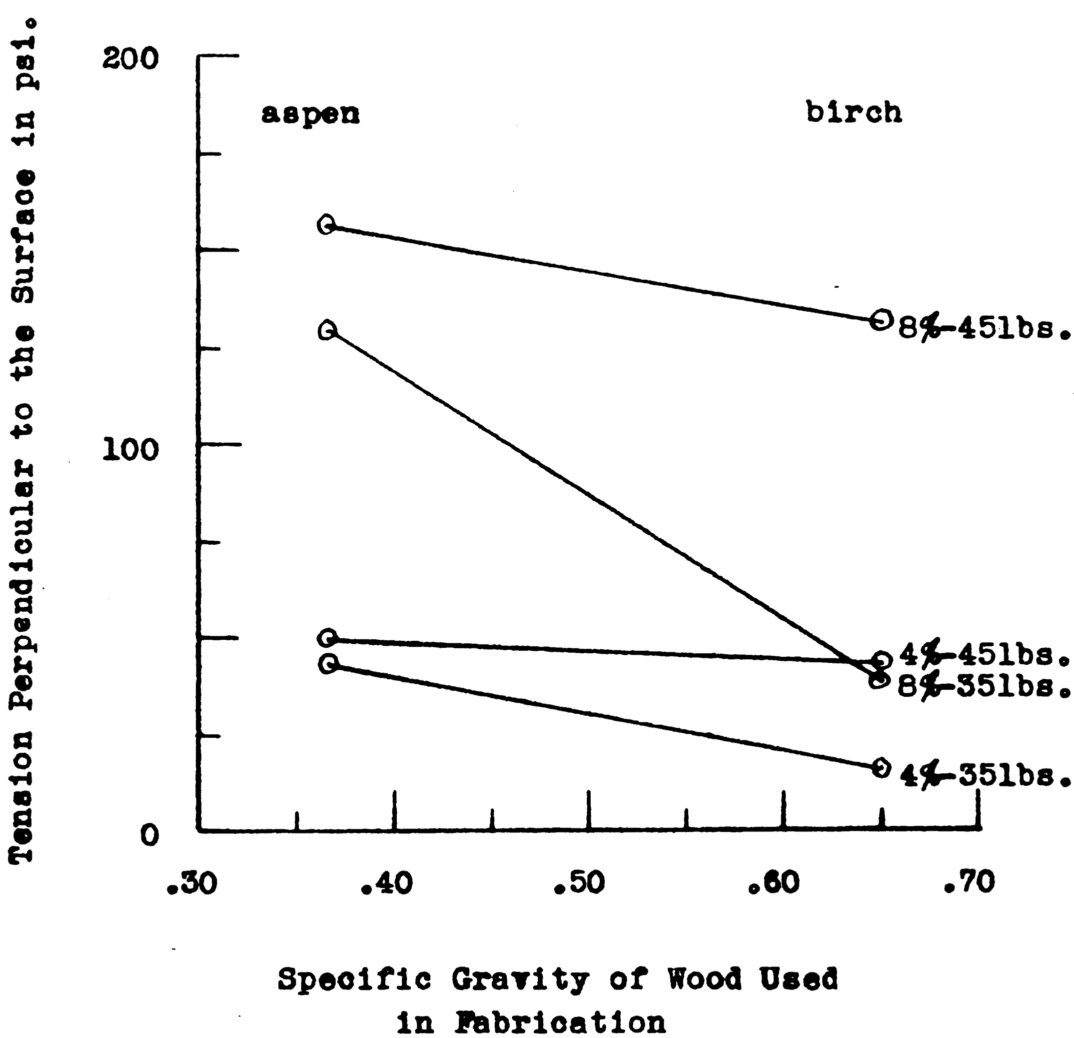
