Laboratory-Scale Development of a Structural Exterior Flakeboard From Hardwoods Growing on Southern Pine Sites

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Abstract

A series of experiments was conducted to develop a 1/2-inch-thick, structural, exterior, mixed-species flakeboard functionally competitive with sheathing grades of plywood. The board design settled on is comprised of equal-weight portions throughout of *Carya* spp., *Quercus alba* L., *Quercus falcata* Michx., *Liquidambar styraciflua* L., and southern pine (e.g., *Pinus taeda* L.). These species were cut with a shaping-lathe headrig to yield face flakes 0.015 inch thick and core flakes 0.025 inch thick. All flakes were 3 inches long; those used in the core were reduced in width by milling. Phenol-formaldehyde binder (5.5%) was blended with flakes initially at 4 percent moisture content. Just prior to pressing, the mat was water-sprayed on both sides. Press time was 5 minutes at 335°F. All the panels had random flake orientation in the core; half the panels had random faces; the other half had faces comprised of aligned flakes. Properties observed in 18-inch-square panels at 50 percent relative humidity were:

	Face flake orientation	
	Random	Aligned
Density (lb./cu.ft.)	47.5	45.5
Internal bond strength (psi)	83	82
Modulus of elasticity (psi)	800,000	1,090,000
Modulus of rupture (psi)	5,300	6,625

THIS PAPER IS ONE OF A SERIES describing efforts of the Pineville, Louisiana, laboratory of the Southern Forest Experiment Station to develop a process for manufacturing structural exterior flakeboard from mixed hardwoods growing on southern pine sites. The flakeboard is intended to compete in price and function with sheathing grades of plywood.

Other phases of the development, besides those reported here, are described in manuscripts on:

- Development of a machine to make the required flakes on a commercial scale (Koch 1974)[1].
- Factors affecting properties of a hardwood flake-resin composite (Price 1974).
- Species effects on properties of flakeboards made from perfectly formed hardwood flakes (Hse, in press).
- Formulation of a fast-cure phenolic resin binder for exterior structural flakeboard of 22 southern hardwood species (Hse, manuscript in preparation)[1].
- Effect of flake orientation on physical and mechanical properties of hardwood flakeboard (Hse and Price, manuscript in preparation)[1].
- Properties of 4- by 8-foot panels of structural exterior flakeboard from southern hardwoods flaked on a shaping lathe headrig (Price, manuscript in preparation)[1].

In addition, R. Jorgensen, Particleboard Specialist of the State and Private Forestry arm of the Forest Service, has in press a manuscript surveying U.S. experience in application of structural exterior particleboard.[1]

In toto, these seven papers—plus the one at hand—provide the technical background for a potentially important new South-wide industry based on an under-utilized hardwood resource. Timing of the initiation of this industry will depend on the overall demand for wood, and in particular on the demand and supply situation for lumber and plywood of southern pine and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco). Also, ready availability of a low-cost resin binder is required for initiation of this new industry.

Some 99 percent of the volume of hardwoods growing on southern pine sites is comprised of 22 species. The preponderance is in trees measuring 6 to 8 inches DBH, and averaging 40 to 50 years of age. With four exceptions (yellow-poplar, sweetbay, sweetgum,

[1]These papers were presented at a symposium "Utilization of hardwoods growing on southern pine sites" in Alexandria, La. March 10-14, 1975.

The authors are scientists at the Pineville, Louisiana, utilization laboratory of the So. Forest Expt. Sta., USDA Forest Service. This paper was presented at Session 29—Particleboard & Molded Products—of the 28th Annual Meeting of the Forest Products Research Society, June 27, 1974, in Chicago, Ill. It was received for publication in November 1974.

Table 1. — PROPORTIONATE VOLUME, BY SPECIES, OF 22 HARDWOODS GROWING ON SOUTHERN PINE SITES, AND STEMWOOD SPECIFIC GRAVITY (BASIS OF GREEN VOLUME AND OVENDRY WEIGHT).

Species	Percent[1]	Specific gravity[2]
Sweetgum (*Liquidambar styraciflua* L.)	21	0.448
Hickory, true (*Carya* spp.)	10	.619
Black tupelo (*Nyssa sylvatica* Marsh.)	9	.502
Post oak (*Quercus stellata* Wangenh.)	9	.660
Southern red oak (*Q. falcata* Michx.)	9	.609
Water oak (*Q. nigra* L.)	8	.587
White oak (*Q. alba* L.)	8	.673
Yellow-poplar (*Liriodendron tulipifera* L.)	4	.397
Sweetbay (*Magnolia virginiana* L.)	3	.437
Black oak (*Q. velutina* Lam.)	3	.620
Cherrybark oak (*Q. falcata* var. *pagodaefolia* Ell.)	2	.633
White ash (*Fraxinus americana* L.)	2	.582
Green ash (*F. pennsylvanica* Marsh.)	2	.561
Red maple (*Acer rubrum* L.)	1	.496
American elm (*Ulmus americana* L.)	1	.536
Winged elm (*U. alata* Michx.)	1	.623
Hackberry (*Celtis occidentalis* L.)	1	.525
Northern red oak (*Q. rubra* L.)	1	.597
Scarlet oak (*Q. coccinea* Muenchh.)	1	.622
Shumard oak (*Q. shumardii* Buckl.)	1	.625
Laurel oak (*Q. laurifolia* Michx.)	1	.583
Blackjack oak (*Q. marilandica* Muenchh.)	1	.638

[1]Data compiled for Alabama, Louisiana, Texas, and Oklahoma, 1963-1965, by the Forest Resources Research Work Unit, Southern Forest Experiment Station, USDA Forest Service.

