CONSTRUCTION VARIABLES CONSIDERED IN FABRICATION OF A STRUCTURAL FLAKEBOARD

R.L. Geimer
Technologist
Forest Products Laboratory
USDA Forest service
Madison, Wisconsin

E.W. Price[1/]
Technologist
Southern Forest Experiment Station
USDA Forest Service
New Orleans, Louisiana

Abstract

Flake geometry, flake quality, flake alignment, average density, density gradients, layer thicknesses, and resin content were factors considered in determining the final construction details on structural flakeboards made from 1) western softwoods and 2) southern hardwood residues. After making compromises between board properties, a three-layer design was recommended for both board types. Long, thin face flakes enhanced bending properties while thick core flakes maximized internal bond strengths.

The lower compaction ratio associated with high-density hardwood species restricted the range of the variables used, as compared to those considered by the softwood board. The use of high-quality surface flakes and a surface water spray were other methods used to improve the performance of the hardwood board, Alignment of face flakes substantially increased the bending properties in the aligned direction for both board types. Being bound on one hand by economics and on the other by strength and durability requirements, a liquid phenolic resin content of 5 to 6 percent was used for the binder. By carefully choosing construction variables and fabrication techniques, acceptable panels from forest and mill residues were recommended for structural application.

Introduction

The direction of research aimed at utilization of residues in structural boards is determined to a large extent by the form of the residue and the species involved.

The Southern Experiment Station, Alexandria, La., in attempting to economically utilize the smaller hardwood logs., has elected to derive the furnish for a structural board from flakes created on a shaping lathe headrig. A three-layer construction has been developed using long, thin flakes for the faces and thicker, narrower flakes in the core.

The Forest Products Laboratory on the other hand has been charged with making boards from softwood residue ranging in size from 4-foot-diameter logs to small branches (19). The softwood flakeboard is also of three-layer construction. Quality flakes cut from the larger residue, on a disk-type flaker, are used for the face material. Smaller residues, after being chipped, are passed through a ring-type flaker to provide the furnish for the core of the board.

Many factors influence the properties of flakeboard. Construction variables such as board density, press closing speed, and mat moisture content will interact with each other, sometimes in a non-linear fashion, simultaneously to cause favorable and unfavorable reactions in different board properties. Furthermore, mechanical and economical factors such as machinability, resin content, and press time must be considered. Consequently, the choice of variables used (in constructing a flakeboard with structural characteristics) must be a compromise. Because of species effects, a wider range of variables is usually tolerable when using softwoods, than when using the high-density hardwoods.

Review of Major Variables

Flake Geometry

To meet the Forest Service performance goals of 800,000 psi average modulus of elasticity (MOE) and 4,500 psi near-minimum modulus of rupture (MOR) at reasonable board density levels, special attention was given to flake geometry. Numerous researchers have shown bending properties to increase directly with flake length and inversely with flake thickness (1,7,9,13,24,34). Improved bending performance has been shown for flake lengths up to 3 inches (28) and thicknesses as low as 0.006 inch (24).

Slenderness ratio (the relation of flake length divided by flake thickness) is a convenient way of combining these two variables. Slenderness ratios up to 300:l have been shown to affect favorably bending properties (1,25,27) (Fig. 1). Below 1/2 inch, flake width is of minor importance in developing bending properties (4).

There appear to be limits at which the effects and interactions of all of these flake geometry variables cease to be important (4,9,16,34). A practical range from the standpoint of flake production, handling, and mat formation lies between 2 and 3 inches in length, 0.015 to 0.05 inch in thickness, and between 1/2 to 1 inch in width. In contrast to bending properties, internal bond strength (tension perpendicular to the surface)

1/ Stationed at Pineville, La.

increases as the flake thickness increases and flake width decreases(1,12, 18). Depending on particle configuration and relative size, decreasing flake length also increases internal bond (IB) (1). While the true significance of the IB property is not fully understood, it can be correlated to interlaminar shear (23) and is often used as an indicator of bonding quality and durability (the ability of a board to withstand accelerated aging).

Flake geometry affects durability by its influence on springback. Springback is the irreversible thickness swelling which occurs after wetting and is attributed to the release of stresses accompanied by some loss of glue bonds. As mentioned previously, increasing flake thickness improves strength properties perpendicular to the surface. Decreasing flake thickness, however, improves thickness swelling and linear expansion properties(1,18,24). Springback generally increases with an increase in flake thickness (18,25). The optimum flake thickness for durability and dimensional stability then becomes a compromise. Since the range of flake thickness in which significant improvements occur differs with each property and also depends to some extent on other flake dimensions, the optimum geometry is best found by empirical methods.

The effect of flake length on either durability or dimensional stability can also vary. Lehmann (18) found no connection between flake length and thickness swelling but did show reduced linear expansion in boards made from long flakes. Post (25) found springback increased with increasing flake length up to 2 inches but was drastically reduced with a 4-inch-long flake.

Other board properties such as edgewise shear and nail holdings also depend to some degree on flake geometry. However, no problem was encountered in meeting the goals and no effort was made to alter these properties by further manipulating the variables.

Flake Quality

The importance of flake quality in promoting resin efficiency and bond formation is shown in studies by Lehmann (18). Although quality is hard to define, the term is generally used to describe a furnish having flakes with smooth-cut surfaces and edges and possessing a minimum of fines.

The term is relative, of course, as shown by Price's (26) comparison of a veneer flake and a flake cut on a shaping headrig. While both types are considered to be quality flakes, the veneer flake has a decided advantage as indicated by IB tests. Quality can be enhanced by such practices as presoaking the logs in hot water. Heebink (8,10) and Maier (21) agree that a long chip (1-1/2 to 2-1/2 inches) will produce a better furnish when flaked in a ring flaker than the conventional 3/4-inch pulp chip. This is because the long chips align themselves with the grain parallel to the knives. Longer flakes with less cross grain and fines are produced.

While flake quality does affect internal bond directly (26), there seem to be strong interactions between quality, flake geometry, and bonding. Part of this interaction is due to resin efficiency (12,17), part due to differences in orientation of the particles with respect to the board thickness direction or orientation of the grain within the particles, and part attributed to conditions present in the core during bond formation.

Flake Alignment

The tremendous influence of flake alignment on increased board bending properties are investigated as early as 1952 by Klauditz (15). Other researchers have shown the extent of improvement with various flake types and degree of alignment (2,4,26,31). Using random orientation of ring-cut Douglas-fir for the core and aligned disk-cut face flakes at a face:core:face ratio of 15:70:15 percent, Ramaker and Lehmann (28) increased bending stiffness in the aligned direction by 73 percent and strength by 36 percent over a similar board with randomly distributed face and core flakes The change of properties in one direction is, of course, made at the expense of those same properties in the opposite (90°) direction, (Fig. 2). Flake alignment does affect the dimensional stability of the board but has no effect on internal bond. Few data are available to show the effect of flake alignment on the various shear strengths (5).

