THE PRESS CYCLE AS A PROCESS VARIABLE IN FLAKE BOARD MANUFACTURING AND ITS EFFECT ON BOARD PROPERTIES

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A B S T R A C T

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The problem studied here was the effect of certain raw-material and process variables on the properties of a homogeneous wood flake board. Sample boards were made in which the variables were moisture distribution, initial pressure, and overall board density. The study emphasized the effects of these variables on the distribution of the density through the thickness of the finished boards; and in turn, the effect of the density distribution on the elastic properties of the board, especially the modulus of elasticity.

Also included was a study of the temperature changes at different points in the board during pressing. This was used to explain the drying process of the boards in the heated press.

It was found that the three variables had a considerable influence on the density distribution in the finished board and this in turn had an influence on the modulus of elasticity of the boards. The density of the surface layers of the boards was increased by adding moisture to the surface of the mat before pressing, by increasing the initial pressure; and the relative density of the face layers was increased by decreasing the overall board density.

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INTRODUCTION

The manufacture of wood particle board is essentially a laminating process in which a batch of small wood particles in the form of flakes, chips, or splinters is mixed with a binder and compressed into a thin sheet in a heated press. Flake boards, one type of particle board, is composed of small, thin, rectangular flakes of wood (8).

There are two types of variables involved in the manufacture of wood flake board which affect the properties of the finished board: 1. the raw-material variables and 2. the variables of the press cycle. The raw-material variables are flake species, flake geometry, flake moisture content, and glue content (9).

The variation in properties would obviously affect the density, compressibility, etc. of flakes produced from the various species. By flake geometry is meant the size and shape of the individual flakes. Most flakes are produced with a thickness within the range of 0.005 inch to 0.015 inch, a width of 1/8 to 3/8 inch, and a length of 1/2 to 1 inch. Flakes are usually cut by means of planer-type knives set into the face of a circular disc. The flake length is controlled by scoring knives projecting from the disc or by precutting the boards to length. The flake thickness is controlled by adjusting the projection of the knives. The width of the flake is the most variable of its dimensions. It is random and depends on the type of cutting machine used. Further reduction by hammermilling is generally necessary.

The flake moisture content is usually kept within the range of 6 to 12 per cent. Sometimes, however, the moisture content of the surface-layer flakes is increased to as high as 30 per cent in order to attain desired results in the properties of the finished board.

The adhesive used in the manufacture of wood flake board is a thermosetting, synthetic resin; for example, urea formaldehyde or phenol formaldehyde. The amount of adhesive added is usually between 6 and 12 per cent based on the dry weight of the flakes. A water solution of the adhesive containing about 50 to 60 per cent solids is sprayed onto the flakes in some type of rotating mixer.

The variables of the press cycle are press temperature, initial pressure, and press time (9). Commercial operations use multiple-opening hydraulic hot presses which have high heat capacities. Press temperatures in the range of 300 to 350° F. are necessary for adequate curing of the glue. The press temperature is kept constant during the pressing time. The initial pressure is that which is applied to the mat of flakes in order to compress it to some predetermined thickness. This thickness is controlled by steel stops which are placed in the press. The time it takes for the press to reach these stops is called the press closing time. The initial pressure may vary from 100 psi in some operations to as high as 500 psi in others. The purpose of the pressure is to bring about the largest possible contact area between the flakes. The length of the press cycle is defined as the total time that the board is in the press. Usually 8 to 12 minutes are necessary to insure an adequate curing of the glue. The press cycle is discussed in detail below.

THE PRESS CYCLE

The relationships between the variables which make up the press cycle are demonstrated by a test involving the use of a stack of veneers in place of a mat of flakes. A stack of veneers 0.60 inch in thickness was placed between heated platens which were mounted in a testing machine. The temperature of the platens was 300° F. A predetermined load was applied and held constant until the veneer stack had been compressed to a thickness of 0.50 inch. The machine was then shut off for the remainder of 10 minutes. The changes in pressure and veneer thickness with time were recorded for the 10-minute "press cycle".

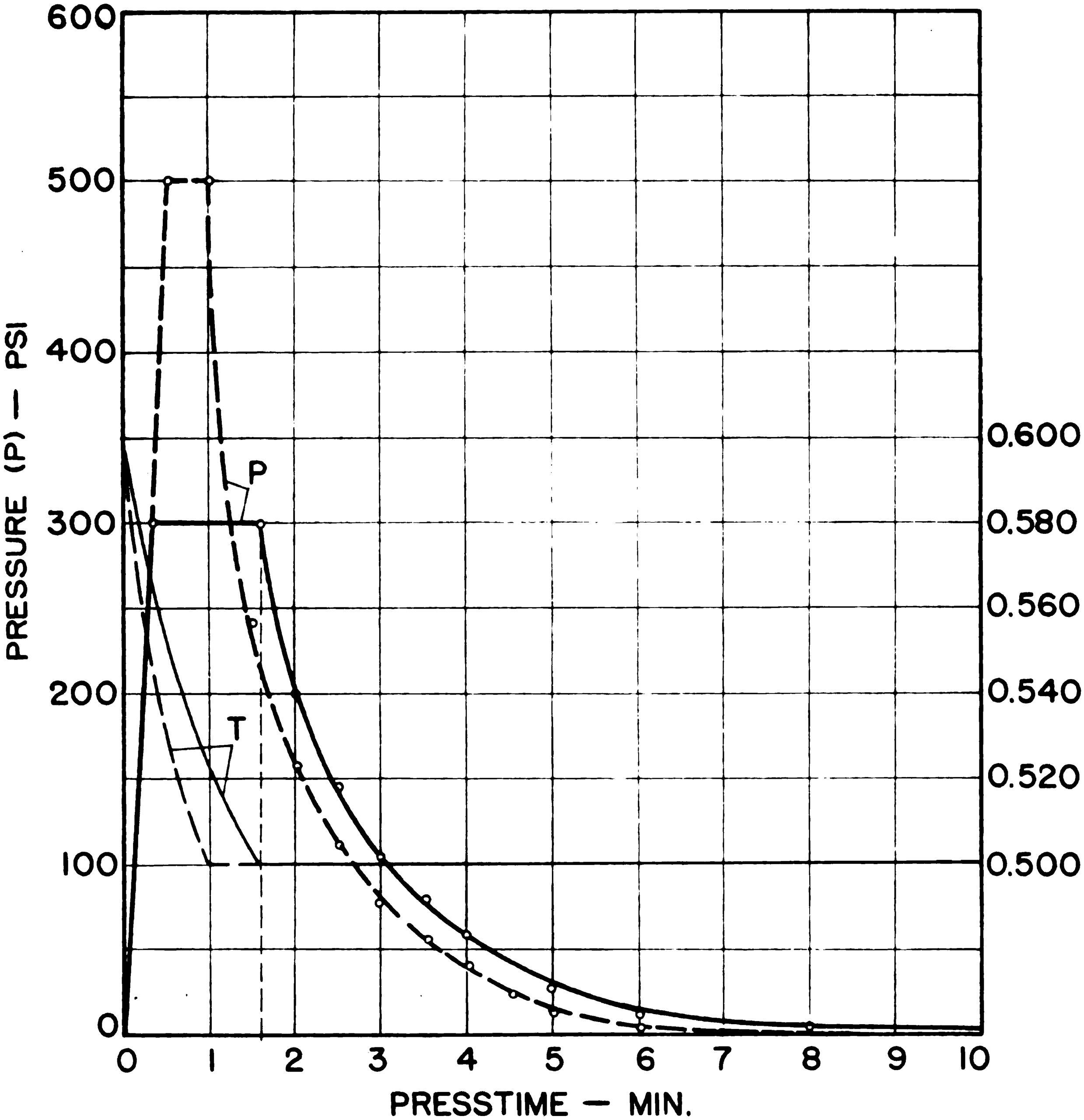
Figure 1 and Figure 2 show the result of the test on birch veneers and prima vera veneers respectively. The stack of 0.035-inch birch veneers at an initial moisture content of 13.8 per cent was compressed from a density of o.665 gm/cm^3 to a density of 0.790 gm/cm^3. The stack of 0.037-inch prima vera veneers at an initial moisture content of 10.3 per cent was compressed from a density of 0.500 gm/cm^3 to a density of 0.600 gm/cm^3. Figure 1 shows that the higher initial pressure results in a shorter "closing time" and a greater drop off in pressure afterwards. Figure 2 shows that if the initial pressure is not sufficiently high, the veneers cannot be compressed to the desired thickness even though the pressure is maintained for a considerable length of time.

A comparison of Figures 1 and 2 would suggest that moisture content has some effect on the compressibility of the veneers. The birch veneers had an initial moisture content 3.5 per cent higher than the

Figure 1. "Press Cycle" for Birch Veneer Stacks

Veneer thickness	0.035 inch
Initial moisture content	13.8%
Initial density	0.665 gm/cm^3
Final density	o.790 gm/cm^3

