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fiberboard

produced in an oil-heated laboratory press

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Properties of Medium-Density Fiberboard Produced in an Oil-Heated Laboratory Press

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Medium-density fiberboards from pressurized double-disk refined fibers have a close correlation between layer density and layer dynamic modulus of elasticity. Density distribution over the thickness was readily controlled by manipulating platen temperature and applied pressure. Thus, overall modulus of elasticity could be adjusted. In contrast to modulus of elasticity, internal bond was sensitive to resin level and resin distribution. Milling the fibers after blending with 8, 10, and 12 percent resin solids increased internal bond strengths by 73, 71, and 82 percent, respectively. Fiberboards from mixed hardwoods produced commercially in a high frequency press had dense face layers (0.98 g/cc) and less dense cores (0.60 g/cc); such density profiles could be duplicated with sweetgum fibers pressed at 335°F and 480 to 820 psi in a conventionally heated press. Linear expansion of the commercial boards was higher and thickness swell lower than that of laboratory hot-pressed sweetgum boards. At equal densities, dynamic modulus of elasticity was lower in the commercial boards than in the sweetgum boards.

ADDITIONAL KEYWORDS: Density profiles, modulus of elasticity, platen temperature, internal bond, resin level, resin distribution, *Liquidambar styraciflua*, linear expansion, thickness swell.

Medium-density fiberboard (MDF) is utilized in manufacture of furniture, cabinets, and core stock under fine veneers and other surface finishes. It is produced by reducing raw material to fibers in pressurized disk refiners; these fibers are then bonded together with low viscosity, low tack, synthetic resins and formed into mats. The process offers an opportunity for profitably utilizing wood once considered waste because it tolerates wide variation in raw material such as species composition, geometric configuration, and bark inclusion.

Commercially produced MDF has better machining characteristics than conventional particleboard, good screw-holding power, and high internal bond strength. These features are in part attributed to the use of high frequency energy to cure the resin in the press (Raddin 1967). In conventional pressing, severe density contrasts (face to core) are produced at high temperatures and high pressures, and are caused by the temperature gradients occurring in the mat during the initial phase of the press cycle (Strickler 1959, Suchsland 1967). It is claimed that high frequency moderates this density contrast (Anon. 1974). On the other hand, high frequency curing requires higher initial investment and results in higher operating costs (Vajda 1970).

The primary objective of this study was to investigate the possibilities of producing high quality medium-density fiberboard without the use of high frequency energy. Preliminary results were presented earlier (Suchsland and Woodson 1975).

PROCEDURE

Material Collection and Preparation

Thirteen sweetgum (*Liquidambar styraciflua* L.) trees were felled, hand-peeled, and chipped at a local sawmill. Trees averaged 8.4 inches in

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d.b.h. and 52.4 feet in total height. All material to a 4-inch top diameter was utilized. Average specific gravity of disks removed at breast height was 0.51 (based on ovendry weight and green volume).

Green chips were transported to the Bauer Bros. Company laboratory in Springfield, Ohio, for refining in a Bauer 418 pressurized refiner.[1] Refiner conditions were held constant at dwell time of 5 minutes, steam pressure of 100 psi, plate clearance of 0.050 inch, and feed rate of 4.53 ovendry tons per day. Green chips entered the refiner at a density of 21.7 lb/ft^3 and 109 percent moisture content. Wet fibers emerged at a density of 4.3 lb/ft^3 and 130 percent moisture content.

Fibers were dried in a small rotating drum capable of drying about 100 pounds of wet fibers per load. Hot air (about 240°F) was introduced through the tumbling fibers from the center; wet fibers were dried to less than 5 percent moisture content in 3½ hours.

The distribution of fiber lengths was measured on a Bauer-McNett model 203-A classifier:

Mesh[2]	Percent
+8	33.8
—8/+14	17.5
—14/+28	21.8
—28/+48	13.0
—48/+100	2.4
—100	11.5

Fiber Blending and Mat Formation

Fibers were tumbled in a rotating wooden drum while a center-mounted spray gun dispersed a resin and wax mixture. Resin level was 8 percent (Allied Chemical Fiberbond binder); wax solids equalled 1 percent (Hercules Inc., Paracol 404N).

Treated fibers were brushed through ¾-inch hardware cloth mounted on top of a forming box. Final mat size was 18 by 20 inches and about 13 inches thick for a ¾-inch board at a density of 45 lb/ft^3; mats for ⅜-inch boards were half as thick. Mat moisture content was about 12 percent.

[1] Mention of trade names is solely to identify material and equipment used and does not imply endorsement by the U. S. Department of Agriculture.

[2] Tyler standard sieves; minus indicates passing a given screen; plus indicates retained by a given screen.