[2]Southwide average, for trees 6 inches DBH collected in connection with F. G. Manwiller's study FS-SO-3201-1.40, of wood and bark specific gravity and heartwood content of 22 hardwood species growing on southern pine sites. Southern Forest Experiment Station, Pineville, La.

and red maple), all exceed 0.5 in specific gravity (Table 1). Eleven of the 22 species are oak; these oaks account for about 44 percent of the total volume. In aggregate, there is about 0.8 cu. ft. of these hardwoods for every cu. ft. of southern pine on the same sites.

Target Specifications

In 1972, following review of the Close Timber Utilization Committee Report, the Forest Service announced that over the next 5 years it would undertake a major effort to reduce undesirable logging residues. The conversion of logging residues into structural exterior flakeboard was identified as a research component of Close Timber Utilization having a high potential for success. A nine-man Planning Force, chaired by John Zerbe, director of Forest Products and Engineering Research, was charged with developing a coordinated research program to achieve this goal. The national program has been described by Schaffer (1974).

Flakeboard for potential use as roof or wall sheathing or subflooring must have certain minimum properties if it is to perform satisfactorily. To provide guidelines for researchers developing such flakeboards, the Planning Force established target specifications. These goals, promulgated in March of 1973, are briefed as follows:

Property	Target or goal
Modulus of elasticity in bending (average)	800,000 psi
Modulus of rupture (near minimum)	4,500 psi
Internal bond strength (average)	
Dry	70 psi
After accelerated aging (ASTM D1037)	35 psi
Lateral nail resistance in 1/2-inch-thick board	300 lb.
Nailhead pullthrough in 1/2-inch thick board	250 lb.
Nail withdrawal from dry board	40 lb.
Hardness	500 to 1,200 lb.
Linear expansion (30 to 90 percent relative humidity (RH))	0.25%
Thickness swelling (30 to 90 percent RH)	8%
Density	37 to 43 lb./cu. ft.

There is not complete agreement on the appropriateness of these values, but they have been the goals for the research reported in this paper.

Procedure

The target specifications were attained (except for density), or closely approached, through a series of experiments each designed to elucidate a limited facet of the problem. Fabrication procedures were altered in successive steps as more was learned about factors controlling board properties.

These experiments determined the effects of species and species mix, flake dimensions, orientation and quality, flaking temperature, board density, flake moisture content (MC), and resin content on modulus of elasticity (MOE), modulus of rupture (MOR), and internal bond strength (IB). Strength properties were measured with boards at or near equilibrium in an atmosphere held at 50 percent RH and 72°F.

Results

It was early observed that the major problem was attainment–at an acceptable density–of target values of MOE and IB. If MOE was up to target, MOR was usually more than adequate. The experiments described on the following pages concentrated, therefore, on the two properties of MOE and IB.

Flake Orientation

Price (1974) provided basic information that confirmed results of other workers and showed that MOE and ultimate tensile strength of 1/2-inch sweetgum board could be very substantially increased by aligning flakes so that their grain angle was within 15 degrees of alignment with direction of load

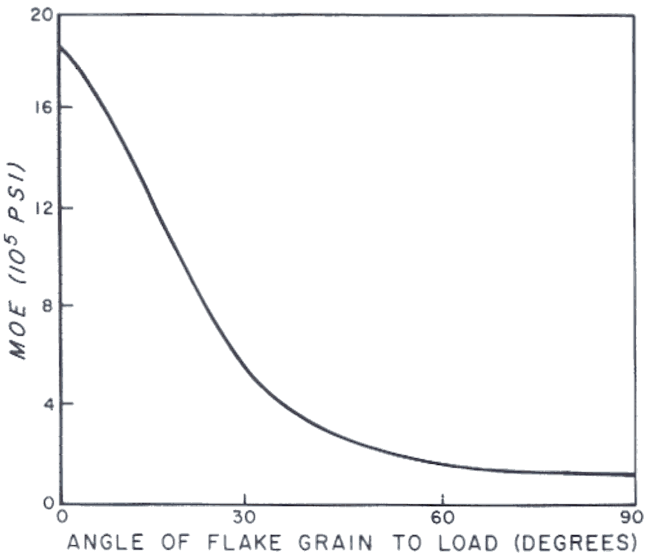

Figure 1. — Relationship between MOE and orientation of flakes in tensile specimens cut from 42-pound, 1/2-inch flakeboard of sweetgum veneer flakes 0.015 inch thick, 3 inches long, and 3/8-inch wide. Resin content 5 percent. After Price (1974).