fig. 1

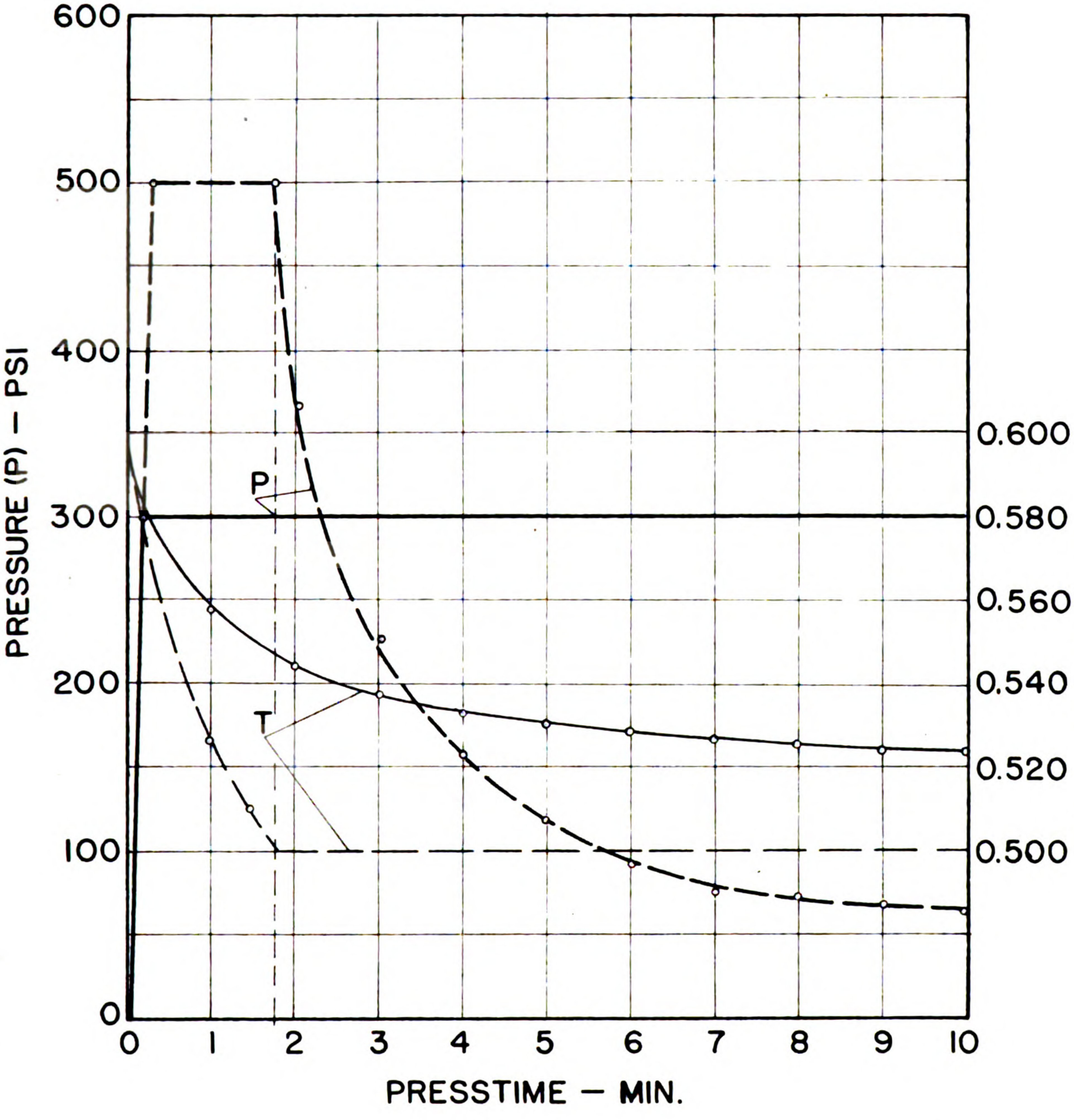


600
500
400
300
200
100
0
PRESSURE (P) — PSI
0.600
0.580
0.560
0.540
0.520
0.500
THICKNESS (T) — IN
P
T
0
1
2
3
4
5
6
7
8
9
10
PRESSTIME — MIN.

Figure 2. "Press Cycle" for Prima Vera Veneer Stacks

Veneer thickness	0.037 inch
Initial moisture content	10.3%
Initial density	0.500 gm/cm^3
Final density	0.600 gm/cm^3

Fig.


PRESSURE (P) — PSI
THICKNESS (T) — IN
PRESSTIME — MIN.
P
T
600
500
400
300
200
100
0
0.600
0.580
0.560
0.540
0.520
0.500
0 1 2 3 4 5 6 7 8 9 10

prima vera veneers. At the 500 psi level, the "closing time" of the birch veneers was 45 seconds shorter than that of the prima vera, in spite of the higher density and compressive strength of birch.

Expressing the results of this study in terms of the manufacture of flake board, the press cycle can be separated into two parts. The first part of the cycle is the period during which the flake mat is compressed to a desired thickness. The period of time covered by this part of the press cycle is the closing time of the press. The remainder of the press cycle comprises the second part. During the first part, the initial pressure is built up and remains constand until the press closes. The deflection of the mat during this time is a process involving heat and moisture transfer inward from the mat surface. This movement of heat and moisture causes a decrease in the compressive strength of successive layers of flakes. The consequence of this successive weakening of layers is an uneven density distribution through the thickness of the finished board. The highest density will occur at the point in the board thickness where the effect of heat and moisture is greatest. The density distribution in the finished board is, therefore, determined during the first part of the press cycle while the full initial pressure is acting on the mat. During the second part of the press cycle, the pressure on the board is indeterminate and usually decreases as a function of time.

REVIEW OF LITERATURE

Only one article was found in which the author actually plotted curves of the density distribution through the thickness of the board (7). Considerable work, however, has been done in the area of raw-material and press cycle variables and their effect on the properties of flake board. Also useful information was found in a study of the effect of heat and moisture on the strength of solid wood (2).

M. D. Strickler found in a study of Douglas-fir flake board that a density distribution is the direct result of varying the press cycle and moisture content. He found that by increasing the initial pressure, the density of the surface layers was increased and the center density was decreased. An increase in the moisture content of the surface layers had the same effect if the initial pressure was high but for lower pressures the point of maximum density occurred at a point about 1/4 the distance from the surface of the board to the center. When the initial moisture content of the flakes was low and the boards were produced with a low overall density, the density distribution tended to "even out".

The mechanical properties of the board illustrate the effect of pressure and moisture on the density distribution. The modulus of elasticity generally increased with an increase in initial moisture content and initial pressure. The effect of moisture distribution is shown by the fact that the modulus of elasticity increased with an increase in surface-layer moisture content up to about 21 per cent moisture content, then decreased. Too much moisture adversely affects the gluing process, and therefore decreases the density of the surface layers.

Strickler used thermocouples placed in the mats to study the temperature increase during the pressing. Initial pressure, moisture, and moisture distribution all influenced temperature increase. Heating up of the center of the board was accelerated by increasing the initial pressure, increasing the initial overall moisture content, and increasing the surface moisture content. Increasing the overall density of the boards did not have any significant influence on temperature increase.

The press cycles used in the study were somewhat artificial since the boards were not pressed to stops. Therefore, the effect of the closing time could not be evaluated because there was no determinable closing time.

Heat transfer was the subject of a study conducted by T. F. Duncan (1). He studied the effects of heat transfer on the properties of 3/4-inch particle board in which he varied the particle geometry, overall board density, press temperature and resin type. He found that the board density did affect the rate of heat transfer. He noted that the center-line temperature of the denser boards was lower than that of the less-dense boards at the same platen temperature. This was attributed to the fact that although heat conductivity is directly related to density, the amount of heat required to increase the temperature of the denser board is greater than that required for a low-density board. He indicated that the leveling off of the time-temperature curves was probably due to either moisture escaping from the board or a temperature gradient being set up in which the flakes lost heat as fast as they absorbed it.

Another study on heat transfer was conducted by G. Rackwitz (6). A temperature increase in the board above 100° C. can best occur if all the moisture in the board is converted to steam. Then, according to Rackwitz, this temperature increase follows the laws of equilibrium moisture content of wood in superheated steam. The center of the board always has the lowest temperature and highest moisture content. As the steam pressure builds up in the center of the board, the temperature increases. Therefore the temperature gradient between the center of the board and the surface decreases, resulting in an increased heating time.

The heating time necessary to cure the adhesive is expressed by the following formula (6):

$$t = K(1.87U_a - 9.3)\left(\frac{2d}{20}\right)^{1.75}$$

in which t = heating time in minutes

K = temperature factor depending upon the platen temperature (K decreases with increased platen temperature)

U_a= initial flake moisture content in per cent

$2d$= board thickness in mm

According to this formula, the press cycle can be shortened by decreasing the initial moisture content of the flakes or by increasing the platen temperature. Shortening the press cycle would increase production in a commercial operation, but either of the above-mentioned methods would have adverse effects on the finished board quality. A better method of increasing production would be to add more openings to the press.

R. Keylwerth (5) analyzed the importance of moisture content on the density distribution in one- and three-layer flake boards. In the production of flake board, the extent to which wood is plasticized depends upon the temperature of the wood, the wood moisture content, and the pressure. This "softening" of the wood is important in flake board because it affects the amount of contact area achieved when the mat of flakes is pressed. If it is assumed that wood does not have a pronounced yield point, then the proportional limit can be considered to be the starting point of plastic deformation.

E. L. Ellwood (2) studied the effect of temperature on the mechanical properties of beech in compression perpendicular to the grain. Keylwerth used the results of this study to show the relationship between the proportional limit stress (σp), the wood moisture content (m), and the wood temperature (T). This relationship is expressed by the formula:

$$\sigma p = 70 \log \frac{(100)}{(M)} - 0.454T \quad (kg./cm^2)$$

Figure 3, taken from Keylwerth's article, is the graphic representation of this formula. This graph shows that by increasing the moisture content and temperature, the proportional limit of the wood will be lowered.

Figure 4, also taken from Keylwerth's article, shows the effect of the moisture content of the flakes in the surface layer on the density of the surface layer, the density of the center of the board, and the overall density of the board. The values used in this graph were taken from a study by F. Fahrni (3) on the effects of high moisture contents in the surface layers.

Figure 4 shows that by increasing the moisture content of the surface layers, the density of the surface layers is increased without increasing the overall density of the board. The graph also indicates that there is a limit to the amount of water that can be added to the surface layers and still increase their density.

O. Suchsland (8) studied the effect of raw-material and process variables on the properties of a two-species, three-layer flake board. The core consisted of elm flakes and the faces were composed of aspen flakes. The thin, narrow, high-density elm flakes were less compressible than the thin, wide, low-density aspen flakes. This resulted in a sandwich-type construction in which the core density was lower than the face density.

Figure 5 shows the effect of the press closing time and the face material moisture content on the modulus of elasticity of this board. The two closing times of 0.5 min. and 1.5 min. were obtained by using initial pressures of 500 psi and 250 psi respectively. The graph is plotted in terms of shelling ratio, core density, and face density. These had to be determined before the effect of the raw-material and process variables on the finished board properties could be analyzed. The shelling ratio (λ) is defined as follows:

$$\lambda = \frac{\text{thickness of the two faces}}{\text{total thickness of the board}}$$

From Figure 5 it can be seen that the modulus of elasticity is increased by decreasing the closing time or increasing the moisture content of the face material. This increase in modulus of elasticity is due primarily to the increase in face density. At the same time, the core density decreases since the overall density of the board remained constant at about 0.700 gm/cm^3. The modulus of elasticity of a sandwich construction is dependent almost entirely on the stiffness of the face material.