Density

Increasing board density improves all the physical strength and stiffness properties. Comparison of density versus MOE for various species is well illustrated by Heebink (11) and Hse (12,13). Vital (35) has shown that the relationship between compaction ratio (board density divided by species density) and bending properties is independent of species mix. Internal bond is very sensitive to density (12,18,22). Nail-holding properties and hardness likewise depend to a great extent on board density. Research relating density to either thickness swelling or linear expansion is rather inconsistent. There appears to be some rather important interactions occurring between density, particle geometry, and bonding conditions which often tend to mask or even change the effect of density. Density has been shown to affect the rate of change in thickness swelling by controlling the rate of water absorption (29).

An important board characteristic stressed by Kelly (14) is the density gradient which exists throughout the thickness of hot-pressed boards. The gradient is controlled by a number of factors including press temperature, press closing time, mat moisture content, and flake layer thickness (3,32,33), (Fig. 3). Internal bond failures generally occur in the center line of hot-pressed boards because this is the low-density region associated with the vertical density gradient. Any controlled shifting of the density gradient to favor bending characteristics developed in the face layer necessarily decreases the core density and consequently tends to lower IB.

<u>Layering</u>

Since many of the boards' physical properties depend on the characteristics of a restricted area of the thickness zone, it is advantageous to form a layered board. By manipulating the variables independently in the various zones, board properties can be enhanced more economically. Geimer et al. (3) have indicated that a face:core:face ratio of 15:70:15 will account for 52 to 62 percent of the stiffness increase possible if the boards were made of all-face material. The thin face layers also allow for a greater utilization of poor grade, smaller size residue in the core, and permit flake alignment in the faces independent from the core. Use of a three-layer construction technique also permits utilizing different resin levels or resin types in face and core.

<u>Resin Content</u>

All boards made in the Forest Service Structural Flakeboard From Forest Residues Program used a phenol-formaldehyde resin to achieve exterior durability performance. Increasing resin content does improve all of the physical properties (18,20,24). The rate of improvement, however, varies with different properties and optimum levels are affected by particle geometry. MOE and MOR increase only slightly if at all above 5 percent resin content (17,24, 30). IB levels continue to increase at resin levels of 8 percent. Durability is increased when the resin content is raised from 3 to 9 percent (18,6). Thickness swelling as measured in relative humidity conditions show various responses to resin content levels dependent on the test conditions and the particle geometry. There appears to be an optimum level around 12 percent above which thickness swelling again increases (30). Particle geometry not only affects resin efficiency but also controls curing rate. Use of thick, coarse, but small particles in the core material results in a more porous core layer and provides for better steam release during the pressing cycle, which in turn aids the resin curing process. The same high-porosity conditions exist in low-density boards and partially explains why internal bond and density are often not well correlated.

<u>Optimization of Variables</u>

The effects of resin content, density, flake thickness, and flake length on bending stiffness (MOE) of homogeneous Douglas-fir flakeboard are shown in Figure 4. With 6 percent resin content, MOE varied from a low of 402,000 psi (0.045-inch-thick, 1/2-inch-long flake and 37.5 pcf density board) to a high of 665,000 psi (0.030-inch-thick, 2-inch-long flake and 42.5 pcf board). Decreasing the flake thickness to 0.020 inch and increasing length to 3 inches further increased the level of MOE attainable in a homogeneous board to 800,000 psi (Fig. 5). The relative MOE level attainable with 3-inch hardwood flakes is also shown in Figure 5 and partially reflects the differences between the softwood and hardwood slenderness ratio curves shown in Figure 1. It is readily apparent that to meet the bending stiffness goals a very high slenderness ratio or high board density must be used with the hardwoods. Work done at the Southern Station indicates that a compaction ratio of 1.185 is needed if the bending properties are to be met with a 0.015- by 3-inch flake (Fig. 6). Using a specific gravity of 0.639 for an average furnish species, a board density of 47.5 pcf is necessary to attain the 800,000 psi MOE value.

Trial experiments with a three-layer, 41 pcf Douglas-fir flakeboard showed that an effective MOE of 760,000 could be obtained by using a 0.020- by 2-inch disk flake in the faces and 0.050- by 2-inch ring flakes for the core. By using a 0.020-inch-thick core flake and a 3-inch-long face flake, MOE increased to 865,000 psi (Fig. 7).

The possibility of using flake alignment to obtain rather large increases in bending properties was also investigated. Board stiffnesses were increased by 70 to 75 percent in the aligned direction using Douglas-fir furnish (Fig. 8). Aligned hardwood boards showed slightly smaller bending stiffness increases, 44 to 57 percent, but were still dramatically stiffer than a random configuration. The effect of flake alignment on MOR properties was similar to that shown for MOE (13,28).

Numerical differences in bending properties of the three-layer boards

(Fig. 7) as compared to those homogeneous boards (Fig. 5) may be explained in part by a difference in density gradients. The rates of heat and moisture transfer during pressing and the resultant plastization of the furnish can be affected by the various layer combinations of face and core material (Fig. 9). Twelve percent mat moisture was used in constructing the three-layer boards, as compared to 10 percent mat moisture used in the homogeneous construction. Increased moisture will tend to increase the density gradient. The skin or I-beam effect is extremely important in achieving bending properties as shown by the rapid increase in MOE (tensile) experienced in face layer material at specific gravities exceeding 0.75 (Fig. 10). A water spray as used in constructing the hardwood structural boards will further promote a sharp density gradient approaching that shown for the fast press closure in Figure 3.

The effects of density, flake thickness, flake length, and resin contents on the internal bond property is shown in Figure 11. The relative magnitudes of the internal bond increase (Fig. 11) as opposed to the bending properties decrease (Fig. 7) with an increase in flake thickness was a major factor in using a thicker core flake. Additional internal bond increases were achieved with the hardwood lathe flakes by reducing the average flake width in a milling process. Data showed that an IB of 70 could be attained in the hardwood board at a comparison ratio of 1.15 (Fig. 6). With the five species mix under consideration this ratio corresponds to a density of 46.0 pcf.

The relative degree to which the different construction variables control dimensional stability is shown in Figures 12 and 13. Flake length has little effect on thickness swelling but does markedly control linear expansion. Reducing flake thickness decreases both TS and LE. Increasing density causes only a slight increase in either TS or LE, while increasing resin content from 3 to 9 percent affects a significant reduction in TS but reduces LE only slightly. The pattern of springback response to the variables is similar to that of thickness swelling (Fig. 14).