A supplementary study was designed to investigate the effect of resin level (8, 10, or 12 percent) and resin distribution. Fibers were run through a Sprout Waldron 12-inch single-disk refiner equipped with spike-tooth disk sections either before (b) or before and after (b & a) the blending operation (fig. 1A). The plate clearance was adjusted so that fiber characteristics remained unchanged and fiber clumps formed in the blender were dispersed. Mats were formed on an improved, time-saving

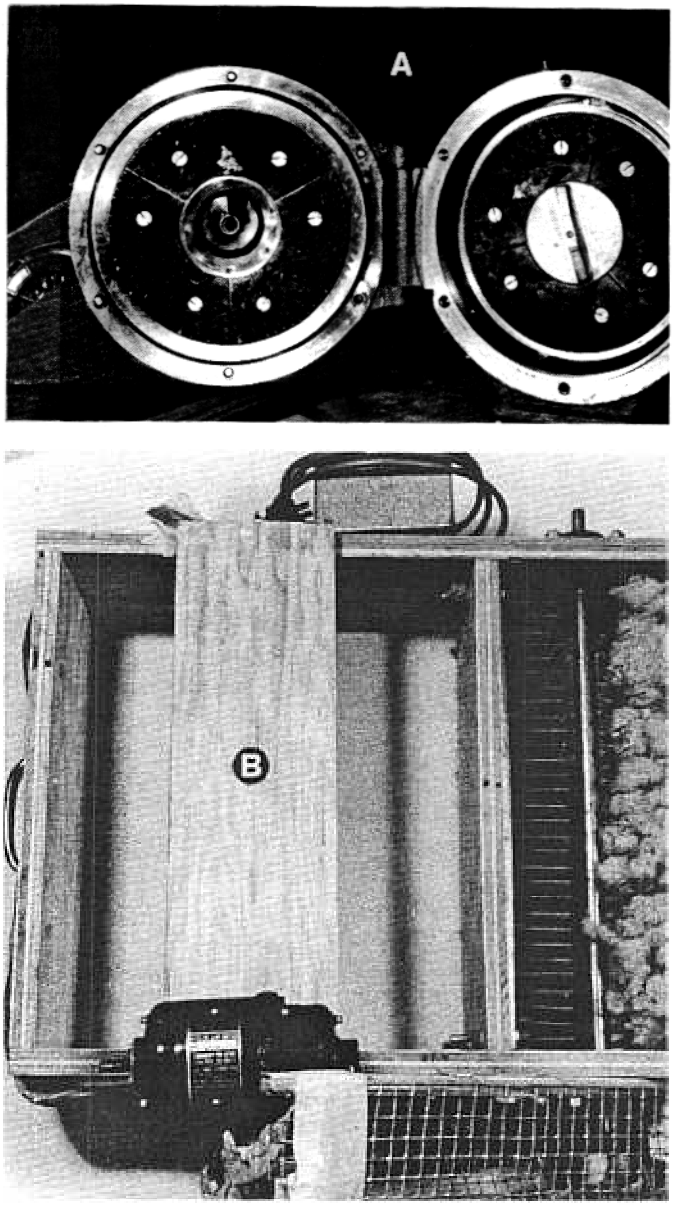


Figure 1.—*In the supplementary experiment, fibers were fluffed in a Sprout-Waldron refiner (A), then run through a mechanized forming device (B).*

device, employing a set of engaging spikes which evenly distributed the fibers in a forming box beneath (fig. 1B).

Board Manufacture

In the main experiment (table 1), we varied prepress pressure, hot-press pressure, and platen temperature to try to reduce closing time and thus moderate density contrast. All mats were prepressed at room temperature in a Riehle testing machine. Series A, B, and C were pressed at 60 psi. To obtain pressure of 650 psi, it was necessary to rip mats into 9- by 20-inch halves and press each half individually (Series D, E, F). Several of these half-mats were separated into face and core layers (50 percent in core and 25 percent in each face); the layers were prepressed at 60 psi or 650 psi and reassembled before hot-pressing (fig. 2). This high compression combined with high laminating pressure of 1,500 psi was intended to approach a uniform density condition.