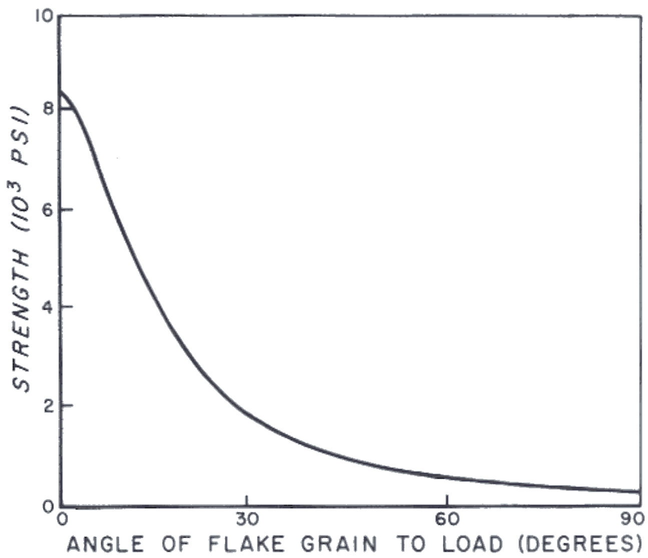

Figure 2. — Relationship between ultimate tensile strength and orientation of flakes in tensile specimens cut from 42-pound, 1/2-inch flakeboard of sweetgum veneer flakes 0.015 inch thick, 3 inches long, and 3/8-inch wide. Resin content 5 percent. After Price (1974).

application. With perfectly formed, 0.015-inch thick, 3-inch-long flakes perfectly aligned with the direction of tension loading, it was possible to obtain an MOE of over 1,800,000 psi and an ultimate tensile strength of over 8,000 psi (Figs. 1 and 2). These values were attained at a panel density of only 42 lb./cu. ft.

The flakes used by Price were cut from 0.015-inch-thick veneer to precise length (3 inches) and then clipped to precise width (3/8-inch) to yield extremely uniform flakes (Fig. 3). In subsequent discussion these perfect flakes will be termed *veneer* flakes.

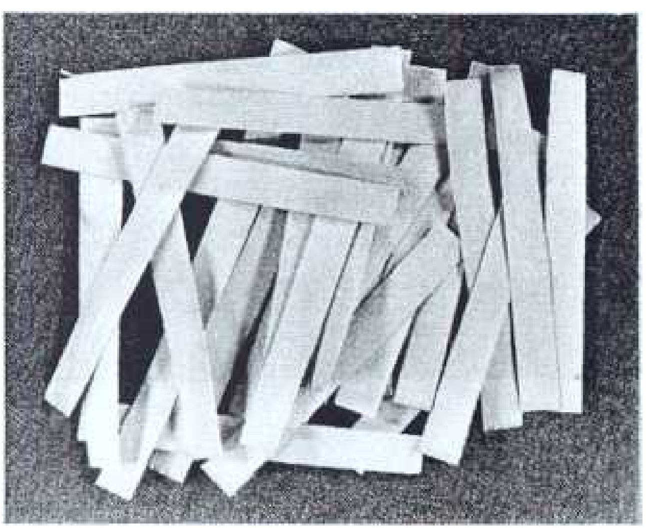

Figure 3. — Sweetgum veneer flakes accurately and uniformly peeled 0.015 inch thick, scored to 3-inch length, and clipped to 3/8-inch width.

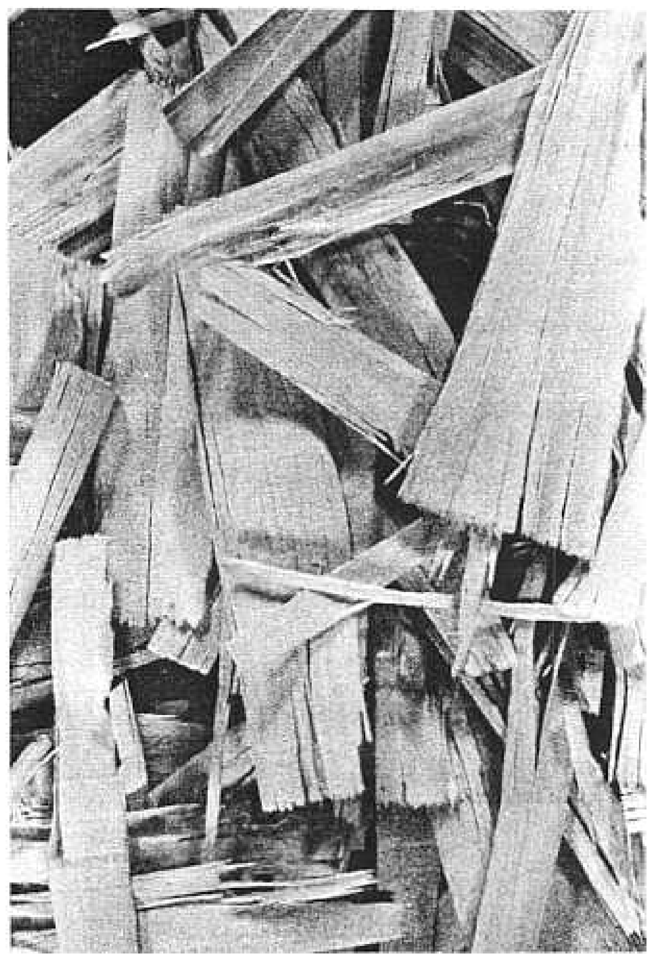

Figure 4. — Sweetgum lathe flakes cut on a shaping-lathe headrig to a length of 3 inches, an average thickness of 0.015 inch, and variable width.