Retention of bending and IB properties following accelerated aging are shown in Figure 15 for a three-layer Douglas-fir board made using two densities and two resin content levels. The retention levels of MOE and MOR are based on measurements in the board's expanded condition but calculated on the initial thickness. This analytical procedure describes the board's retention of initial load-carrying capacity rather than change in the material. The internal bond data on the other hand are directly related to density and consequently reflects the influence of springback. Whereas resin content has little to do with retention of the bending properties as calculated, lowering resin levels from 7 to 5 percent considerably reduces IB retention.

Final choice of the variables used to manufacture large, 1/2-inch-thick panels is given in Table 1. Analysis of the above referenced data can aid in further manipulation of the variables to achieve board property levels desired for specific structural applications.

Summary

In an attempt to maximize those board properties generally accepted as critical for structural purposes, compromises were made in arriving at optimum construction variables. The compaction ratio (board density:species density) effect had considerable influence in determining the parameters used for hardwoods as opposed to those developed for the softwood species. Average density levels of 40 to 42 pcf appeared as optimum in Douglas-fir laboratory panels while panel density was increased to 47.5 pcf for the hardwood boards. Economics and durability were the major criteria for establishing the resin level at 5 to 6 percent.

Face flake geometry and quality are largely responsible for attaining bending properties. A slenderness ratio (flake length:flake thickness) of 100 was used with the Douglas-fir boards while a ratio of 200 was used with the hardwood boards. Steep vertical density gradients, favorable to bending properties, were achieved in both boards by using a fairly rapid press closing of (3/4-1 min.) A surface water spray further increased the density gradient in the hardwood panels.

Use of long but thick and narrower flakes in the core promoted internal bond properties with a minimum reduction in bending characteristics. Dimensional stability and bending durability characteristics were adequately obtained with the selected variables. Retention of internal bond strengths following aging were marginal but could be improved with additional resin. No problem was encountered in meeting goal specification for nail pull-through, nail withdrawal, or the various tension, compression, and shear properties; as such, they were not considered directly in optimizing the variables. Studies were extended to establish the practical limit of strength and other property improvements attainable with further manipulation of the variables. Flake alignment proved to be a method of achieving high bending properties (well

over a million psi) in the critical aligneddirection.

References

1. Brumbaugh, J. 1960. Effect of flake dimensions on the properties of particleboards. For. Prod. J. 10(5):243-246.

2. Elmendorf, H. 1965. U.S. Patent 3164511. June 5.

3. Geimer, R., Montrey, H., and Lehmann, W. 1975. Effects of layer characteristics on the properties of three-layer particleboards. For. Prod. J. 25(3): 19-29.

4. Geimer, R. 1976. Flake alinement in particleboard as affected by machine variables and particle geometry. USDA For. Serv. Res. Pap. FPL 275. For. Prod. Lab., Madison, Wis.

5. Geimer, R., Lehmann, W., and McNatt, J. 1974. Engineering properties of structural particleboards from forest residues. Proc. 11th WSU Particleboard Symp. Washington State Univ., Pullman, Wash.

6. Hann, R.A., Black, J.M., Blomquist, R.J. 1963. How durable is particleboard II, The effect of temperature and humidity. For. Prod. J. 13(15):169-174.

7. Heebink, B., and Hann, R. 1959. How wax and particle shape affect stability and strength of oak particleboards. For. Prod. J. 9(7):197-203.

8. Heebink, B. and Dominick, R.M.F. 1971. Forest residues: Future source of particleboard? Wood and Wood Products 76(11): 26-28.

9. Heebink, B. 1974. Particleboards from lodgepole pine forest residue. USDA For. Serv. Res. Pap. FPL 221. For. Prod. Lab., Madison, Wis.

10. Heebink, B., Schaffer, E., Chern, J., and Haskell, J. 1977. Structural flakeboards using ring flakes from fingerling chips. USDA For. Serv. Res. Pap. FPL 296. For. Prod. Lab., Madison, Wis.

11. Heebink, B. and Lehmann, W. 1977. Particleboards from lower grade hardwoods. USDA For. Serv. Res. Pap. FPL 297. For. Prod. Lab., Madison, Wis.

12. Hse, Chung-Yun. 1975. Properties of flakeboards from hardwoods grown on Southern pine sites. For. Prod. J. 25(3): 48-53.

13. Hse, C., Koch, P., McMillin, C., and Price, E. 1975. Laboratory scale development of a structural exterior flakeboard from hardwoods grown on Southern pine sites. For. Prod. J. 25(4):42-50.

14. Kelly, M. 1977. Critical literature review of relationships between processing parameters and physical properties of particleboard. USDA For. Serv. Gen. Tech. Rpt. FPL-10. For. Prod. Lab., Madison, Wis.

15. Klauditz, W.G., Stegman, G., Boro, A., Kratz, U., and May, H. 1965. Research and developments in construction materials made from wood particles: techniques for producing wood-chip or compound materials with directional strength. Forschungsber Des Landes Nordrhein, Westfalen, Koch No. 1520, p. 47.

16. Kusian, R. 1968. Modern investigations about the influence of particle size on structural and strength properties of particle materials: Experimental investigations. Holz Technologie 9(4): 241-48.

17. Lehmann, W.F. 1970. Resin efficiency in particleboards as influenced by density atomization and resin content. For. Prod. J. 20(11):48-54.

18. Lehmann, W.F. 1974. Properties of structural particleboards. For. Prod. J. 24(1): 19-26.

19. Lehmann, W.F. and Geimer, R. 1974. Properties of structural particleboards from Douglas-fir residues. For. Prod. J. 24(10):17-25.

20. Lehmann, W.F. 1974. Durability of composition board products. Proc. 11th WSU Particleboard Symp. Washington State Univ., Pullman, Wash.

21. Maier, G. 1977. Effects of chip shape on the flake quality in producing flakes from chips. Holz Roh Werkst. 35:365-367

22. McMillin, C. and Koch, P. 1973. Final report - Properties of homogeneous exterior structural boards made from southern hardwood or loblolly pine flakes cut on a Koch lathe. USDA For. Serv. Southern For. Exp. Sta., Alexandria, La. [Unpublished]

23. McNatt, J.D. 1973. Basic engineering properties of particleboard. USDA For. Serv. Res. Pap. FPL 206. For. Prod. Lab., Madison, Wis.

24. Post. 1958. The effect of particle geometry and resin content on bending strength of oak particleboard. For. Prod. J. 8(10):317-322.

25. Post. 1961. Relationship of flake size and resin content to mechanical and dimensional properties of flakeboard. For. Prod. J. 11(1):34-37.