Figure 3 Effect of temperature and moisture content on the proportional limit of American beech— reproduced from Keylwerth's article (5)

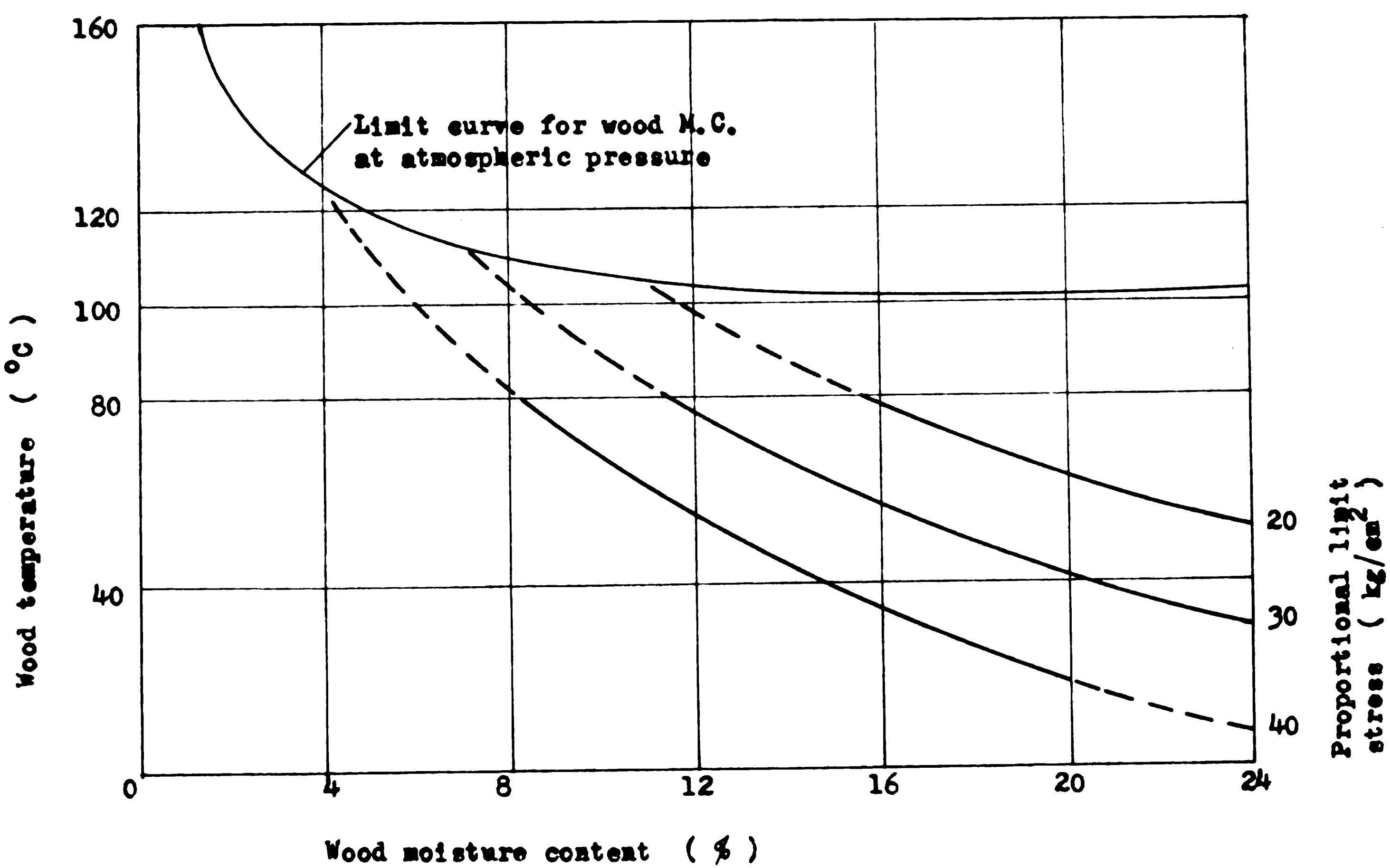
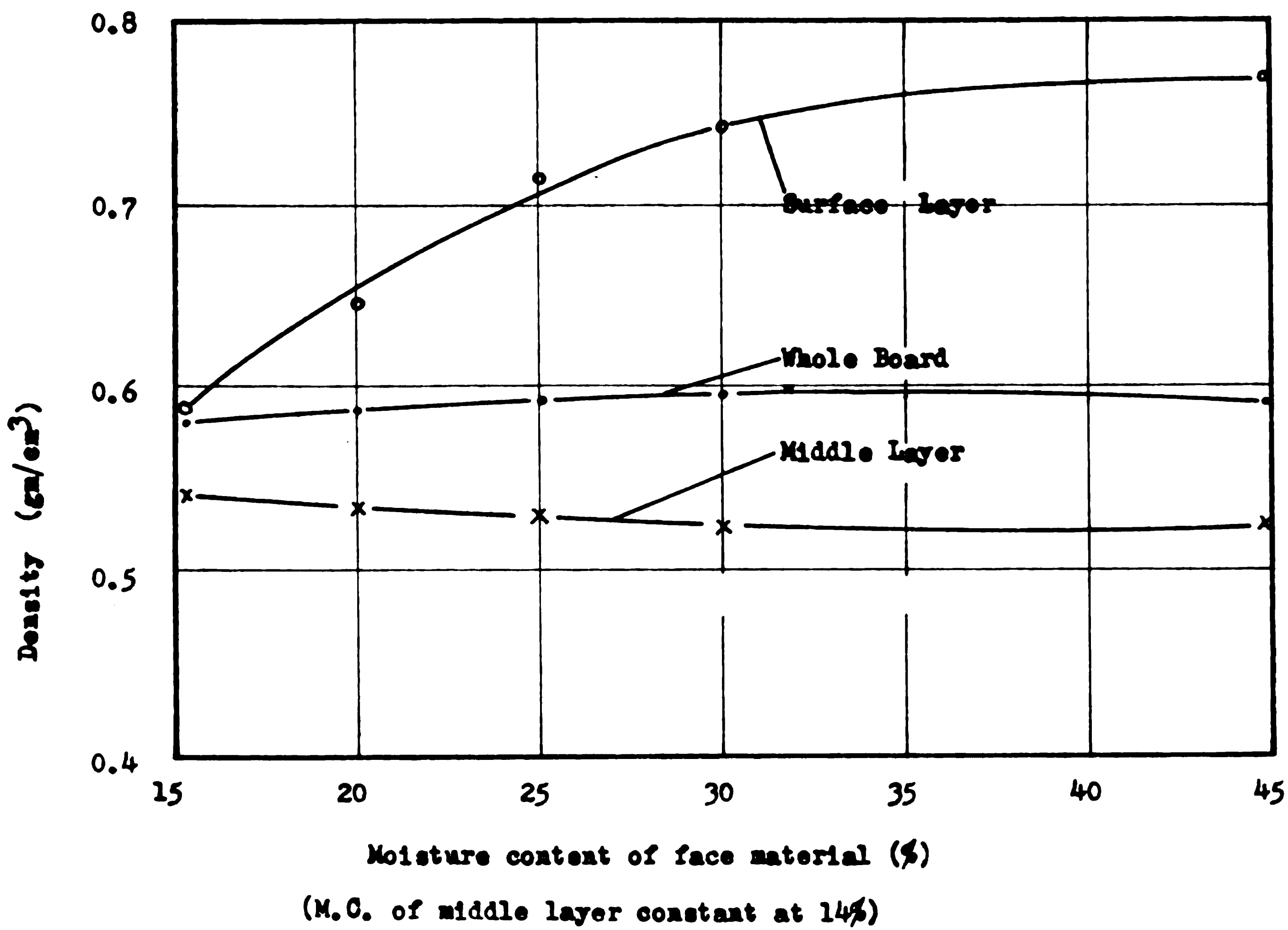


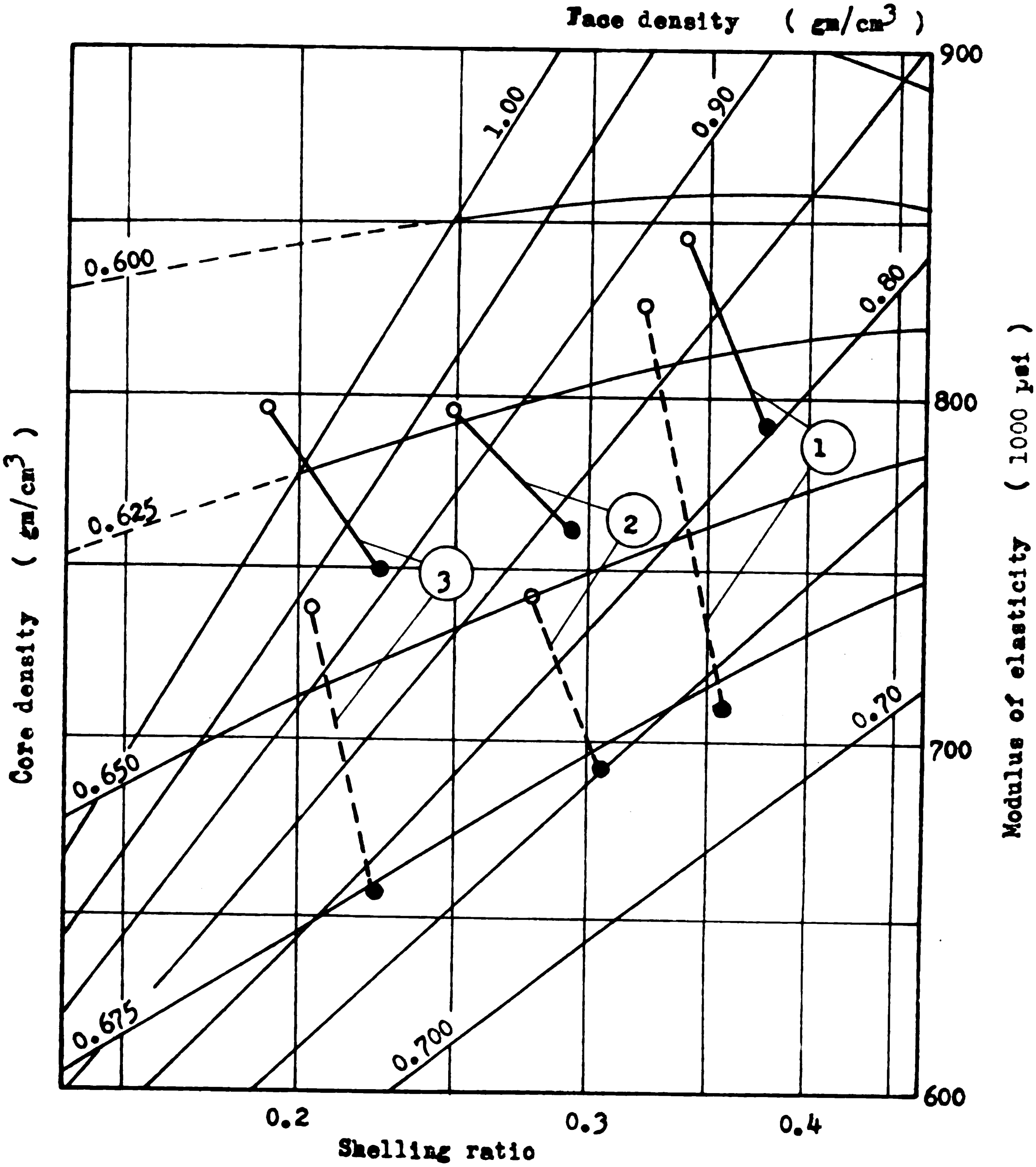
Figure 4 Effect of moisture content increase in the face material on the density of a three-layer flakeboard

reproduced from Keylwerth's article (5), values by Fahrni (3)



On the basis of the material discussed in the Introduction and Review of Literature, an experiment was designed to study the effect of the press cycle as a variable on the density distribution and other properties of a homogeneous (one-layer) flake board.