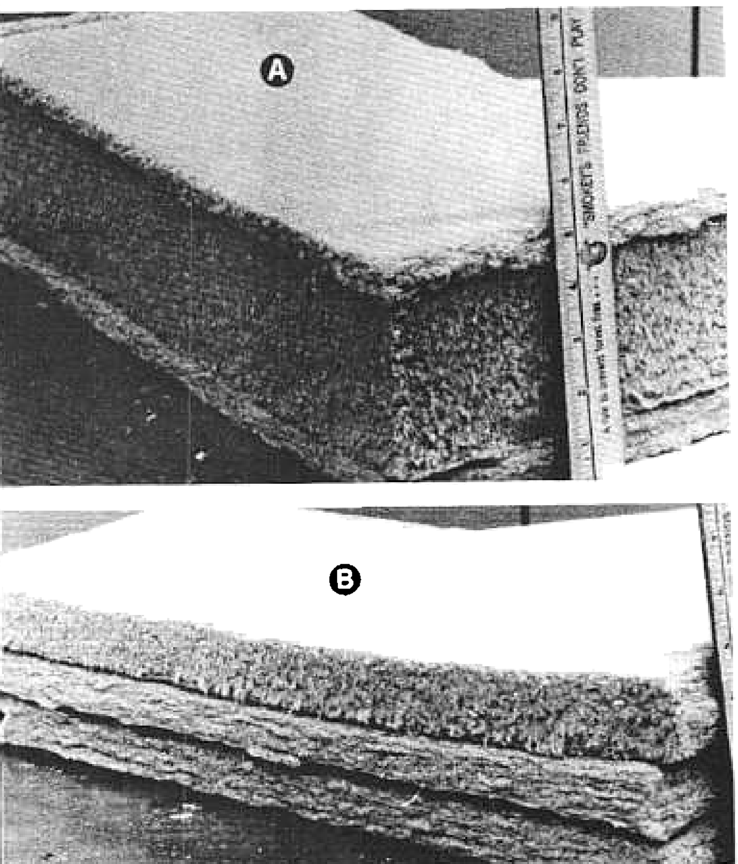


Figure 2.—*Mats for three-layer boards: (A) series E—face prepressed at 650 psi and core prepressed at 60 psi for 2 minutes, (B) series F—face prepressed at 60 psi and core prepressed at 650 psi for 2 minutes.*

Preliminary tests showed that the following curing times in the hot-press were adequate for the corresponding platen temperatures and board thicknesses:

Platen temperature	Board thickness	Total press time
°F	*Inch*	*Min*
335	¾	9
	⅜	6
250	¾	12
	⅜	8

Thickness stops controlled board thickness. Closing time was controlled indirectly by the magnitude of the applied pressure.

Series G boards were a special effort to eliminate density contrast entirely. Mats were compressed to final thickness (¾ inch) in the unheated hot-press before applying heat. Temperature was increased from 70°F to 285°F over a period of 1¼ hours. During this period of time and before any resin curing had taken place, the mat had lost essentially all resistance to compression and therefore was not trying to spring back to its original shape.

In the supplementary experiment (table 2), all mats were prepressed at 60 psi and hot-pressed at 820 psi. Platen temperatures were 250 and 335°F, and closing time ranged from 8 to 10 seconds.

Determination of Board Properties

Two strips 1⅛ by 18 inches were ripped from the center of each board, weighed, and measured for density calculations.

The resonance frequency, i.e., frequency at which maximum vibrations existed (Bair 1964), was measured on an oscilloscope and used to calculate the dynamic modulus of elasticity (E) as follows:

$$E = \frac{fr^2 l^3 w(5.4 \times 10^{-6})}{h^3 b}$$

where:

E = effective dynamic modulus of elasticity, psi

fr = resonance frequency

l = length, in

Table 1.—*Design of experiment and summary of results from boards made under different press schedules and with 8 percent resin content*

Furnish	Sweetgum																					Mixed hardwoods
Series	A				B				C				D				E		F		G	H
Pressure—psi	240				480				820				1,500				1,500		1,500		820 → 480	Commercial board
Prepressure—psi	60				60				60				650				Face: 650 Core: 60		Face: 60 Core: 650		—	
Platen temperature, °F	250		335		250		335		250		335		250		335		250	335	250	335	70 → 285	
Board thickness, in	¾	⅝	¾	⅝	¾	⅝	¾	⅝	¾	⅝	¾	⅝	¾	⅝	¾	⅝	¾	¾	¾	¾	¾	¾
Group number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Replications	3	3	3	3	3	3	3	3	3	3	3	3	6	6	6	6	4	4	4	4	2	...
Closing time, seconds	299	109	128	49	57	24	32	11	9	6	10	7	2	2	2	2	5	5	4	5	...	...
Density—g/cm³	.713	.773	.718	.757	.733	.791	.732	.786	.742	.798	.745	.798	.736	.743	.724	.739	.751	.755	.760	.758	.736	.721
Modulus of elast., 1,000 psi	423	476	517	571	517	575	633	717	504	623	645	764	506	538	578	610	569	663	585	653	469	531
Internal bond—psi	44.1	53.7	30.6	50.3	35.0	52.7	30.7	52.4	41.4	61.0	40.3	71.6	39.0	45.3	43.7	46.4	43.0	46.5	40.0	38.9	54.2	111.3

Table 2.—*Summary of results for supplemental study using sweetgum fibers prepressed at 60 psi and hot-pressed at 820 psi (closing time 8-10 seconds)*

Platen temperature °F	250												335					
Board thickness, in	⅝						¾						⅝					
Resin content, percent	8		10		12		8		10		12		8		10		12	
Milled	b	b & a	b	b & a	b	b & a	b	b & a	b	b & a	b	b & a	b	b & a	b	b & a	b	b & a
Density—g/cm³	.714	.652	.766	.727	.798	.765	.680	.692	.706	.709	.746	.720	.686	.664	.757	.731	.775	.756
Modulus of elast., 1,000 psi	494	424	569	545	639	591	471	499	514	529	620	544	529	514	760	627	744	649
Internal bond—psi	34.7	48.4	58.1	108.1	72.1	106.2	33.3	71.4	56.9	95.8	54.0	131.3	23.8	38.5	57.3	90.7	65.6	111.1

w = weight, g
h = thickness, in
b = width, in

Density profiles and E profiles through board thickness were also determined. In a given pair of matched strips, material was planed from the top surface of one and bottom surface of the other. These pieces were then laminated together with the planed surfaces as the contact area. Since the planer was preset to a desired thickness, initial thickness of all laminated specimens was constant, and thin layers of uniform thickness could be removed; material was removed until half the original board thickness had been planed off each side. Density of each layer was calculated and the dynamic modulus of elasticity of each layer (E_L) was determined by measuring the effective E before and after planing as follows:

$$E_L = \frac{E_1 - E_2 \left[\frac{h_2}{h_1}\right]^3}{1 - \left[\frac{h_2}{h_1}\right]^3}$$

where:

E_L = dynamic modulus of elasticity of layer removed, psi

E_1 = E before planing, psi

E_2 = E after planing, psi

h_1 = thickness before planing, in

h_2 = thickness after planing, in

Equilibrium moisture content and thickness swelling were determined on small blocks measuring ¾- by ¾-inch by board thickness. Blocks were equilibrated in six dessicators containing salt solutions ranging from 0 percent to 93 percent relative humidity (RH).

Linear expansion was determined on 12-inch long specimens by means of a optical comparator described by Suchsland (1970). Exposure conditions were 48 percent and 90 percent relative humidity at 70°F.

Internal bond tests were done in accordance with ASTM specifications D-1037-64.

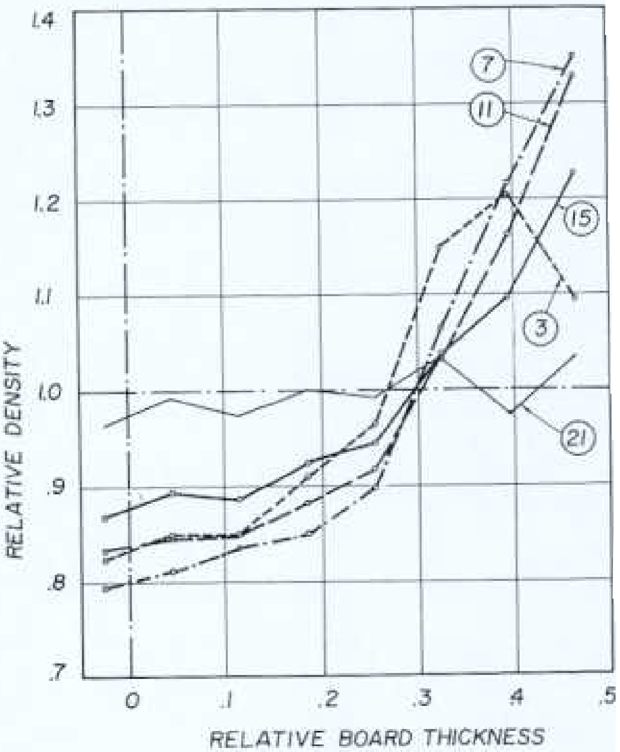
Properties of ¾-inch experimental boards were compared with those of commercial boards made from mixed hardwoods and cured with high frequency energy.

RESULTS AND DISCUSSION

Density Distribution

Relative density profiles (layer density divided by average density) of typical ¾-inch boards are shown in figures 3 and 4.

Boards made by pressing the mat to stops in an unheated press (Series G) had nearly uniform density throughout the thickness (fig. 3). Those pressed at 335°F and at 480 or 820 psi had face densities more than 30 percent higher than the average density; density contrast was somewhat less in boards prepressed at 650 psi and hot-pressed at 1,500 psi. In boards pressed at 240 psi, maximum density occurred beneath the face, resulting in a sinusoidal density profile. Profiles for ⅜-inch



Group No.	Prepressure psi	Pressure psi
3	60	240
7	60	480
11	60	820
15	650	1500
21	pressed in unheated press.	

Figure 3.—*Density profiles of ¾-inch boards pressed at 335°F compared to that of cold-pressed board (No. 21).*

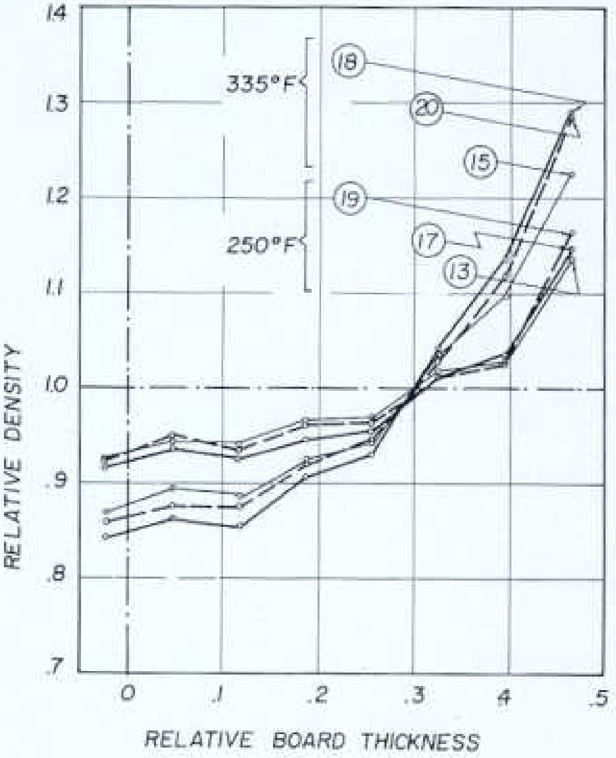
boards were similar to those for comparable ¾-inch boards but had less density contrast from face to core.