26. Price, E. and Kesler, C. 1974. Analysis of southern hardwoods as furnish for a wood flake-resin composite structural

material. T. & AM Report #389, Dept. of Theoretical and Applied Mechanics, Univ. of Illinois, Urbana, Illinois. Report USDA 19-130.

27. Rackwitz. 1963. Influence of chip dimensions on some properties of wood particleboard. Holz Roh-Werkst 21(6): 200-209.

28. Ramaker, T., and Lehmann, W. 1976. High performance structural flakeboards from Douglas-fir and lodgepole pine forest residues. USDA For. Serv. Res. Pap. FPL 286. For. Prod. Lab., Madison, Wis.

29. Roffael, E., and Rauch, W. 1972. Influence of density on the swelling behavior of phenolic resin bonded particleboard. Holz Roh-Werkst 30(5): 178-181.

30. Schuler, C.E. 1974. Pilot study of the use of pulpwood chipping residue for producing particleboard in Maine. Tech. Bull. No. 67 Life Sci. and Agr. Exp. St. Univ. of Maine, Orono.

31. Stofko, J. 1962. Flakeboard material with oriented wood chips. Drev Vysk 2: 127-146.

32. Suchsland, O. An analysis of the particleboard process. Quarterly Bulletin, Mich. Agric. Exp. St. 42(2): 350-372. Mich. State Univ.,East Lansing.

33. Suchsland, O. 1960. An analysis of a two species, three-layer wood flakeboard. Quarterly Bulletin, Mich. Agric. St. 43(2): 375-393. Mich. State Univ., East Lansing.

34. Turner, D. 1954. Effect of particle size and shape on strength and dimensional stability of resin bonded wood particleboards. For. Prod. J. 4(5): 210-222.

35. Vital, B., Lehmann, W., and Boone, R.S. 1974. How species and board densities affect properties of exotic hardwood particleboards. For. Prod. J. 24(12): 37-45.

Table 1.--VARIABLES CHOSEN TO MANUFACTURE 1/2 INCH BY 4-BY 8-FOOT STRUCTURAL FLAKEBOARD PANELS FROM FOREST RESIDUES

Manufacturing Variables	Softwood	Hardwood
Raw material	Douglas-fir residues	Equal amounts of white oak, hickory, southern red oak, sweetgum, and southern pine
Panel density	43 pcf[1]	47.5 pcf[2] random, 45.5 pcf[2] alined
Face flakes	0.02 x 1 x 2 in disk flakes	0.015 x 3 in x random width shaping headrig flakes, bolts heated to 160°F
Core flakes	0.05 x 2 in x random width ring flakes	0.025 x 3 in shaping headrig flakes, milled to reduce width
Face:core:face flake ratio	15:70:15 by weight	25:50:25 by weight
Phenolic resin	5% solids[3]	6% solids[3]
Wax emulsion	1% solids[3]	1% solids[3]
Mat moisture content	10%	10%, addition 4.32 g of water/ft^2 sprayed on surface
Press cycle	10 min at 350°F Press closed to stops in 1 min	5 min at 350°F Press closed to stops in 314 min

[1] Based on oven dry weight and nominal volume.

[2] Based on 6% panel moisture content.

[3] Based on oven dry weight of flakes.

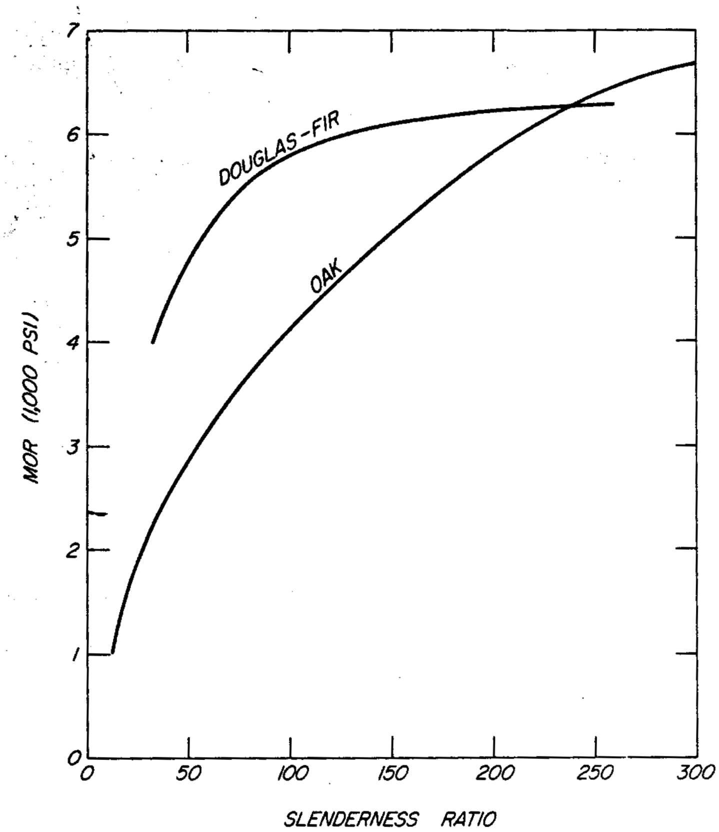


Figure 1.-- Slenderness ratio (flake length/flake thickness) vs. modulus of rupture (MOR). Douglas-fir values are from Brumbaugh (1); oak figures from Post (24).

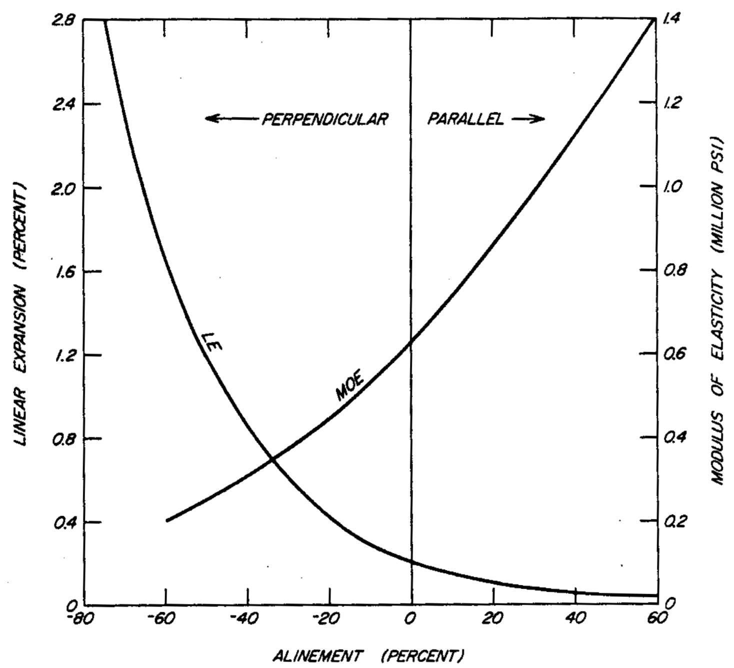


Figure 2.--Percent of flake alignment vs. linear expansion (LE) and modulus of elasticity (MOE). From Geimer (4).