Flake Quality

Price (1974) also demonstrated the major dependence of MOE and IB on flake quality. Flakes cut on the shaping-lathe-headrig (Koch 1974)–hereafter termed *lathe* flakes–are good for an industrial flaker (Fig. 4), but they are substantially less uniform in thickness and width than the veneer flakes.

Price showed that the lathe flakes made boards of substantially lower MOE and IB than did veneer flakes; moreover, achievable properties followed the rule of mixtures which predicts property values as correlated with proportions of the two flake types. The relationships are illustrated by Figure 5 and by the following tabulation (both for sweetgum board):

Type and proportion of flakes	IB strength
	psi
100% veneer and 0% lathe	214
75% veneer and 25% lathe	123
50% veneer and 50% lathe	96
25% veneer and 75% lathe	75
0% veneer and 100% lathe	57

Wood Density and Species

Hse (in press), using veneer flakes of nine of the 22 species listed in Table 1, showed that MOE, IB, and MOR were all linearly correlated with the compaction ratio, i.e., the ratio of panel density to the density of the solid wood from which component flakes were cut. Slopes of the relationships were very steep, and compaction ratios of 1.1 to 1.3 were necessary to achieve strengths approaching target values (Figs. 6, 7, and 8). These relationships are of major significance, because they indicate the difficulty in making low-density flakeboard of target strength from high-density woods.

Price (1974) further demonstrated the strong effect of species mix on MOE and IB. Using lathe flakes of white oak (a very dense wood) and sweetgum (a low-density wood) Price found that, if panel density was fixed, these properties were correlated with the proportions of the species mix (Fig. 9 and Table 2). This effect has also been observed by Hse (Table 2), who used veneer flakes of nine hardwood species and fixed panel density at 48 lb./cu. ft.

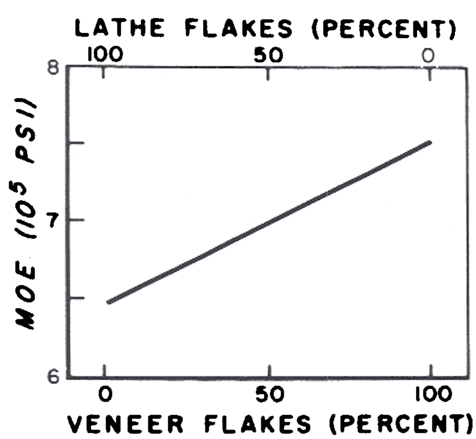

Figure 5. — Relationship of MOE to proportions of veneer and lathe flakes in 1/2-inch sweetgum flakeboard with density of 42 pounds per cubic foot. After Price (1974).

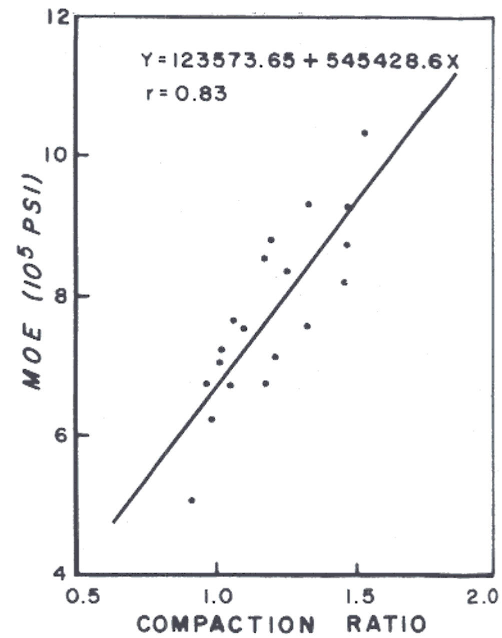

Figure 6. — Relationship of compaction ratio to MOE of boards made from veneer flakes.

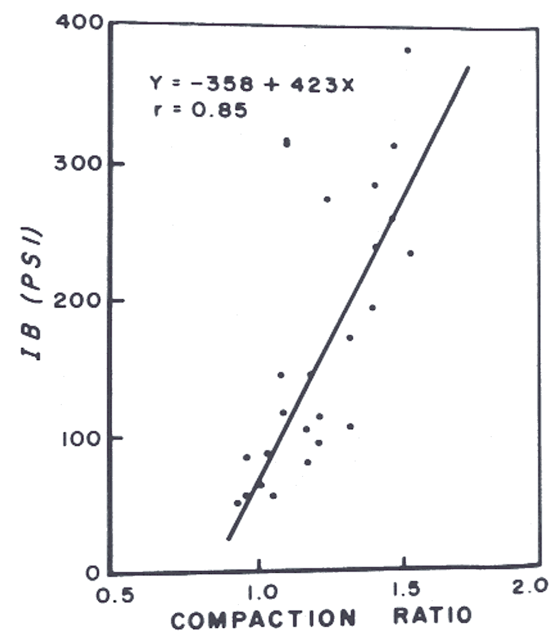

Figure 7. - Relationship of compaction ratio to IB strength of boards made from veneer flakes.