Efforts to influence the density distribution by prepressing faces and core at different pressures were not successful (fig. 4). Three-layer boards with cores prepressed at 650 psi and faces at 60 psi had almost identical density profiles as those with cores prepressed at 60 psi and faces at 650 psi. All three-layer boards had more severe density contrast than single-layer boards prepressed at 650 and pressed at 1,500 psi.

For all boards, curing temperature of 250°F produced lower face density and higher core density than 335°F. For example, in boards pressed at 480 or 820 psi, face densities were 10 percent lower with 250°F curing than with 335°F.

Density profiles of commercial boards were almost identical to those of the experimental boards with the most severe density contrast (boards pressed at 820 psi and 335°F) (fig. 5). Commercial boards had been sanded on both faces, and experimental boards were unsanded.

Density profiles of boards in the supplemental experiment were almost identical to those of series C (same press cycle).



Group No.	Prepressure psi		Temperature °F
18	Face:	650	335
	Core:	60	
20	Face:	60	335
	Core:	650	
15		650	335
17	Face:	650	250
	Core:	60	
19	Face:	60	250
	Core:	650	
13		650	250

Figure 4.—*Density profiles of three-layer boards compared with that of single-layer boards pressed at 1,500 psi.*

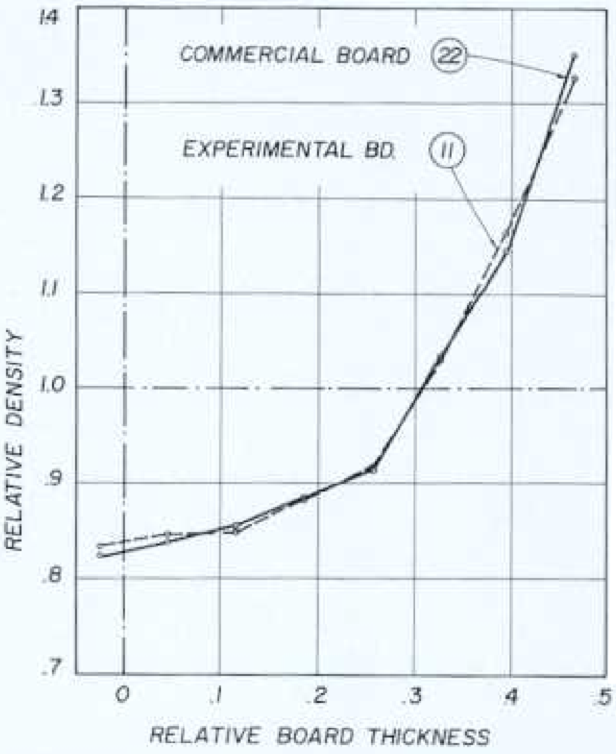


Figure 5.—*Density profile of commercial board compared with that of the experimental board with the most severe density contrast (No. 11—pressed at 820 psi and 335°F).*

Dynamic E Properties

Dynamic E of all ¾-inch experimental boards pressed at 480 psi or greater and at 335°F was greater than the E for commercial boards (table 1). Differences in density alone can not explain the experimental board's superior E, since the board with density profile identical to that of the commercial board had an E of 645,000 psi and the commercial board's was only 531,000 psi. Fiber alignment or species differences could be causing the variation in E.

The dynamic E and density of individual layers were closely correlated when all data were pooled according to cure temperature (fig. 6). Analysis of covariance indicated that the E to density ratio for the commercial boards was lower than that for experimental boards. The close correlation between modulus of elasticity and layer density makes the overall E of the board a good indicator of density contrast.

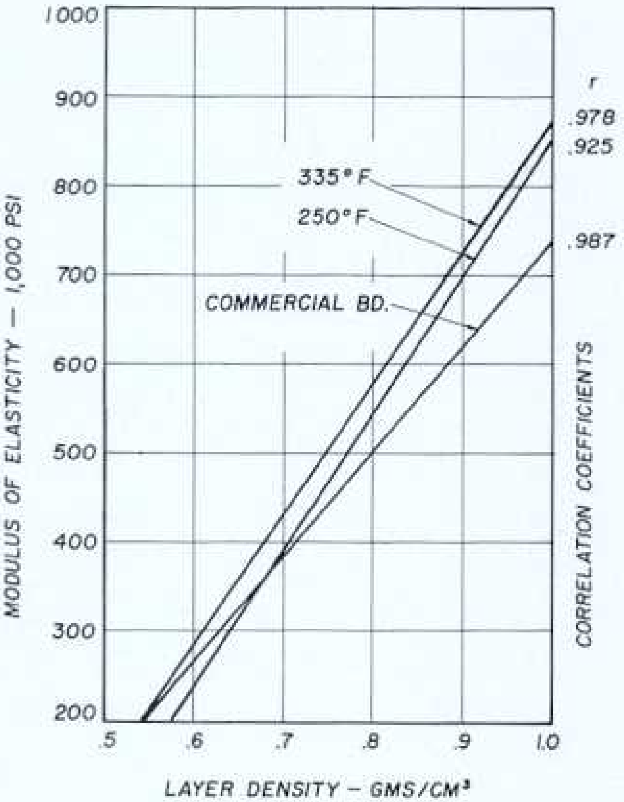


Figure 6.—*Relationship between layer density and modulus of elasticity for all experimental boards pressed at 250°F or 335°F and for commercial board.*

In the supplemental study, regression analysis of E versus layer density indicated that milling the fibers after blending had a limited effect on E (fig. 7). However, covariate analyses (density as the covariate) showed that resin level had no significant effect on E.