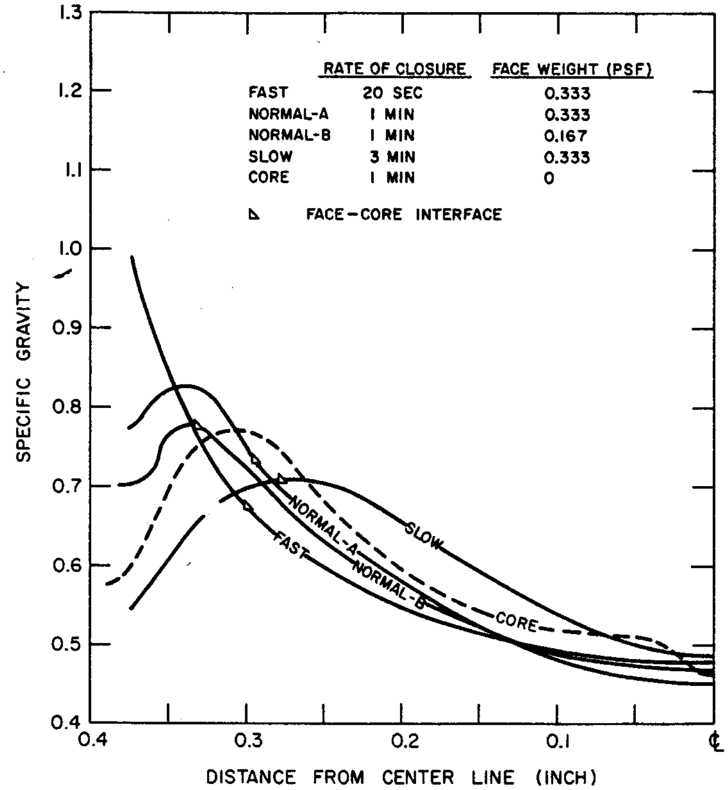


Figure 3.-- Density gradient for 3/4-inch particleboards as affected by rate of closure and face weight. From Geimer et al. (3).

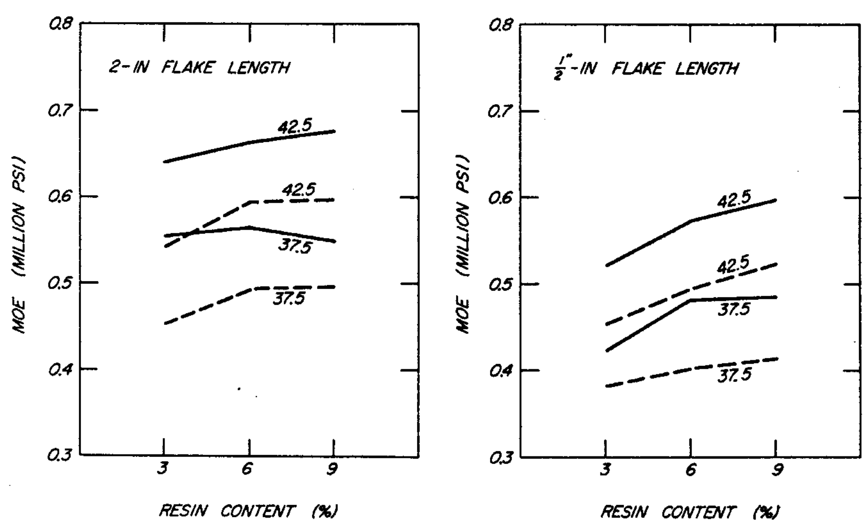


Figure 4.--Effect of resin content, density, flake thickness, and flake length on MOE. Values from Lehmann (18) with data adjusted to densities of 37.5 or 42.5 pcf. Solid lines depict data from board made with 0.045-inch-inch-thick flakes; dashed lines refer to 0.045-inch-thick flakes.

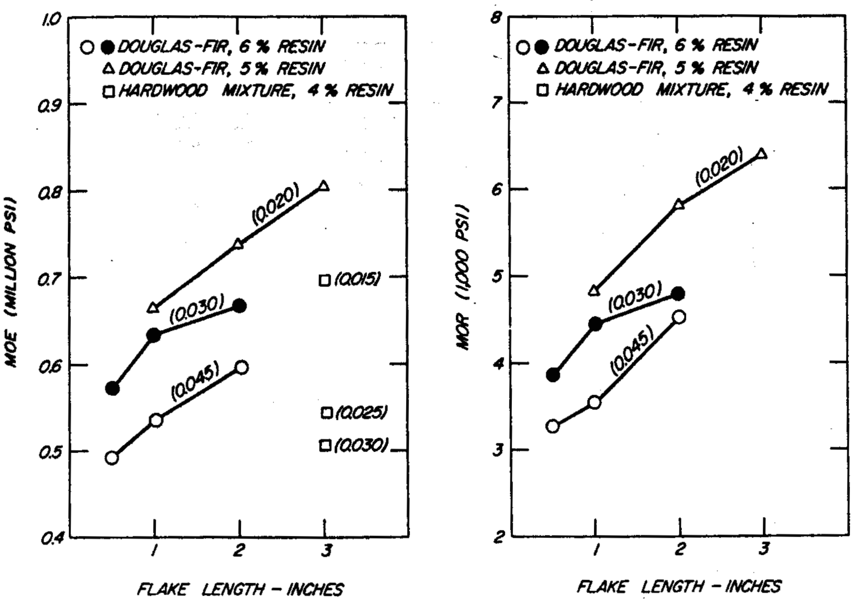


Figure 5.--Effect of flake length and flake thickness on modulus of elasticity (MOE) and modulus of rupture (MOR). Number in parenthesis is flake thickness in inches. Values for Douglas-fir 6% resin solids are from Lehmann(18); Douglas-fir 5% resin solids from Geimer(4); hardwood mixture 4% resin solids from McMillan and Koch(22).