Figure 5 Effect of raw material and process variables on the modulus of elasticity of a 2 - species 3 - layer flake board



o 0.5 min. closing time
● 1.5 min. closing time

------ 6% face M.C.
———— 12% face M.C.

Core/Face weight ratio

① 1.50
② 2.13
③ 3.16

Graph reproduced from Suchsland's article (8)

THE EXPERIMENT

Design of the Experiment

After a study of the results of some preliminary tests, it was decided to make the flake boards at two overall density levels using three different initial pressures. Surface water was added to half the boards made at the lower density level and to all the boards made at the higher density level as shown in Table 1.

Preparation of the Flakes

Aspen flakes were used which were cut with a nominal thickness of 0.010 inch. The flake length was 1/2 inch and the flake width before reducing was 1 inch. The flakes were reduced in width by hammermilling through a 3/4-inch screen. They were brought to a uniform moisture content of about 6 per cent in a controlled humidity cabinet.

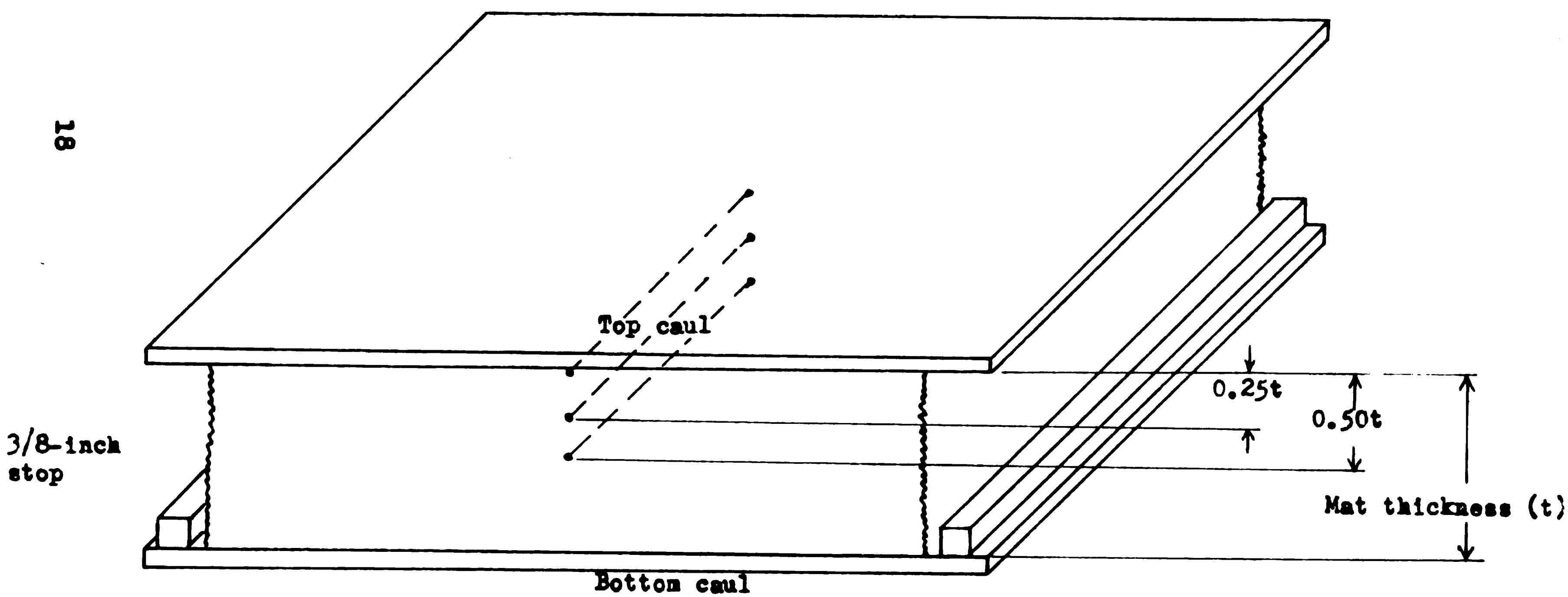
The Thermocouples

Thermocouples were made from 8-foot lengths of 30-gauge copper wire and constantan wire. One end of a length of copper wire was wrapped together with one end of a length of constantan wire and the connection was then soldered. The length of this soldered connection was approximately 1/2-inch. This end of the thermocouple was placed in the mat to measure the temperature increase. Three thermocouples were placed in each mat as it was formed: One at the center of the mat thickness, one midway between the center of the mat and the surface, and one on the top surface of the mat directly under the top caul as shown in Figure 6. After the boards were removed from the press the wires leading into them were cut off and reused by soldering together the ends as before. New thermocouples were prepared when the wires became too short.

Table 1 Design of the experiment

Pressure (psi)	100			200			300			400		
Grams of dry flakes per board	1050		1150	1050		1150	1050		1150	1050		1150
Surface water added	yes	no	yes	yes	no	yes	yes	no	yes	yes	no	yes
Board number	1	19	16	6	20	17	11	21	18	22	24	23

Figure 6   Location of thermocouples



Addition of Surface Water

Surface water was added to the various mats by spraying a very fine mist onto the cauls from a small container attached to a spray gun. The water was sprayed onto the top surface of the bottom caul before the mat was formed. The same amount was sprayed onto the underside of the top caul before it was placed over the mat. Fifteen grams of water were sprayed onto each caul, but only about half of it was retained due to evaporation.

Application of the Adhesive

The adhesive used was urea formaldehyde [illegible]-17 diluted to 50 per cent solids content for easier spraying and better coverage of the flakes. The amount of glue sprayed onto the flakes in a rotary drum mixer was 8 per cent glue solids, based on the dry weight of the flakes.

Formation of the Boards

The moisture content of the flakes was recorded before the adhesive was added, after the adhesive was added, and just before the mats were placed in the press. In addition, the total weight of the mat before pressing was recorded.

The mats, held between the two aluminum cauls, were pressed to 3/8-inch steel stops in a 20 x 20-inch, single-opening hot press. In each case the press closing time was recorded. The press platen temperature was 325° F., and the press cycle was 10 minutes long. The initial pressure was 100, 200, 300 and 400 psi.

A continuous time-temperature curve was obtained for each of the three thermocouples in the boards. They were connected to an automatic X-Y recorder through a device used to switch from one thermocouple to another. Each of the boards was removed from the press after the 10 minutes, and immediately moisture content samples were taken from the edge and center.

THE TESTING PROCEDURES

Cutting the Specimens

The following specimens were cut from each board:

- 2 for moisture content (mentioned above)
- 1 for density distribution
- 1 for thermocouple location
- 7 or 8 for bending tests

The method of cutting these is shown in Figure 7.

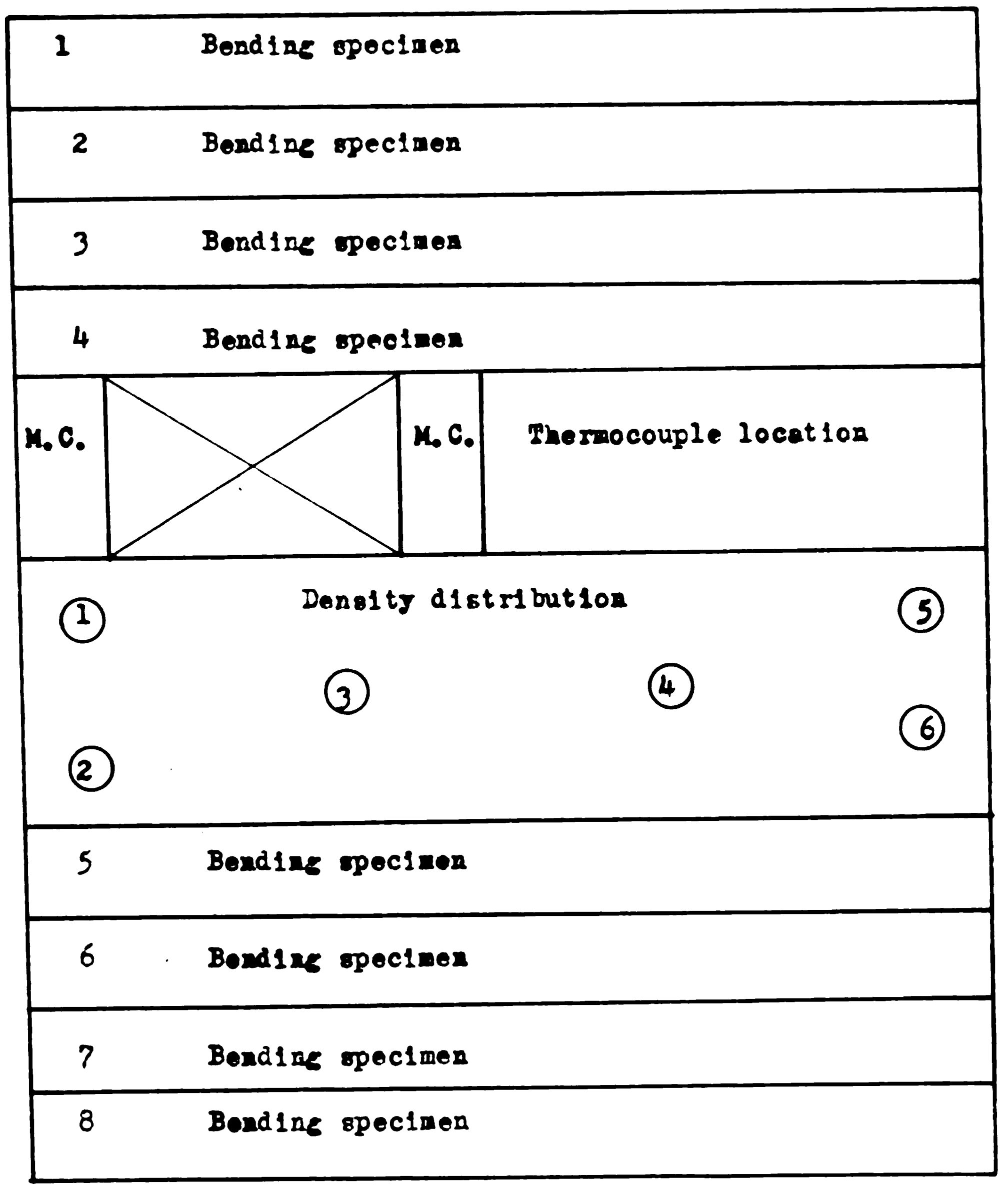
Tests Conducted

The moisture content of each board immediately after pressing was determined as described in Formation of the boards.