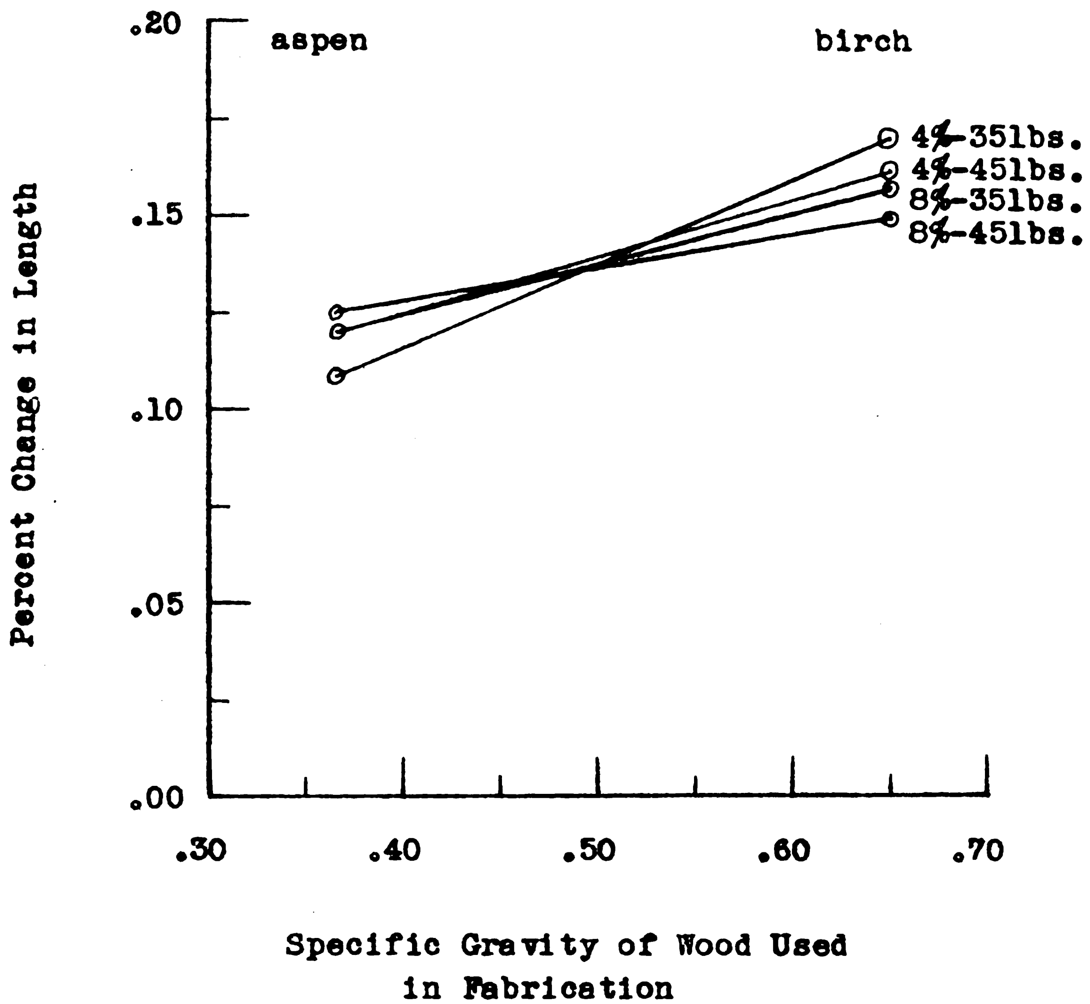