Flake Thickness and Width

McMillin and Koch (1974), in a study of boards made from mixed lathe flakes of sweetgum, hickory,

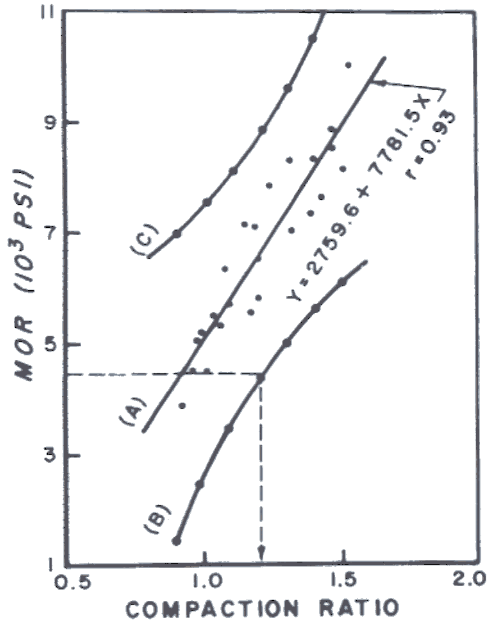

Figure 8. — Relationship of compaction ratio to bending strength of boards made from veneer flakes. Upper and lower lines show 95 percent exclusion limits.

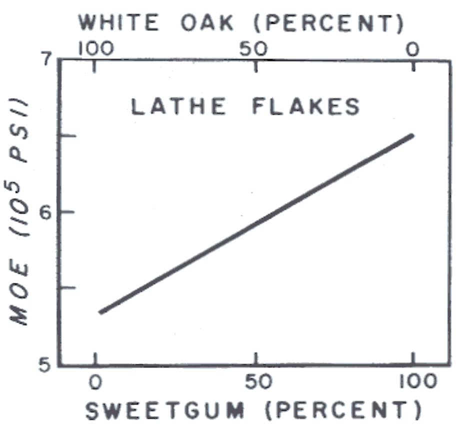

Figure 9. — Relationship of MOE to proportions of white oak and sweetgum lathe flakes in 1/2-inch flakeboard.

Table 2. — IB STRENGTH AND MOE OF FLAKEBOARD AS RELATED TO PROPORTIONS OF WHITE OAK AND SWEETGUM IN THE BOARD.

Proportion of flakes by species		Price's data[1]	Hse's data[2]	
Sweetgum	White Oak	on IB	IB	MOE
%		psi		
100	0	57	196	825,000
75	25	53	162	761,000
50	50	55	133	734,000
25	75	47	128	699,000
0	100	35	88	677,000

[1]Price (1974).
[2]Hse (in press).

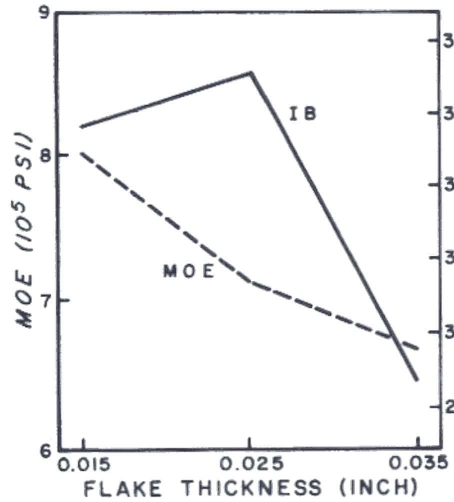

Figure 10. — Relationships of flake thickness to MOE and IB strength of mixed-species boards made from lathe flakes. Boards were 25 percent sweetgum, 25 percent hickory, and 50 percent southern red oak.

and southern red oak, showed that MOE was maximized through use of flakes 0.015-inch thick, but that IB was maximum with 0.025-inch flakes (Fig. 10). When boards were made of these single species, and also of loblolly pine, the same relationships prevailed.

This observation provided strong impetus to consider a 3-layer board having 0.015-inch face flakes and 0.025-inch core flakes.