The exact location of the thermocouples in each board was determined by first measuring the thickness of the specimen, then planing it down from the top surface to the thermocouples. The thickness of the remaining part of the specimen was measured at each of the thermocouple locations. The locations were expressed as a per cent of the board thickness, measured in from the top surface of the board. Theoretically they should be 0%, 25%, and 50% in all the boards (see Figure 6).

The modulus of elasticity for each of the bending specimens was determined according to the ASTM standards for evaluating the properties of fiberboard (10) except that the specimens were one inch wide instead of 3 inches. The tests were done on a Baldwin-Emery SR-4 testing machine. Before testing, the specimens were conditioned at 68° F. and 50 per cent relative humidity to bring them to a uniform moisture content of about 8 per cent.

Figure 7 Method of cutting specimens from finished boards



The density distribution in the top half of each board was determined as follows:

1. The thickness of the density distribution specimen was measured to the nearest 0.001 inch at 6 locations which were marked on the bottom surface as shown in Figure 7.
2. The length and width of the specimens was measured to the nearest 0.01 inch.
3. The specimen was weighed to the nearest 0.01 gram.
4. A nominal thickness of 0.005 inch was taken off the top surface with a table jointer and the specimens were again weighed and the thickness measured at the same six locations .

Step 4 was repeated until just over half of the specimen was removed. From the data thus obtained, the overall density of each specimen could be determined as well as the density of each layer removed by the jointer.

RESULTS OF THE EXPERIMENT

The results of the experiment are shown in Table 2. Using the data obtained from the density distribution specimens, a graph was constructed for each board showing the density of each of the 0.005-inch layers removed from the top half of the specimen. For convenience of comparison, the relative density was plotted instead of the actual density. The base density, represented by 1.000 on the graphs, is the overall density of the top half of the specimen.

Some of the irregularities in the densities of adjacent layers is due to errors in measuring the thickness of the layers. The accuracy of the measurements (0.001 inch) was not sufficient for the thickness being measured (0.005 inch). The effect of this error was reduced by constructing a graph in which two layers were combined to form one and the density computed accordingly. The graph for board number 22, used as an example, is shown in Figure 8. The effect of the error was further reduced by constructing another graph in which three layers were combined to form one. This graph for board number 22 is shown in Figure 9.

The modulus of elasticity for each board was taken to be the average of the 7 or 8 bending specimens. This modulus of elasticity was adjusted to the target density of the board by the use of regression lines. The "least-square" method was used to determine the equation of the regression lines in which board density was the independent variable and modulus of elasticity was the dependent variable.

Table 2 Results of the experiment

Pressure (psi)	100			200			300			400		
Grams of dry flakes per board	1050		1150	1050		1150	1050		1150	1050		1150
Surface water added	yes	no	yes	yes	no	yes	yes	no	yes	yes	no	yes
Board number	1	19	16	6	20	17	11	21	18	22	24	23
M.C. of flakes before mixing with glue (%)	4.5	6.2	6.2	5.5	6.2	6.2	4.5	5.6	7.2	6.4	5.5	6.4
M.C. of flakes after mixing with glue (%)	12.7	14.4	13.6	13.6	14.5	14.6	11.0	13.4	14.4	14.6	13.9	14.7
M.C. of flakes just before pressing (%)	12.0	13.3	12.8	13.1	13.2	12.9	10.2	12.4	13.3	13.6	12.9	13.6
M.C. of board immediately after pressing (%)	3.0	4.0	4.0	2.6	3.3	3.1	2.5	1.8	2.4	2.6	2.3	3.0
Press closing time (min.)	1.50	**	**	0.60	1.00	0.80	0.55	0.55	0.50	0.00*	0.25	0.30
Center-line temperature of board at closing time (°F)	223	---	---	115	198	184	138	106	122	---	85	88
"Leveling off" point of center-line temperature (°F)	234	220	231	240	235	251	232	244	262	248	245	260
Time at which center-line temp. reached 220°F (min.)	1.40	2,90	1.90	1.10	1.40	1.10	0.90	1.15	1.00	0.80	1.10	1.10
Board thickness (inches)	0.364	.406	.397	.359	.362	.360	.354	.355	.351	.348	.350	.349
Actual board density (gm/cm^3)	0.578	0.533	0.591	0.594	0.593	0.639	0.568	0.617	0.666	0.620	0.625	0.681
Modulus of elasticity — Adjusted to target density (1000 psi)	586	462	631	712	659	758	677	703	828	741	645	784

** Press did not close   * Press closed immediately

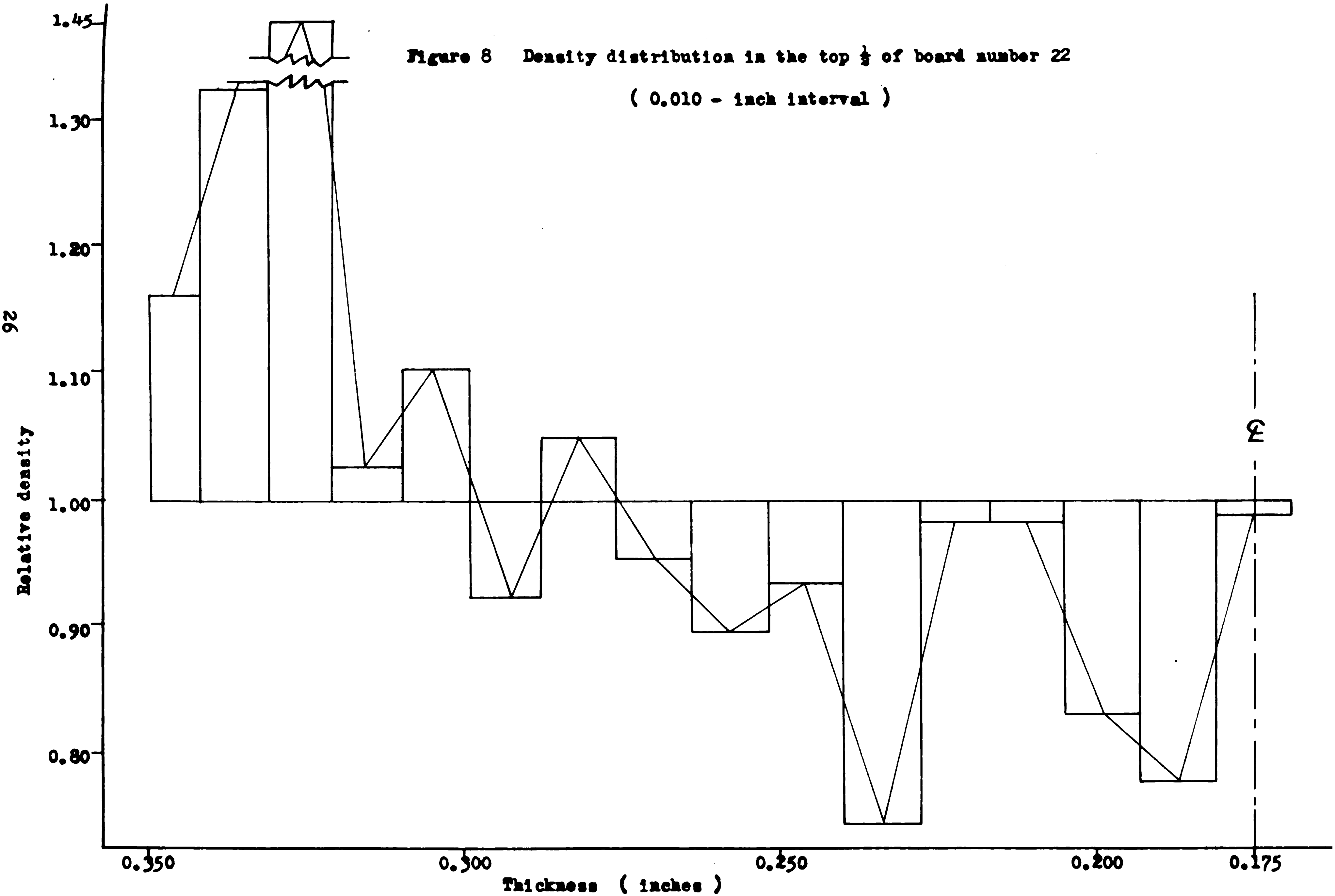


Figure 8 Density distribution in the top ½ of board number 22

(0.010 - inch interval)