Fig. 15 Effects of Resin Content and Board Density on the Percent Change in Length for Particle Board Relative to the Specific Gravity of the Wood Used.



to equalize. In other words, at some high board density the modulus of rupture for boards made of woods of varying specific gravity will be equal or nearly so.

B. Statistical Analysis

Duncan's text on Quality Control and Industrial Statistics *(3) was closely followed in the selection of the proper error mean squares to be used for testing each variable.

An analysis of variance was performed first for the board specific gravities within each specific gravity class. In other words, an analysis of variance was performed to determine whether there were any boards in the 0.56 specific gravity class having significantly different specific gravities. A similar analysis was performed for the 0.72 specific gravity class. There was no significant difference within the specific gravity classes. These analyses are shown in table 4.

After the strength and dimensional properties of the boards were calculated, an analysis of variance for the three variables was performed. From the analysis of variance, an $\underline{F}$ test was made. The analysis of variance tables for the properties investigated are given in table 5 through table 11. A summary of the results of these seven analyses is given in table 12.

The statistical analyses showed that the specific gravity of the wood used in fabricating the particle boards influenced the modulus

Table 4.--Analysis of variance for board specific gravities

	DF	Sum Sq	Mn Sq	F	$F_{.05}$	$F_{.01}$
		CLASS AVERAGE 0.563				
Total	47	0.01177				
Between boards	11	.00097	0.00008	0.267	2.06	2.78
Within boards	36	.01080	.00030			
		CLASS AVERAGE 0.723				
Total	47	.01733				
Between boards	11	.00509	.00046	1.353	2.06	2.78
Within boards	36	.01224	.0034			

Table 5.--Analysis of variance for modulus of rupture

	DF	Sum Sq	Mn Sq	F	$F_{.05}$	$F_{.01}$
Total[1]	23	82,474,395				
W.S.[1]	1	32,799,802	32,799,802	16.51	161	4,050
R.[2]	1	6,611,850	6,611,850	3.99	161	4,050
B.S.[3]	1	37,762,959	37,762,959			
W.S. x R.	1	64,792	64,792	.65	4.49	8.53
W.S. x B.S.	1	1,982,026	1,982,026	19.89**	4.49	8.53
R. x B.S.	1	1,657,428	1,657,428	16.63**	4.49	8.53
R. x W.S. x B.S.	1	1,819	1,819	.02	4.49	8.53
Error term	16	1,593,719	99,607			

[1]W.S. stands for wood specific gravity.

[2]R. stands for resin content.

[3]B.S. stands for board specific gravity.

Note: The independent board specific gravity can not be tested because of the significant interactions.

Table 6.--Analysis of variance for proportional limit stress

	DF	Sum Sq	Mn Sq	F	$F_{.05}$	$F_{.01}$
Total	23	9,511,896				
W.S.[1]	1	2,163,602	2,163,602	5.37	161	4,050
R.[2]	1	444,418	444,418	1.11	161	4,050
B.S.[3]	1	5,339,267	5,339,267	13.25	161	4,050
W.S. x R.	1	97,478	97,478	2.44	4.49	8.53
W.S. x B.S.	1	403,522	403,522	10.11**	4.49	8.53
R. x B.S.	1	26,433	26,433	.60	4.49	8.53
R. x W.S. x B.S.	1	397,453	397,453	9.94**	4.49	8.53
Error term	16	639,723	39,983			

[1]W.S. stands for wood specific gravity.

[2]R. stands for resin content.

[3]B.S. stands for board specific gravity.

**Significance at the 1 percent level.

Table 7.--Analysis of variance for modulus of elasticity

	DF	Sum Sq	Mn Sq	F	$F_{.05}$	$F_{.01}$
Total	23	723,283				
W.S.[1]	1	106,073	106,073	11.54**	4.49	8.53
R.[2]	1	17,603	17,603	1.92	4.49	8.53
B.S.[3]	1	431,392	431,392	46.98**	4.49	8.53
W.S. x R.	1	1,850	1,850	.20	4.49	8.53
W.S. x B.S.	1	7,869	7,869	.86	4.49	8.53
R. x B.S.	1	8,547	8,547	.93	4.49	8.53
R. x W.S. x B.S.	1	3,026	3,026	.33	4.49	8.53
Error term	16	149,923	9,183			

[1]W.S. stands for wood specific gravity.

[2]R. stands for resin content.

[3]B.S. stands for board specific gravity.

**Significance at the 1 percent level.

Table 8.--Analysis of variance for work to maximum load

	DF	Sum Sq	Mn Sq	F	$F_{.05}$	$F_{.01}$
Total	23	26.84				
W.S.[1]	1	13.50	13.50	171 **	4.49	8.53
R.[2]	1	2.50	2.50	3.97	161	4,050
B.S.[3]	1	8.69	8.69	13.79	161	4,050
W.S. x R.	1	.03	.03	.38	4.49	8.53
W.S. x B.S.	1	.22	.22	2.78	4.49	8.53
R. x B.S.	1	.63	.63	7.98*	4.49	8.53
R. x W.S. x B.S.	1	.01	.01	.13	4.49	8.53
Error term	16	1.26	.079			

[1]W.S. stands for wood specific gravity.