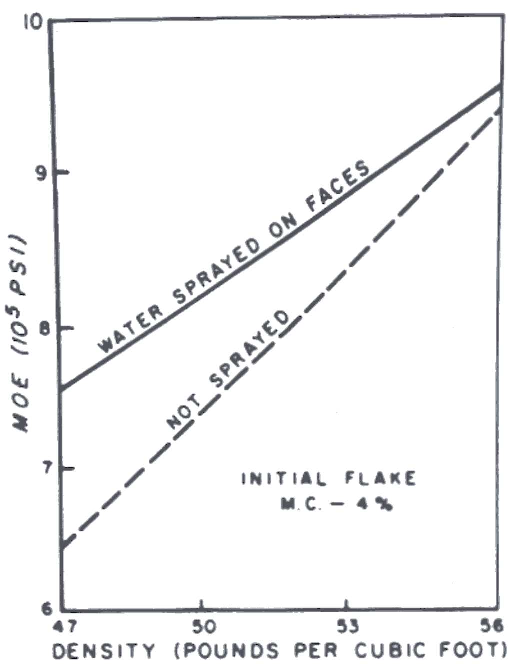

Figure 11. — Effect on MOE of water-spraying top and bottom mat surfaces just prior to hot-pressing three-layer board made of cold-cut lathe flakes 3 inches long and randomly oriented. Flake thickness was 0.025 inch in the core and 0.015 on the faces. Boards contained 25 percent each of sweetgum, hickory, southern red oak, and white oak. Resin content was 5 percent and press time 5 minutes.

Further data from the McMillin-Koch experiment showed that IB is significantly improved if lathe flakes of certain species (e.g., sweetgum, hickory, and loblolly pine) are reduced in width after they are formed on the shaping-lathe headrig. Presumably this improvement results from eliminating very wide flakes that fold (sweetgum and pine) or roll (hickory) in such a manner that resin distribution is poor. Also, horizontal density distribution is generally improved by reduction of flake width.

Width reduction of flakes did not improve MOE, however. These observations provided reason to consider a three-layer board in which core flakes are narrow and face flakes are wider.

MC of Mat

The McMillin-Koch experiment, and ancillary work in connection with it, showed that flake MC before addition of binder should be near 4 percent to maximize IB, but that mat surface MC should be considerably higher to maximize MOE.

Hse and Koch (1974) amplified this observation in a sub-experiment in which both surfaces of a mat were sprayed with water (10 grams to each face of a 20- by 20-inch mat) just prior to hot pressing. When a 3-layer mixture of hardwood flakes was pressed to stops in 45

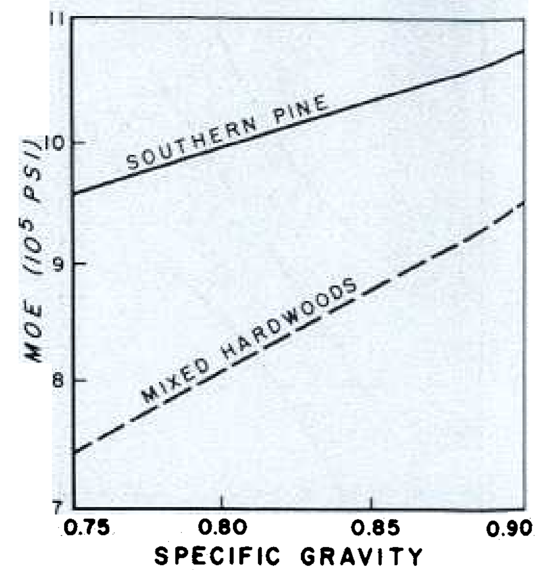

Figure 12. — Relationship between MOE and specific gravity of 1/2-inch board made from 0.015-inch lathe flakes of southern pine and of a mixture of 25 percent sweetgum, 25 percent hickory, and 50 percent southern red oak.