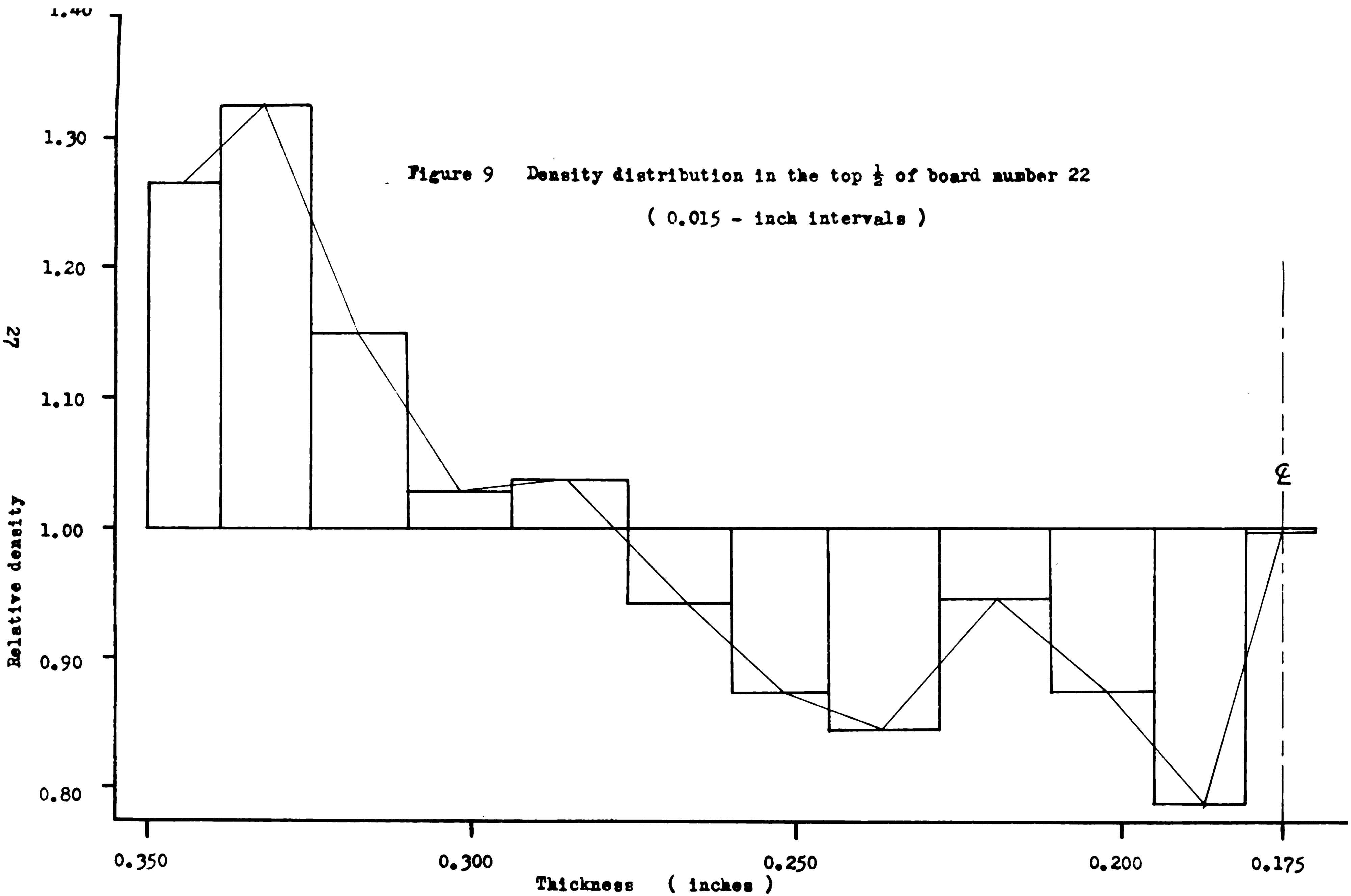


Figure 9 Density distribution in the top ½ of board number 22

(0.015 - inch intervals)

DISCUSSION OF THE RESULTS

Density Distribution

There are actually two types of density distributions in a flake board: 1. the density distribution across the area of a given layer in the plane of the board and 2. the densities of successive layers through the thickness of the board. The first is controlled by the flake geometry and the method used to form the mat. It is determined when the mat is formed and is not changed by the pressing operation. The second type, which will be the subject of this discussion, is not affected by the mat formation.

The results of the experiment show that the density distribution through the thickness of flake board is significantly affected by the raw-material and press-cycle variables. Figures 10 and 11 illustrate the effect of three of the basic variables on this density distribution. Figure 10 illustrates the effect of surface water and initial pressure. Figure 11 also illustrates the effect of initial pressure together with the effects of the overall density of the board. These two figures together include graphs for all 12 boards made and are simplified versions of the type shown in Figures 8 and 9. Each interval is shown in the form of a column. The height of the column represents the density of the "layer", and the width represents its thickness. The thickness is 1/3 of the thickness of the upper half of the board. For reasons of comparison, the thickness is expressed as a per cent.

The influences of the variables on the density distribution occur simultaneously; however, they will be discussed as if they occurred one at a time.

1. The effects of moisture distribution

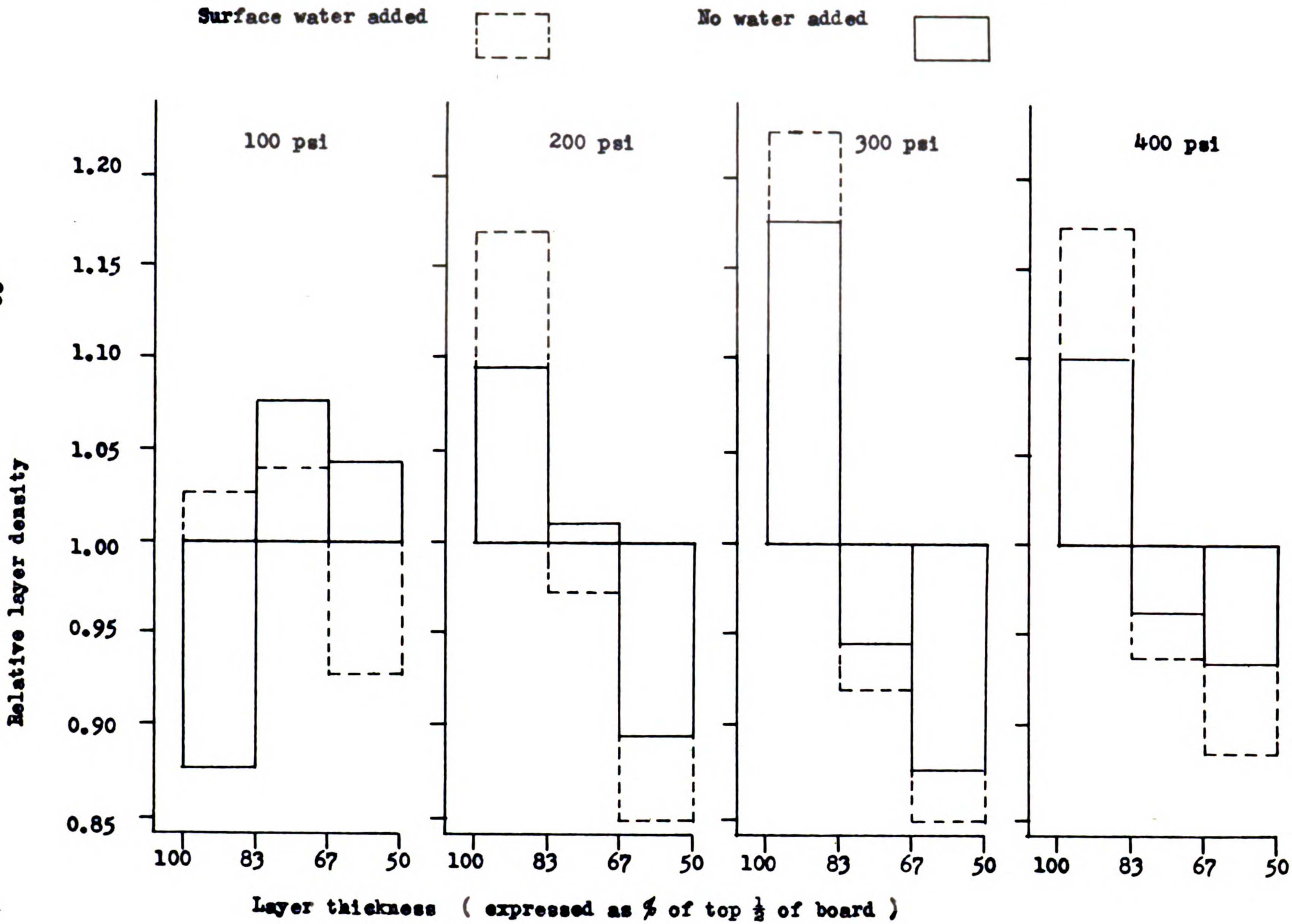
Increasing the moisture content of the surface flakes results in an increase in the density of the layers near the surface and a corresponding decrease in the density of the layers toward the center of the board. Figure 3 shows that by increasing the moisture content of wood, the proportional limit is lowered, making it more compressible. If the surface flakes are easily compressed, a large contact area will result. As was stated earlier, the highest density will occur where the combined effect of heat and moisture is greatest. Because the flakes are made more compressible by the addition of the water the press closing time is reduced. This means the greatest combined effect of heat and moisture will occur near the surface of the board.

The addition of water to the surface also accelerates the heat transfer from the surface to the center of the board. The shortened closing time speeds up the heat conduction between flakes and the moisture in the form of steam carries heat inward from the surface.

2. The effects of initial pressure

With increasing initial pressure, the density near the board surface will increase to a maximum and then decrease. Excluding all other variables, the closing time varies directly as the initial pressure. Moisture and heat have time to move inward considerably before the press closes when the initial pressure is low. Consequently the compressibility of a large portion of the flakes is decreased. The result is an almost uniform density distribution. If the pressure and/ or moisture content is too low, the density of the surface layers

Figure 10 Density distribution as a function of initial pressure and moisture distribution



will be lower than that of the center of the board. This is illustrated by board number 19 in Figure 10 and by board number 16 in Figure 11.

The combined effect of heat and moisture acts nearer and nearer the surface as the closing time is shortened by increasing the pressure. Extremely high pressures close the press almost immediately, and the full effect of heat and moisture is not attained. The result is that the surface layers will not reach the maximum density.

In agreement with the tests on stacks of veneers, high initial pressures result in a rapid drop off in pressure after the press has reached the stops. In certain cases the pressure on the board in the press dropped to zero and the board shrunk away from the platens. This is shown by the fact that the thickness of the finished board was less than the thickness of the stops. Also the temperature of the board surface dropped momentarily near the midpoint of the press cycle indicating that the thermocouple was not in direct contact with the caul (see Figure 14).

The thickness of the finished boards decreased with an increase in initial pressure. When high pressures are used, the mats are compressed to the stops before much if any moisture is lost. Loss in moisture after the press is closed results in a shrinkage of the boards in thickness. The more moisture there is in the board when the press is closed, the greater will be the shrinkage.

The press did not close when boards number 19 and 16 were made, but it did close when board number 1 was made, although the initial pressure was the same in all three cases. The lack of surface moisture kept the press from closing on board number 19, and the increase in the density of the overall board kept it from closing on board number 16.

As was expected, the higher initial pressures accelerated the heat transfer because of the shortened closing time (Table 2).

3. The effects of overall density

Boards made with the lower overall density had a higher relative density in the surface layers than the boards made with the higher overall density. It is necessary to use "relative density" here rather than "actual density" because the boards were made at the two different levels of overall density. The lower density boards had a shorter closing time. The results were higher surface layer densities. The effect of the closing time on density distribution has already been discussed.

<u>Bending Strength of the Boards</u>

Figure 12 illustrates the fact that the effect of the raw-material and press-cycle variables on the modulus of elasticity of the finished boards is a consequence of their effect on the density distribution. A comparison of Figures 10 and 11 with Figure 12 will verify this fact. Both the modulus of elasticity values and the densities of the surface layers increase as the initial pressure increases from 100 to 200 to 300 psi and then decreases as the initial pressure increases from 300 to 400 psi. The one exception in the trend of the modulus of elasticity values is board number 11 (see Figure 12). This is explained by the fact that the flakes from which this board was made had a moisture content which was 2 per cent lower than the other boards. This is equivalent to more than 20 grams of water.