[2]R. stands for resin content.

[3]B.S. stands for board specific gravity.

*Significance at the 5 percent level.
**Significance at the 1 percent level.

Table 9.--Analysis of variance for tension perpendicular

	DF	Sum Sq	Mn Sq	F	$F_{.05}$	$F_{.01}$
Total	23	65,251				
W.S.[1]	1	8,453	8,453			
R.[2]	1	34,247	34,247			
B.S.[3]	1	8,626	8,626			
W.S. x R.	1	2,542	2,542	8.33*	4.49	8.53
W.S. x B.S.	1	2,891	2,891	9.48**	4.49	8.53
R. x B.S.	1	2,878	2,878	9.44**	4.49	8.53
R. x W.S. x B.S.	1	734	734	2.41	4.49	8.53
Error term	16	4,880	305			

[1]W.S. stands for wood specific gravity.

[2]R. stands for resin content

[3]B.S. stands for board specific gravity.

*Significance at the 5 percent level.
**Significance at the 1 percent level.

Note: In the above analysis, all first order interactions are significant. There may also be independent biases, but they can not be tested.

Table 10.--Analysis of variance for percent change in thickness

	DF	Sum Sq	Mn Sq	F	$F_{.05}$	$F_{.01}$
Total[1]	23	48.25				
W.S.[1]	1	.02	0.02	0.00	161	4,050
R.[2]	1	21.10	21.10	20.68**	4.49	8.53
B.S.[3]	1	.88	.88	.15	161	4,050
W.S. x R.	1	.05	.05	.05	4.49	8.53
W.S. x B.S.	1	6.16	6.16	6.01*	4.49	8.53
R. x B.S.	1	.57	.57	.56	4.49	8.53
R. x W.S. x B.S.	1	3.07	3.07	3.00	4.49	8.53
Error term	16	16.40	1.02			

[1] W.S. stands for wood specific gravity.

[2] R. stands for resin content.

[3] B.S. stands for board specific gravity.

*Significance at the 5 percent level.
**Significance at the 1 percent level.

Table 11.--Analysis of variance for percent change in length

	DF	Sum Sq	Mn Sq	F	$F_{.05}$	$F_{.01}$
Total	23	0.0153				
W.S.[1]	1	.0102	0.0102	51.00**	4.49	8.53
R.[2]	1	.0000	.0000			
B.S.[3]	1	.0000	.0000			
W.S. x R.	1	.0007	.0007	3.50	4.49	8.53
W.S. x B.S.	1	.0004	.0004	2.00	4.49	8.53
R. x B.S.	1	.0000	.0000			
R. x W.S. x B.S.	1	.0000	.0000			
Error term	16	.0040	.0002			

[1]W.S. stands for wood specific gravity.

[2]R. stands for resin content.

[3]B.S. stands for board specific gravity.

**Significance at the 1 percent level.

Table 12.--Summary of statistical analysis, indicating variables for which significance was observed

Properties	Independent variables			First order interactions			Second order interactions
	W.S.	R.	B.S.	W.S. x R.	W.S. x B.S.	R. x B.S.	R. x W.S. x B.S.
Modulus of rupture					**	**	
Proportional limit stress					**		**
Modulus of elasticity	**		**				
Work to maximum load	**					*	
Tension perpendicular to surface				*	**	**	
Percent change in thickness		**			*		
Percent change in length	**						

*Indicates significance at the 5 percent level.
**Indicates significance at the 1 percent level.

Note: W.S. stands for wood specific gravity.
R. stands for resin content.
B.S. stands for board specific gravity.

of elasticity, the work to maximum load, and the percent change in length. In these three cases, the wood with the lower specific gravity showed an improved value for each property.

None of the independent board variables could be tested for tension perpendicular to the surface because all three first order interactions were significant.

The statistical analysis showed that the resin content used in fabricating the boards influenced the percent change in thickness. Eight percent resin solids resulted in reduced thickness change over the 4 percent resin level.