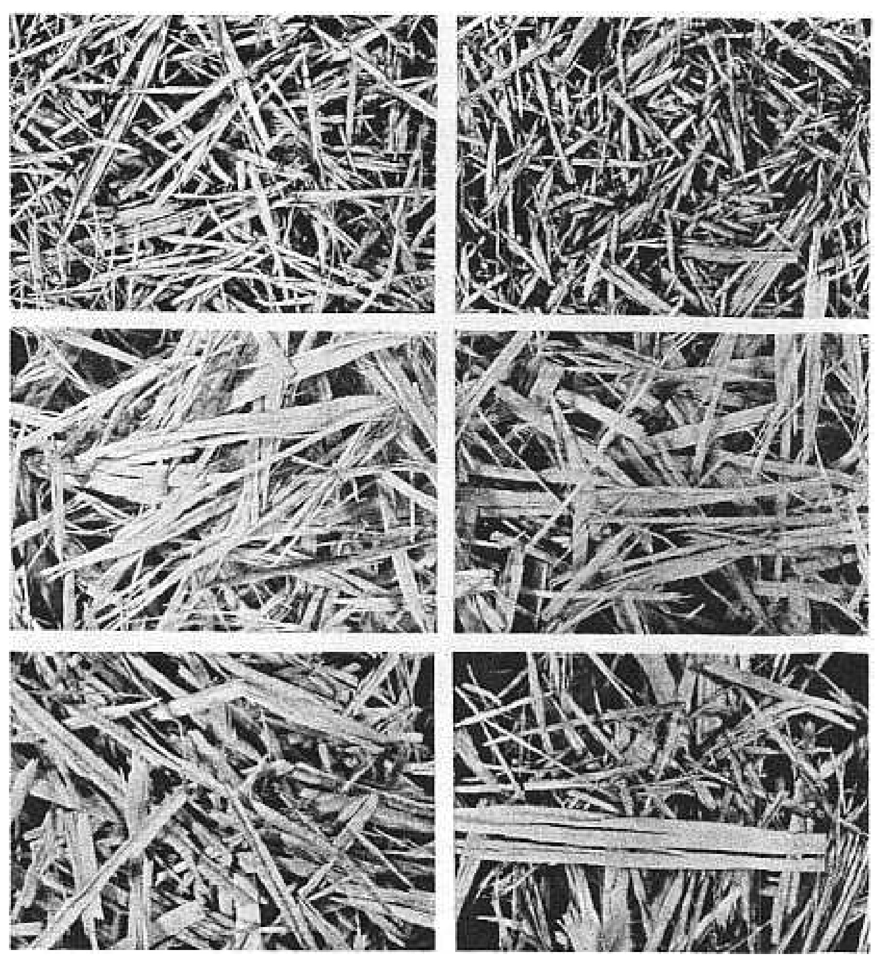

Figure 13. — Core flakes, 0.025 inch thick and 3 inches long, milled to reduce width. Top left, white oak; top right, southern red oak; center left, hickory; center right, sweetgum; bottom left, southern pine; and bottom right, the five species mixed.

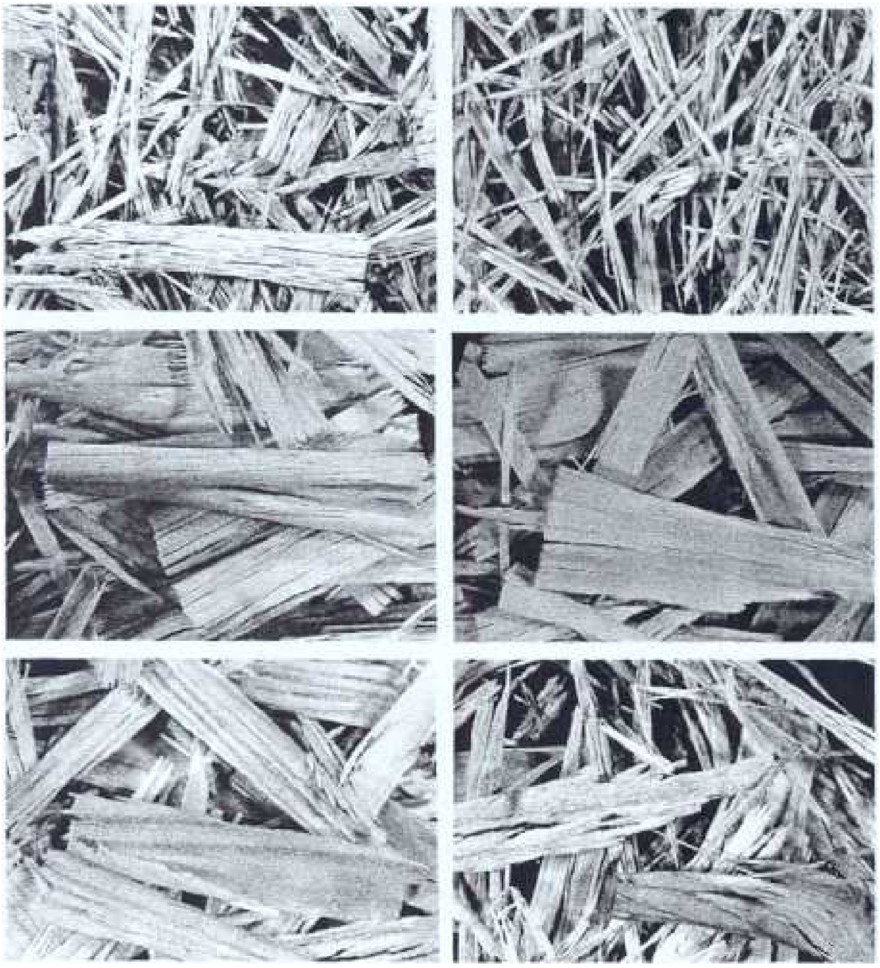

Figure 14. — Face flakes 0.015 inch thick and 3 inches long in random widths as produced on the shaping lathe. Top left, white oak; top right, southern red oak; center left, hickory; center right, sweetgum; bottom left, southern pine; and bottom right, the five species mixed.

seconds to yield a panel density of 50 lb./cu. ft., MOE was raised about 100,000 psi by application of the water spray (Fig. 11). The increase in MOE was mainly attributable to densification of surfaces; density profiles were not quantitatively evaluated, however. Similar observations have been made by Klauditz and Rackwitz (1952) and Strickler (1959).

Inclusion of Southern Pine in the Furnish

The McMillin-Koch experiment included observations of boards made of loblolly pine as well as those made of mixed hardwoods (25% sweetgum, 50% red oak, and 25% hickory). It was abundantly evident that the pine yielded boards of greater MOE than did the mixed hardwoods. Moreover, while the pine board showed positive correlation between MOE and panel specific gravity, the slope of the regression line was less steep than that for the mixed hardwood board (Fig. 12).