Figure 11   Density distribution as a function of initial pressure and overall board density

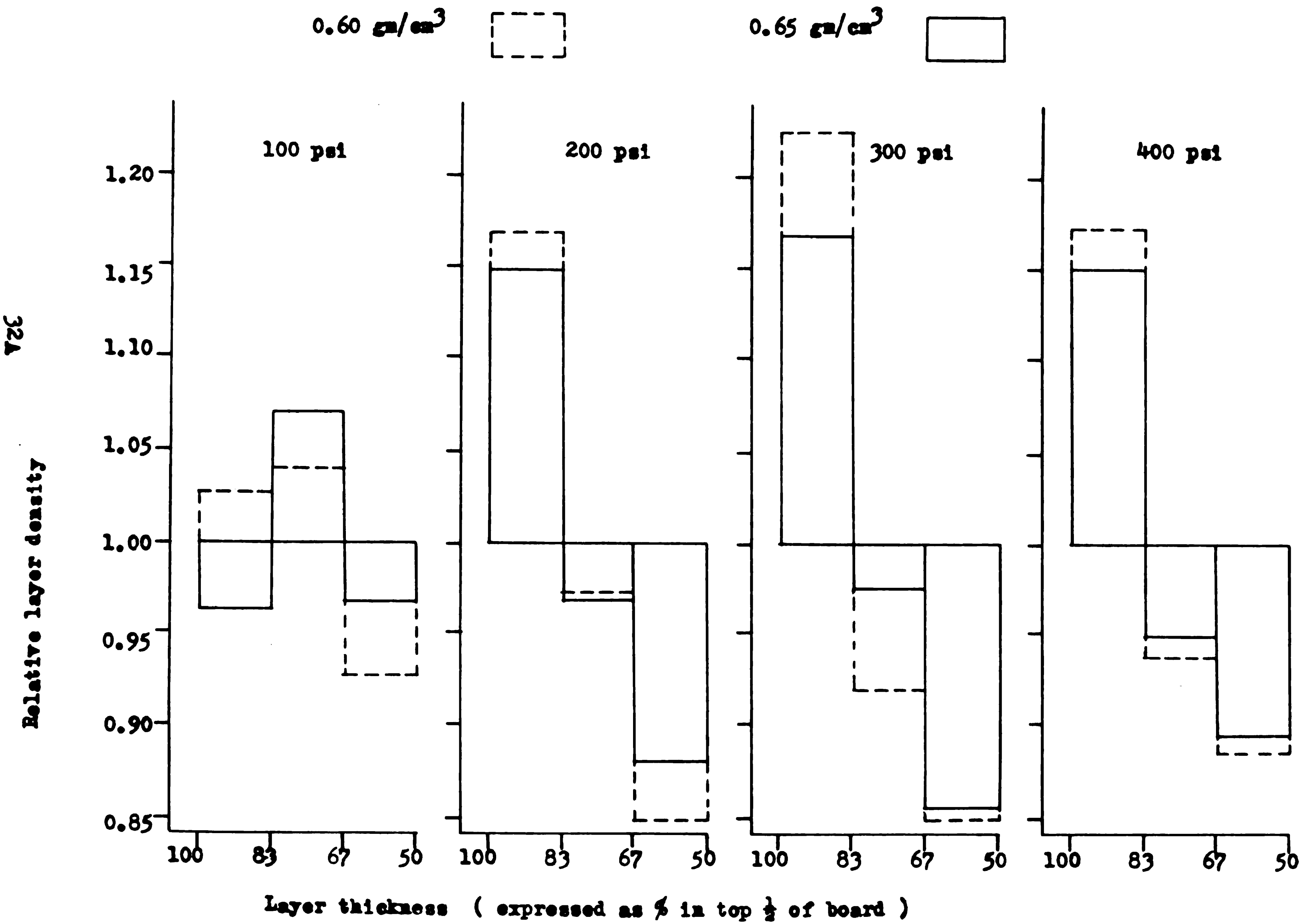
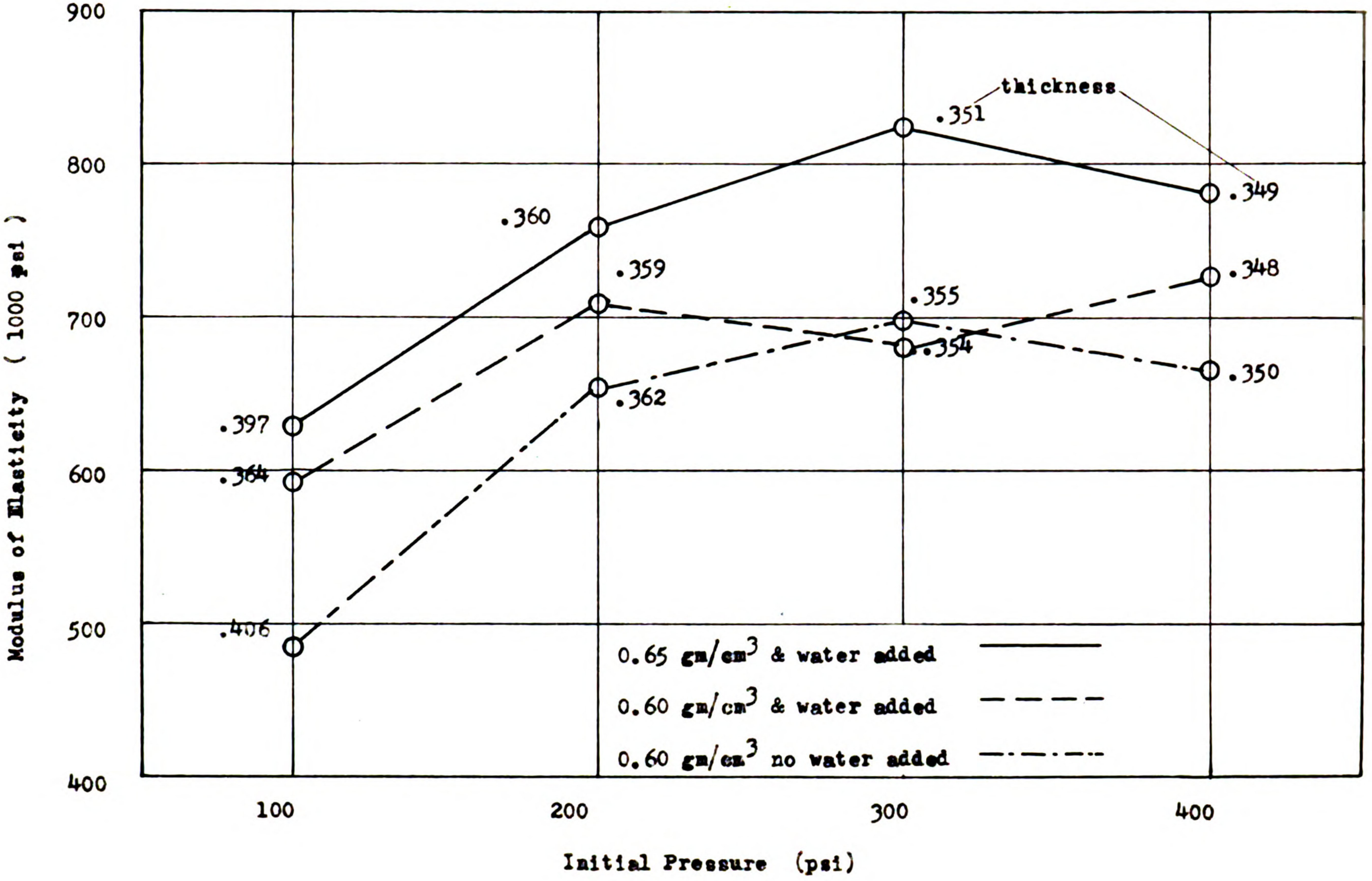


Figure 12 Effect of density distribution on the modulus of elasticity of the boards



It might be concluded from the above discussion that the modulus of elasticity is a function of board density alone. Strictly speaking this is not true because two boards cannot be made which vary in density alone. By adjusting the material or process variables to produce a board with different density, factors which affect the density distribution and other board properties are also affected.

The Drying Process

The graph in Figure 3 has already been used to illustrate the effect of temperature and moisture on the compressibility of the flakes. It can also be used to explain the drying of the flakes which takes place in the board. For this purpose the graph in Figure 3, taken from Keylwerth's article (5), is reproduced again in Figure 13 with the addition of the equilibrium moisture content curves for wood in superheated steam at pressures of 1.5 and 2.0 atmospheres. These two curves were taken from an article by W. G. Kauman.

Figure 14 shows the time-temperature curves for the three thermocouples in board number 22. The curve for the center-line temperature will be used as an illustrative example in the discussion of Figure 13. The center-line temperature for board number 22 after 1/4 minutes in the press was 120° C. After 4.2 minutes in the press it had dropped to 114° C. At the time the board was removed from the press the center-line temperature had increased to 140.5° C. From Table 2 the moisture content of the flakes used to make this board was 13.6 per cent at the time the mat was put in the press. The moisture content of the board immediately after pressing was 2.6 per cent.