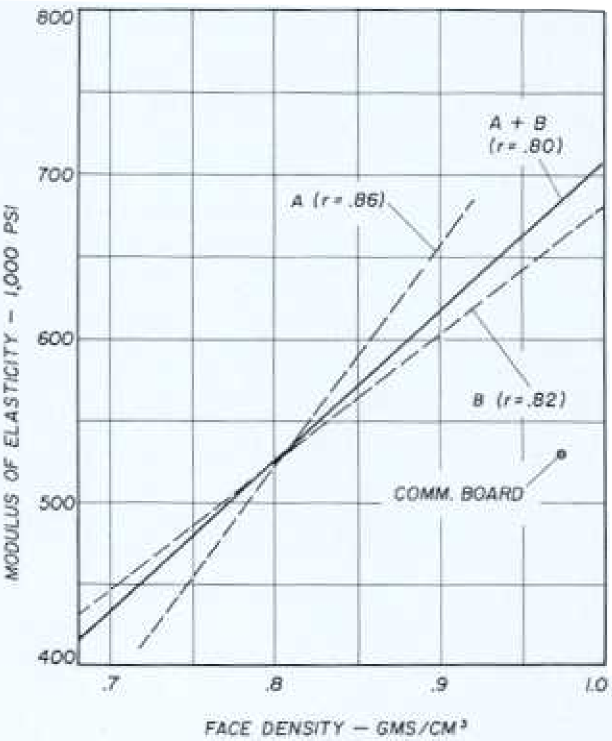


Figure 7.—*Modulus of elasticity as a function of face density for boards in the supplemental experiment (A = boards whose fibers were milled before and after blending; B = boards whose fibers were milled only before blending) and for the commercial board.*

Generally, overall E for the board increases as closing time decreases, but there is a point beyond which closing time will be so short that heat transfer during compression is negligible and therefore density contrast and E are reduced sharply (fig. 8). In commercial operations, zero closing time and uniform density might be achieved by using two presses—the mat would be prepressed cold at such high pressures that it would spring back no further than the final desired board thickness; it would then be put into the hot press. Comparable density and E values could be achieved with long closing times and moderate temperatures. Either technique will yield a board with E and density profile similar to those of the cold press board (series G).

Internal Bond

High internal bond strength is one of the outstanding characteristics of medium-density fiberboard, yet it was difficult to obtain values

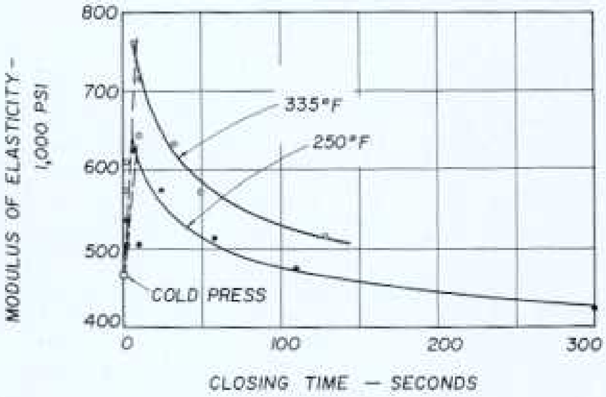


Figure 8.—*Relationship between press closing time and modulus of elasticity for all boards in the main experiment.*

in experimental boards as high as those found in the commercial product (tables 1 and 2). Even at high center densities (fig. 9), the internal bond strength was totally unsatisfactory. Internal bond is sensitive to resin level and resin distribution. In the supplemental experiment, milling before and after blending resulted in dramatic improvements, but even with double milling and 12 percent resin content, IB values were lower than those of the commercial board, which contained 8 percent resin.