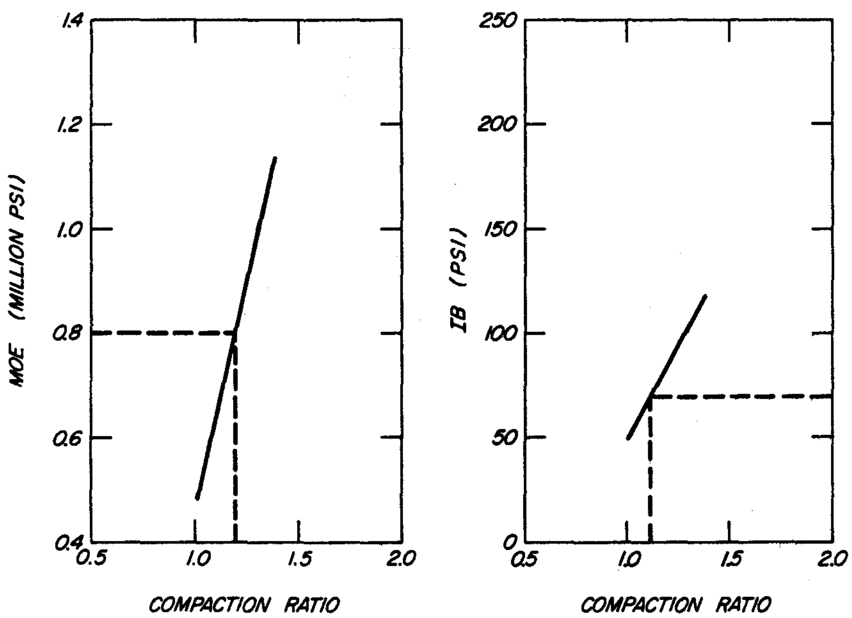


Figure 6.-- Minimum compaction ratio required to achieve the FS goal of 800,000 psi MOE and 70 psi IB using the hardwood mix. Dotted line shows ratio of 1.18 for MOE and 1.15 for IB. Lathe flakes 0.15 and 3 inches are from an equal mixture of four hardwoods and southern pine, from Hse (13).

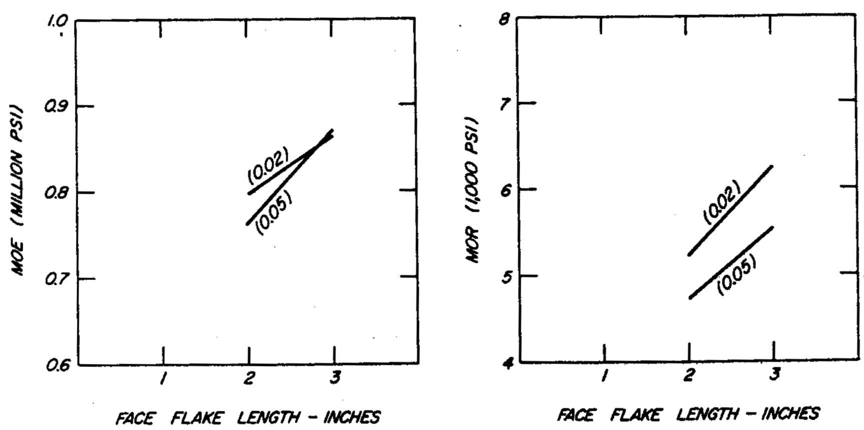


Figure 7.-- Effect of core flake thickness and face flake length on MOE and MOR of three-layer structural flakeboard. Numbers in parentheses are core flake thicknesses in inches. Values are from Ramaker(28).
0.020-inch face flakes
12% face MC, 8% core MC
15:70:155, face:core:face ratio
5% PF resin
Av. panel density 41.0 pcf.

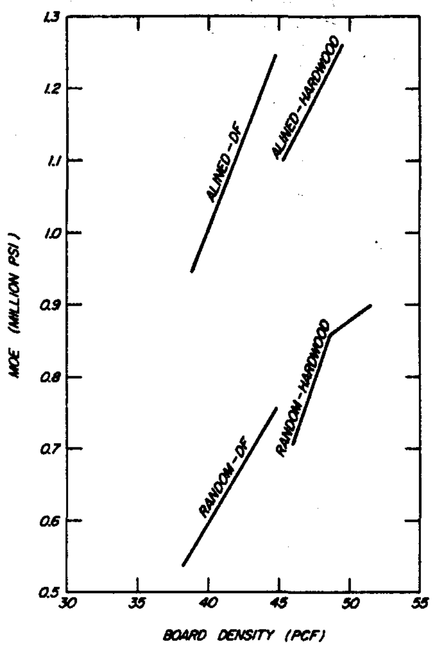


Figure 8.--Effect of density and alignment on MOE of three-layer boards. Values for Douglas-fir (5% resin solids) are from Ramaker (28); values for hardwood mix (5.5% resin solids) are from Hse(l3).

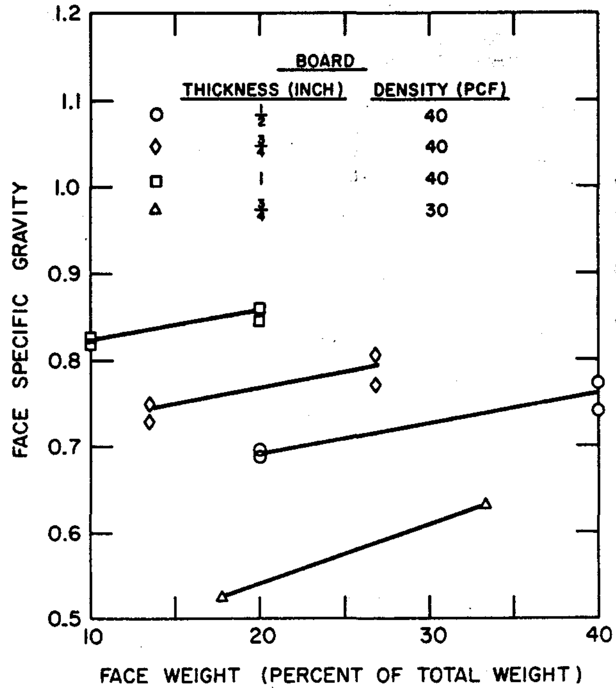


Figure 9.-- Face layer specific gravity as affected by face weight and total board thickness. From Geimer et al. (3).