Figure 13 Effect of temperature and moisture content on the proportional limit of American beech (with additions)

reproduced from Keylwerth's article (5)

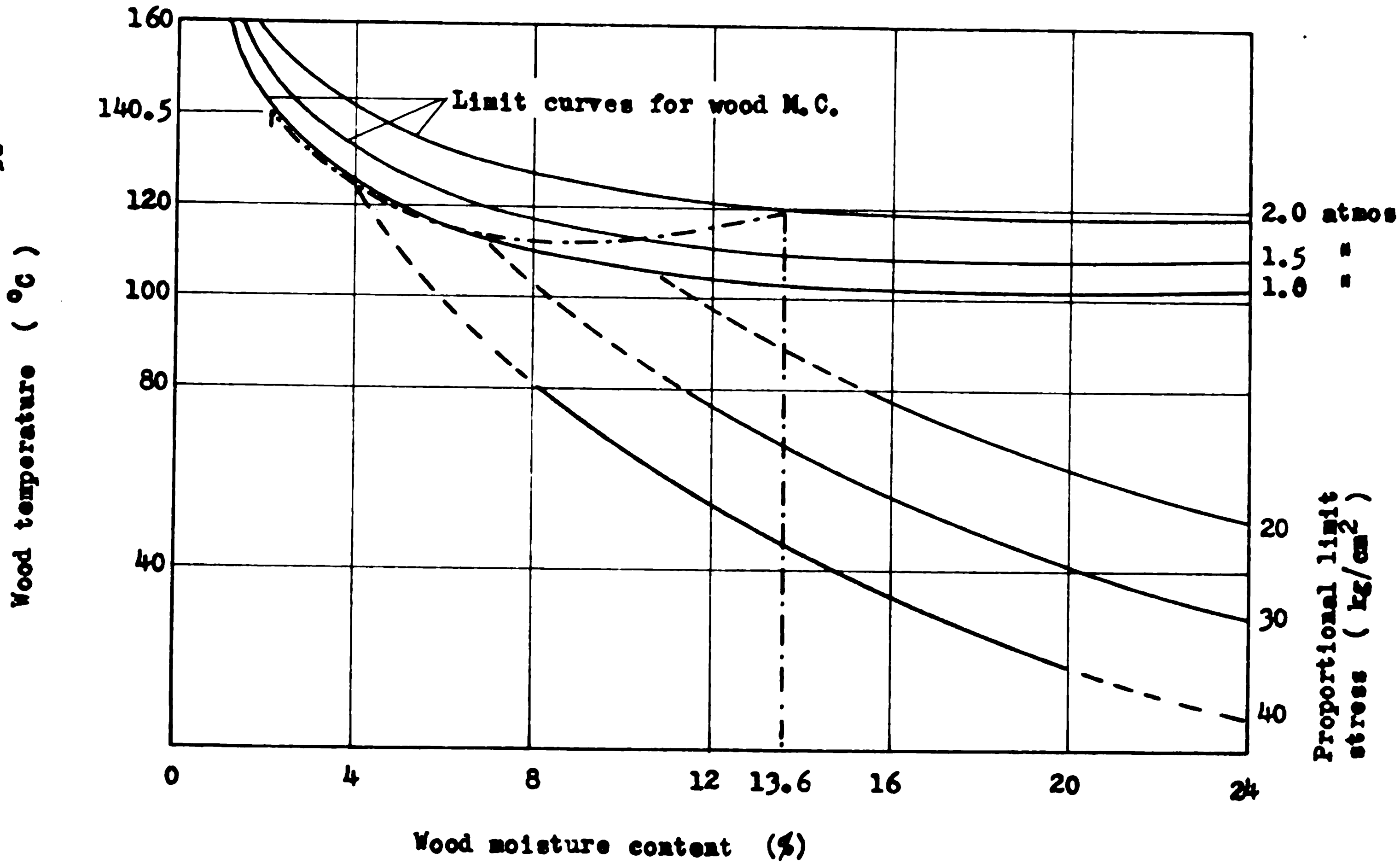
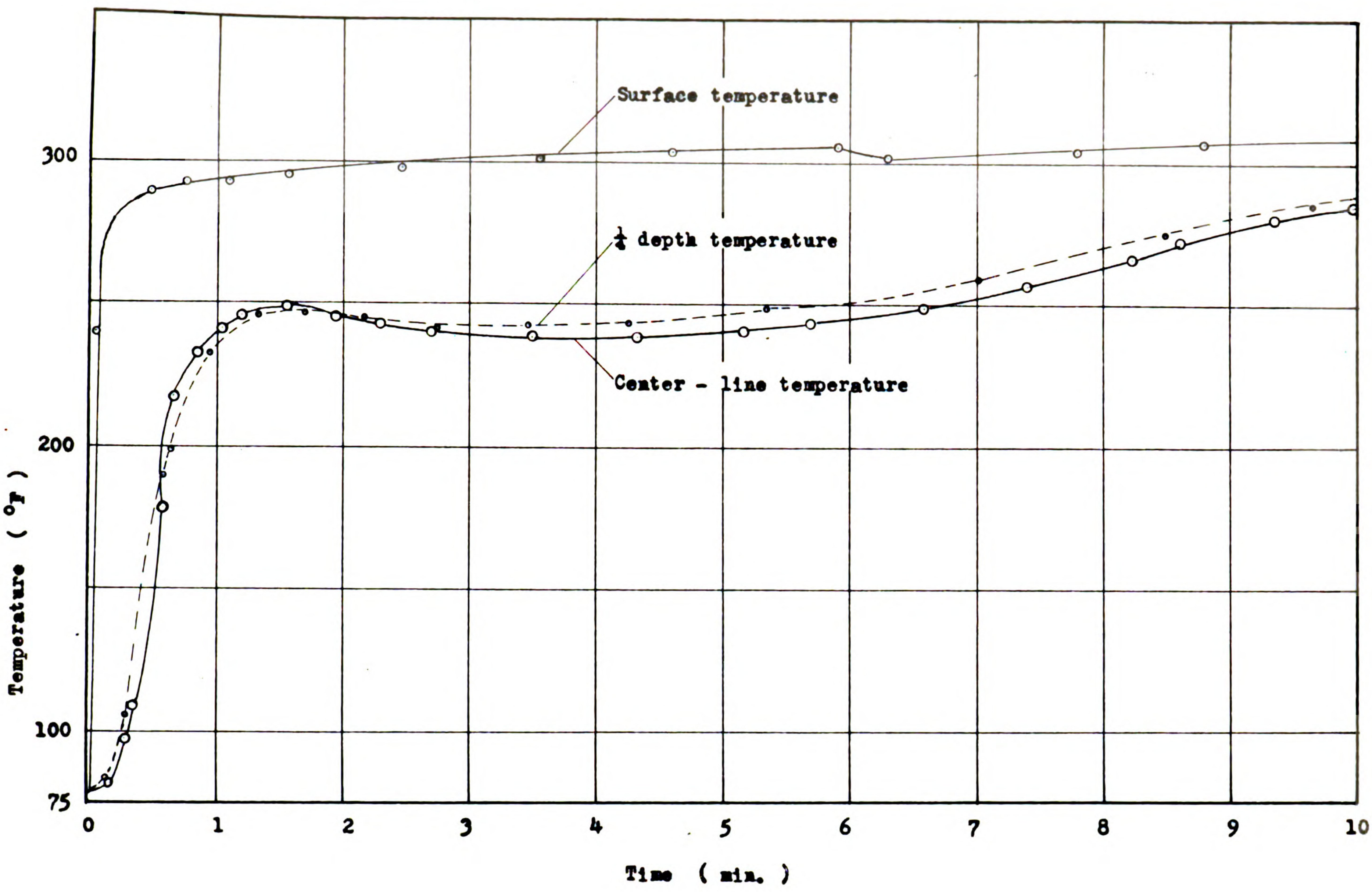


Figure 14 Time - temperature curves for the three thermocouples in board number 22



Surface temperature
¼ depth temperature
Center - line temperature
300
200
100
75
Temperature (°F)
0
1
2
3
4
5
6
7
8
9
10
Time (min.)

There are three "limit curves" for wood moisture content shown in Figure 13; One for steam at atmospheric pressure, one for steam at a pressure of 1.5 atmospheres, and one for a steam pressure of 2.0 atmospheres. These curves mark the upper limit of the moisture content which wood can attain at any given temperature. For example, at a temperature of 118° C., the moisture content of wood cannot increase above 8 per cent unless the steam pressure is increased above 1.5 atmospheres.

Figure 13 suggests three possibilities for the drying process which takes place in the press.

First the board dries out at atmospheric pressure along some curve which does not reach the limit curve for atmospheric pressure until the temperature at the center line has reached 120° C. Then the curve follows this curve up and to the left until the temperature reaches 140.5° C, at which time the press is opened and the board removed. There are two reasons why this is an unlikely possibility. In order for the drying to occur at atmospheric pressure, the board would have to dry out to 4.8 per cent moisture content from 13.6 per cent before the center-line temperature reached 120° C. This temperature was reached in only 1.4 minutes in the example board, and a moisture content drop of almost 9 per cent is not feasible for this short length of time. Also, in order for the temperature to drop from 120° C. to 114° C., as it actually did, the moisture content would have to increase to 6.2 per cent after having initially dropped to 4.8 per cent. This, too, is not likely.

The second possibility is that the temperature increases to 120° C. with little or no change in moisture content, and then a moisture content increase occurs to account for the drop in temperature. The increase in temperature to 120° C. at a moisture content of about 13.6

per cent would result in a steam pressure inside the board of about 1.9 atmospheres or 13.2 psi above normal pressure. This steam pressure is quite possible. The graph, however, shows that at this pressure it would be impossible for a large enough increase in moisture content to occur which would account for the temperature drop of 6° C.

The third possibility is probably the most correct. The temperature of the center of the board increased to 120° C. with little or no change in moisture content, resulting in a steam pressure of 1.9 atmospheres. Then as the board begins to dry out due to steam escaping through the edges of the board, the pressure drops to 1.25 atmospheres causing the drop in temperature. As more steam escapes, the temperature begins to rise again because the moisture content has dropped. Eventually the pressure drops to atmospheric conditions. Then the drying curve follows along the limit curve for atmospheric pressure until the press is opened. According to the graph, the moisture content of the board as it came out of the press at 140.5° C. should be 2.4 per cent. This is only 0.2 per cent lower than the actually measured moisture content for the example board.

SUMMARY

This study shows the effects of moisture distribution, initial pressure, and overall board density on the properties of the finished board. Sample boards were made at two different overall density levels using four levels of initial pressure. Surface water was added to 1/2 the boards made at the lower overall density and to all the boards made at the higher density level. Surface water was added to the flakes by spraying it onto the inner surfaces of the cauls. Fifteen grams were added to each surface. The initial pressures used were 100 psi, 200 psi, and 300 psi. The two target densities were 0.600 and 0.650 gm/cm^3.

The density distribution through the thickness of each board was determined. Thermocouples were used to measure temperature changes at different points in the board thickness while the boards were being pressed.

The way in which the basic variables influenced the finished board properties was discussed and also the consequent effect of the density distribution on the modulus of elasticity of the boards. It was noted that the density distribution was a result of the weakening of successive layers of flakes during the closing time of the press. The drying process in the press was discussed as it was related to the equilibrium moisture content of wood in superheated steam.

LIMITATIONS OF THE STUDY

Although this study illustrates the general effects of the variables in the production of wood flake board, its value is necessarily limited by certain factors. A limited number of sample boards were made. A larger number might have pointed out effects not shown in this study. The size of the specimens were limited by the size of the press available. In order to obtain bending specimens of standard length, the thickness of the boards was limited to 3/8 inch. Larger, thicker boards would have exhibited somewhat different density distributions.

In the laboratory a closer check can be kept on the flake moisture content and size, but the method of felting the mats by hand is not as desirable as the machine-felting process used by industry.

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