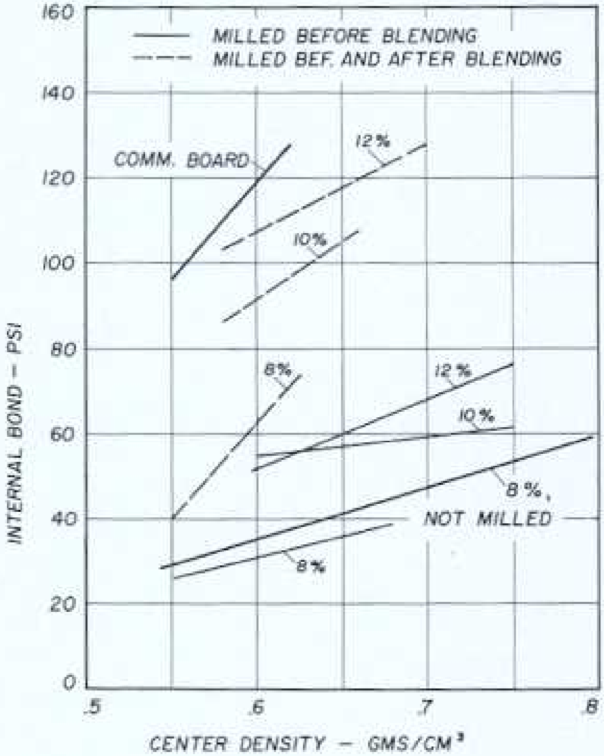


Figure 9.—*Internal bond as a function of core density in experimental and commercial boards. ("8 percent not milled" is a composite value for all boards in the main experiment.)*

Hygroscopic Properties

Average sorption isotherm at 70°F of all boards in the main experiment (fig. 10) indicated the typical depression of the isotherm caused by heat treatment during refining, drying, and pressing (Suchsland 1972). Thickness swelling (48 to 93 percent RH) was higher for experimental boards (13 percent) than for commercial boards (10 percent) (fig. 11). These values are rather high when compared with earlier studies (Suchsland 1973). This discrepancy might be due to the development of mold at the highest relative humidity condition

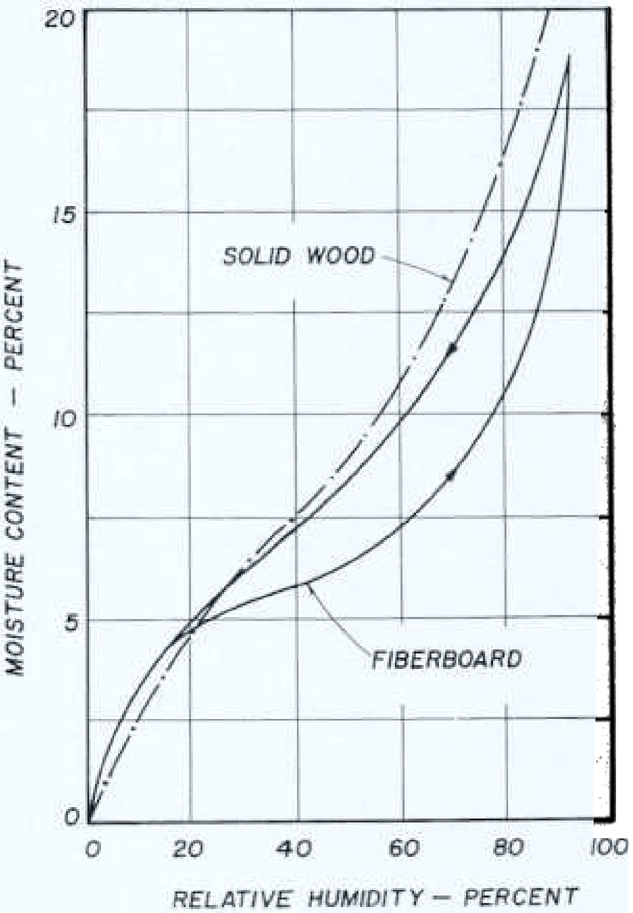


Figure 10.—*Sorption isotherm of fiberboards in the main experiment compared with that of solid wood.*

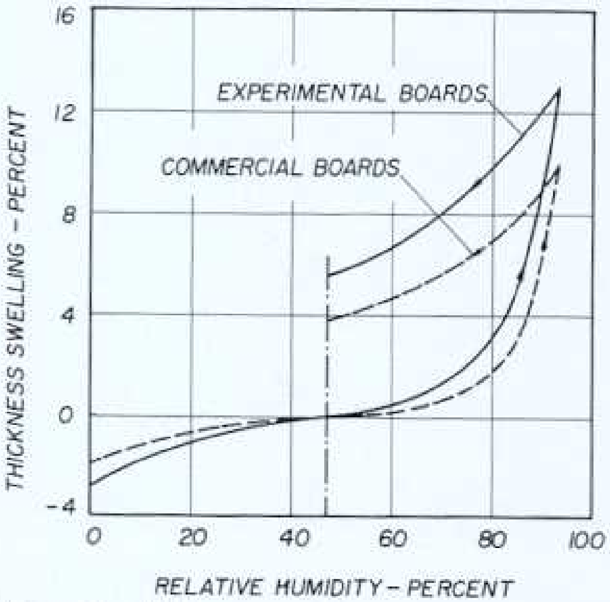


Figure 11.—*Thickness swelling of experimental and commercial medium-density fiberboards.*