The statistical analysis showed that the specific gravity of the boards influenced the modulus of elasticity. Boards of high specific gravity had higher modulus of elasticity values than boards of low specific gravity.

The statistical analyses do not consistently substantiate the apparent relationships as indicated by the graphs of the actual strength values. There may be supporting significant differences which are not shown in the analyses of variance. There are two possible reasons why these differences do not appear. One is that interactions are so large and the other is that there are so few degrees of freedom in the analyses.

IV. Discussion

The hand felting methods used in fabricating the particle boards for this study are a subject of controversy. It is felt by some men in the field that without complete automation in the felting process a uniform board can not be fabricated. All that can be done in any type of felting procedure is to distribute a uniform layer of uncompacted particles on the caul. The forming box used in this work was merely a boundary to define the overall dimensions of the pressed panels. In an automatic felting system, the particles are distributed on a moving conveyor by any of a number of feed mechanisms. The only difficulties encountered in the hand felting system used here was the sticking together of groups of flakes for board types that had heavy resin coverage per flake. These groups were broken up partially by hand and again by the vibrating screen over the forming box, so that, in general, single flakes fell onto the mat. The forming box had a series of horizontal lines 1 inch apart on the inside walls. Low areas were built up progressively by sifting more flakes over these areas than over the higher areas. In no cases were high areas compacted to produce a uniform height of mat. The boards made from wood of high specific gravity and at low board specific gravities did show areas of low density and of high density on the cross section.

V. Conclusion

It may seem strange that a wood of low strength properties (aspen) should produce a particle board with higher strength properties than another board made with a wood of high strength. The answer lies in the specific gravity of the wood and the requirements for a good glue bond. A given weight of flakes of a low specific gravity wood occupies a greater volume than the same weight of similar flakes of a wood of high specific gravity. When these volumes of wood are compressed to the dimensions of a board, a higher relative contact will occur for the greater volume of wood, and a better glue bond between flakes results. There is a greater glue spread per unit of particle surface for the birch flakes as compared to the aspen flakes, but the higher relative contact of the aspen flakes still controls strength properties for medium density particle boards. For high density boards, the glue spread per unit area of particle surface would become the controlling factor.

The scope of this problem is not large, and consequently the results of the work can not be reliably applied over a wide range of wood species. Density of woods rather than species should be used as the basis for comparison. The results should prove reliable for medium density particle boards made with hardwoods.

In general, the use of high density hardwoods for the manufacture of particle boards in the medium density range should be discouraged.

Aspen is one of the hardwoods that will produce excellent flake board.

Further basic research along these lines should improve our ability to predict properties for the boards made with known variables.

List of References

1. American Society for Testing Materials. Tentative Methods of Test for Evaluating the Properties of Building Fiberboards. D 1037-56T.

2. Carlye, A. A., McGee, L. B., and McLean, R. A. Wood Particle Board Handbook. The Industrial Experimental Program of the School of Engineering, North Carolina State College, Raleigh, North Carolina. August, 1956.

3. Duncan, Acheson J. Quality Control and Industrial Statistics. Richard D. Irwin, Inc. Chicago. Homewood, Illinois, First Edition, 1952.

4. Forest Products Laboratory. Wood Handbook. Handbook No. 72, U. S. Department of Agriculture. U. S. Government Printing Office, Washington, D. C.

5. Klauditz, W. Untersuchungen uber die Eignung von verschiedenen Holzarten, insbesondere von Rotbuchenholz zur Herstellung von Holzspanplatten. Institut fur Holzforschung Braunschweig, Bericht 25, 1952.

6. Lewis, Wayne C. Testing and Evaluating Procedures for Building Boards. Forest Products Research Society Journal, July, 1956, Preprint 1016.

7. Marin, Joseph. Engineering Materials Their Mechanical Properties and Applications. Prentice-Hall, Inc., Englewood Cliffs, New Jersey. Fourth Edition, January, 1956.

8. Turner, H. Dale. Effect of Particle Size and Shape on the Strength and Dimensional Stability of Resin-Bonded Wood Particle Panels. Forest Products Research Society Journal, 1954, Preprint 575.