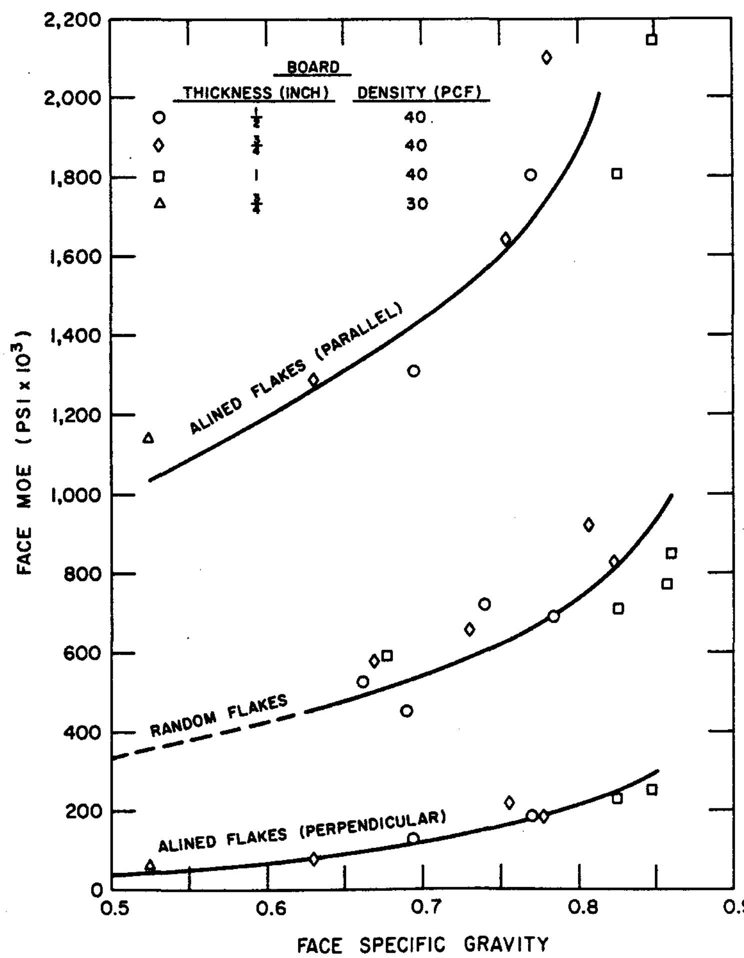


Figure 10.--Influence of specific gravity on the MOE [tensile) and total board thickness. From Geimer et al. (3).

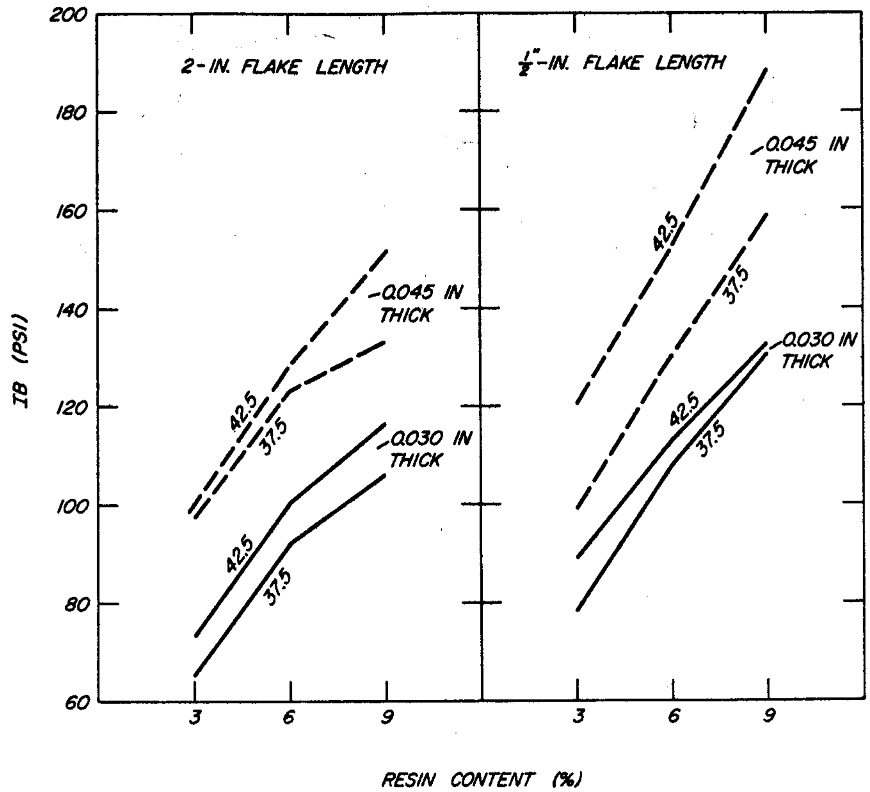


Figure 11.--Effect on internal bond of resin content and density, two flake thicknesses, and two flake lengths. Values are from Lehmann (18).

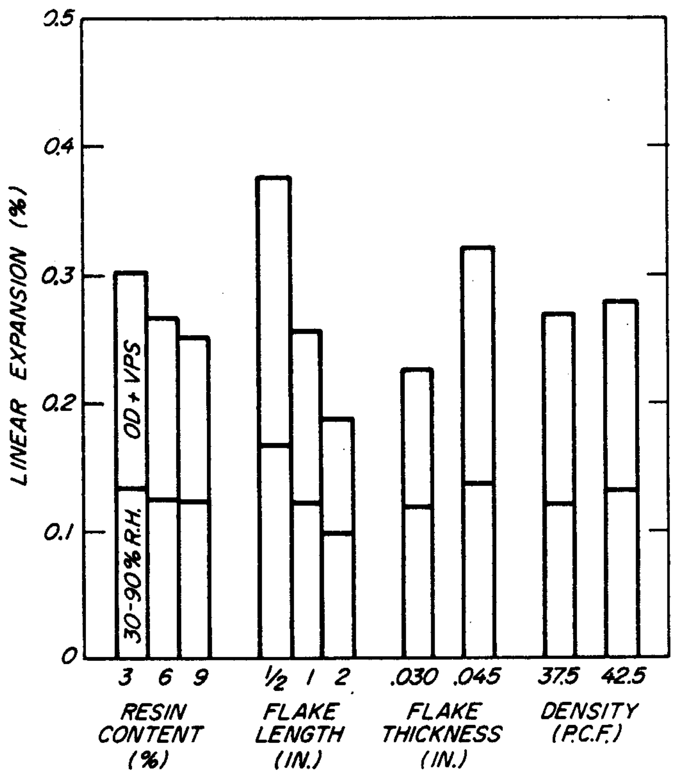


Figure 12.—Overall effects of variables on linear expansion of Douglas-fir flakeboards in 30 to 90% RH and ovendry and vacuum-pressure-soak tests, Values are averaged across the other variables. From Lehmann (18).