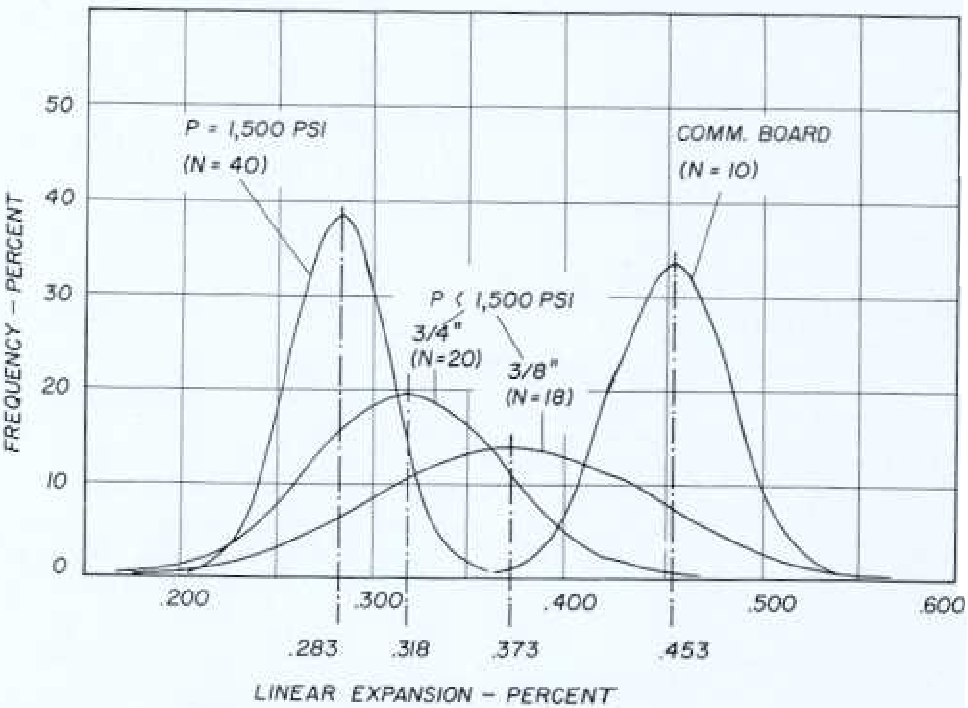
necessitating a treatment with permatox solution. In contrast, linear expansion (48 to 90 percent RH) was 0.453 percent for commercial boards and 0.283 percent for experimental boards pressed at 1,500 psi; experimental boards pressed at less than 1,500 psi had intermediate linear expansion (fig. 12).

CONCLUSIONS

The density distribution in boards made with high frequency energy is not necessarily of low contrast and can readily be duplicated in an oil heated press by appropriate adjustment of the press cycle. This conclusion is supported by the experimental data even though differences existed in species composition of commercial and experimental boards.

In addition, some more general conclusions were derived and are offered here in spite of their somewhat speculative character. Density and density distribution directly affect the modulus of elasticity; moreover, they interact with resin level and distribution in developing internal bond strength. A given density profile might result in a satisfactory E but low internal bond strength, as in our experimental boards. One might speculate that the high E is, at least in part, made possible by the mechanical interweaving of fibers in planes parallel to the board surface. If such interweaving could be developed in planes perpendicular to the board surface, internal bond should increase and E should decrease. The markedly low E and the markedly high internal bond of the commercial board seem to suggest that such a vertical alignment of fibers might exist in the commercial board. Its lower thickness

Figure 12.—*Linear expansion of experimental and commercial medium-density fiberboards. N = number of replicates; P = pressure applied during hot-pressing.*



swelling and higher linear expansion than experimental boards support this explanation.

Thus, the actual process of mat formation is vital in obtaining the specific board characteristics desired and must be considered as well as press cycle.

REFERENCES

Anon.
1974. Summary of the discussion period at the pressure-refined fiber session. *In* Proc., Seventh Washington State Univ. Symp. on Particleboard, p. 69-79.

Bair, J. G., Jr.
1964. Static and dynamic modulus of elasticity of hardboard. Masters Thesis. Mich. State Univ., East Lansing. 67 p.

Raddin, H. A.
1967. High frequency pressing and medium density fiberboard. *In* Proc., First Washington State Univ. Symp. on Particleboard, p. 391-401.

Strickler, M. D.
1959. Effect of press cycles and moisture content on properties of douglas-fir flakeboard. For. Prod. J. 9: 203-215.

Suchsland, Otto.
1967. Behavior of a particleboard mat during the press cycle. For. Prod. J. 17(2): 26-29.

Suchsland, Otto.
1970. Optical determination of linear expansion and shrinkage of wood. For. Prod. J. 20(5): 26-29.

Suchsland, Otto.
1972. Linear hygroscopic expansion of selected commercial particleboards. For. Prod. J. 22(11): 28-32.

Suchsland, Otto.
1973. Hygroscopic thickness swelling and related properties of selected commercial particleboards. For. Prod. J. 23(7): 26-30.

Suchsland, Otto, and G. E. Woodson.
1975. Effect of press cycle variables on density gradient of medium-density fiberboard. *In* Proc., Eighth Washington State Univ. Symp. on Particleboard, p. 375-396.

Vajda, Peter.
1970. The economics of particleboard manufacture revisited or an assessment of the industry in 1970. *In* Proc., Fourth Washington State Univ. Symp. on Particleboard, p. 5-46.

Suchsland, Otto, and George E. Woodson

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