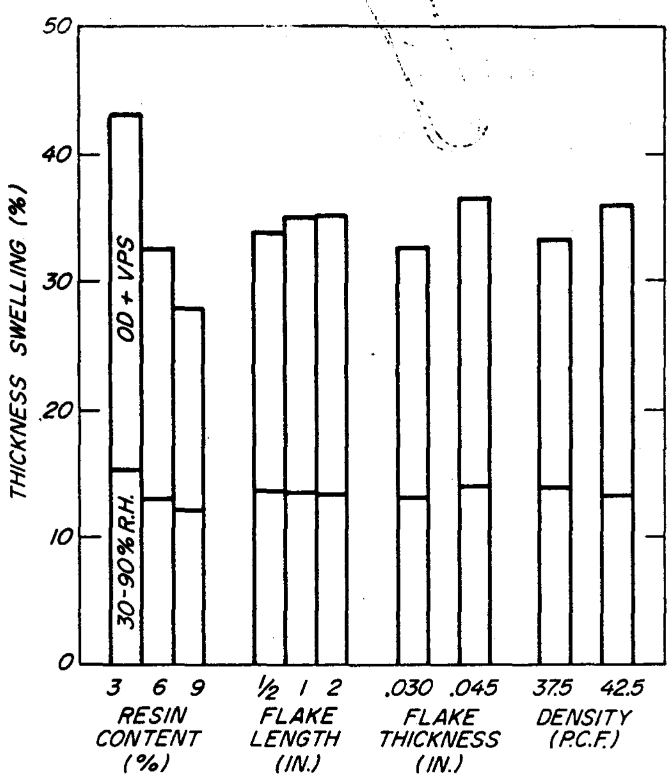


Figure 13.-- Overall effects of variables on thickness swelling of flakeboards in 30 to 90% RH and ovendry and vacuum-pressure-soak tests. Values are averaged across the other variables. From Lehmann (18).

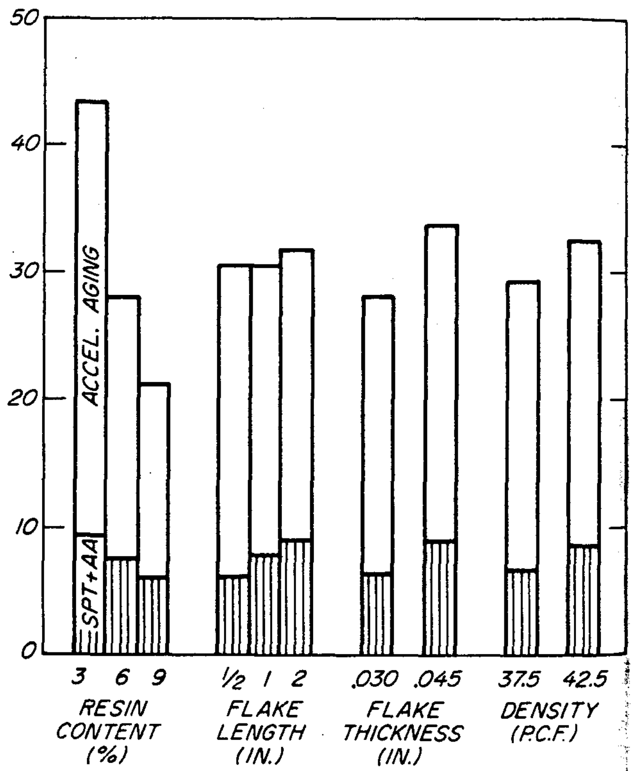


Figure 14.-Overall effets of study variables on thickness swelling retention of flakeboards after steam post-treatment and/or accelerated aging exposure. Values are averaged across the other variables. From Lehmann (18).

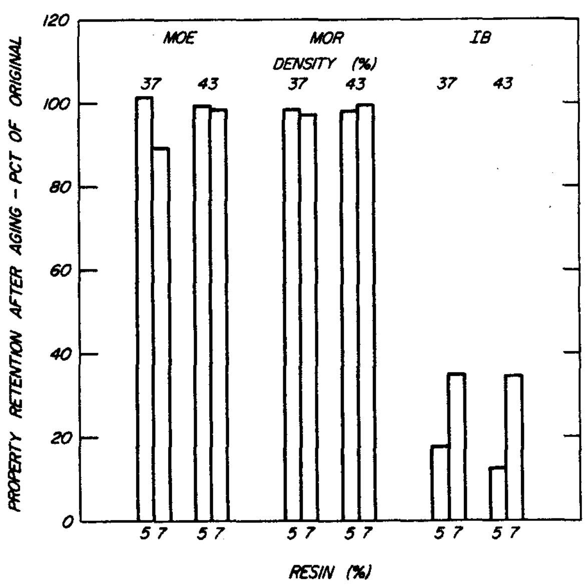
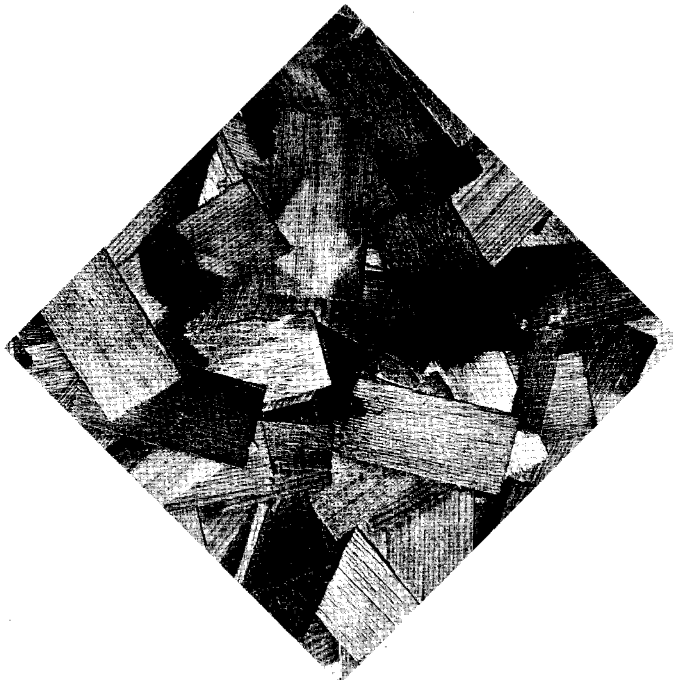


Figure 15.-- Retention of properties following accelerated aging (ASTM D 1037). Values are from Ramaker (28).



STRUCTURAL FLAKEBOARD

STRUCTURAL FLAKEBOARD

FROM FOREST RESIDUES

FROM FOREST RESIDUES

U.S. Department of Agriculture
Forest Service
General Technical Report WO-5

STRUCTURAL FLAKEBOARD FROM FOREST RESIDUES

PROCEEDINGS OF A SYMPOSIUM

PRESENTED BY THE

USDA FOREST SERVICE

JUNE 6-8, 1978

KANSAS CITY, MO,

GENERAL TECHNICAL RERORT WO – 5

FOREST SERVICE

U.S. DEPARTMENT OF AGRICULTURE

WASHINGTON, D.C.

September 1978