From these observations and from Figures 6, 7, and 8, it was concluded that a small proportion of pine would substantially improve MOE, IB, and MOR at panel densities below 50 lb./cu. ft.

Final Board Density and Properties

On the basis of all of the foregoing data, Hse and Koch (1974) performed a final experiment having these factors:

Fixed factors

- Panel thickness: 1/2-inch
- Species mix: 20 percent each of hickory, white oak, southern red oak, sweetgum, and southern pine
- Flake type: Shaping-lathe-headrig; i.e., lathe flakes
- Flake length: 3 inches
- Flake moisture content: 3-4 percent
- Specific pressure on mat: 575 psi
- Press temperature: 335°F
- Press time: 5 minutes (including closing time of 45-60 sec.)
- Resin content: 5-1/2 percent
- Core flakes: Random orientation, 0.025 inch thick width-reduced with special attention to sweetgum and hickory
- Face flakes: 0.015-inch thick, mat water-sprayed on both sides just prior to pressing

Figure 15. — Three-layer, five-species board with randomly oriented lathe flakes throughout.

Figure 16. — Three-layer, five-species board with aligned face flakes and randomly oriented core flakes all cut on the shaping-lathe headrig.

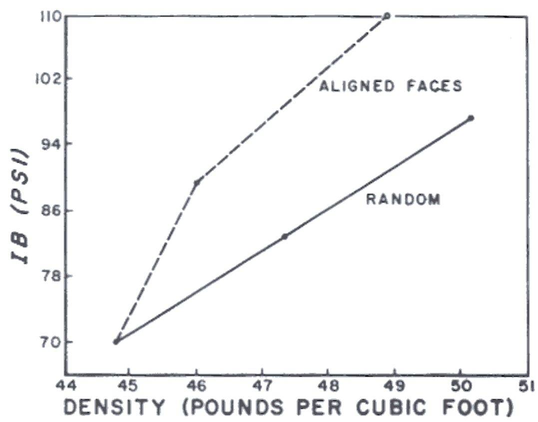

Figure 17. — Relationship of IB strength to panel density in three-layer, 1/2-inch boards made of lathe flakes, with random cores and either aligned or random faces. Cores and faces contained 20 percent each of white oak, hickory, southern red oak, sweetgum, and southern pine. Each point plotted is an average value obtained from 30 specimens.

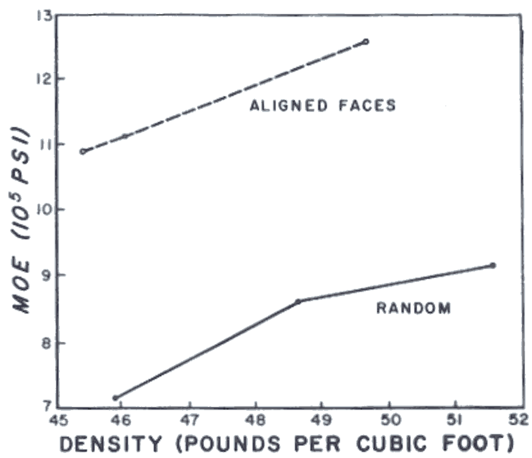

Figure 18. — Relationship of MOE to panel density in three-layer, 1/2-inch boards made of lathe flakes, with random cores and either aligned or random faces. Species mixture same as in Figure 17. Each point plotted is an average value obtained from 12 specimens.

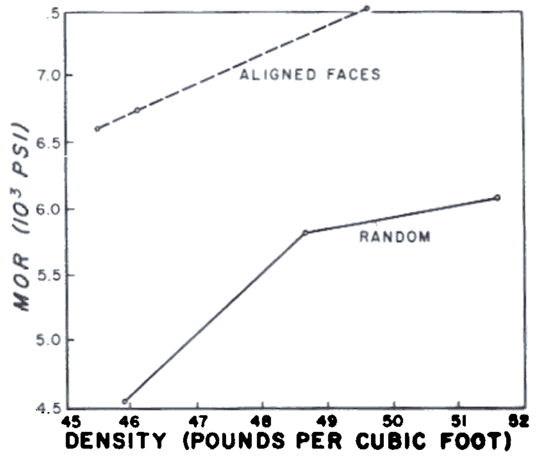

Figure 19. — Relationship of MOR to panel density in three-layer, 1/2-inch boards made of lathe flakes, with random cores and either aligned or random faces. Species mixture same as in Figure 17. Each point plotted is an average value obtained from 12 specimens.

Variable factors

Panel density at 50 percent RH: 45, 47, and 49 lb./cu. ft.

Face flakes:

1) Random orientation; not width reduced
2) Aligned; sweetgum, hickory, and southern pine flakes reduced in width for ease of feeding through the aligning mechanism

Replications of boards: 3

Core flakes are illustrated in Figure 13 and face flakes in Figure 14. The random board is shown in Figure 15 and the board with aligned faces in Figure 16.

This 3-layer design met the specifications for MOE, MOR, and IB at densities below 50 lb./cu. ft.:

	Face flake orientation	
Panel property at 50% RH	Random	Aligned
Density (lb./cu. ft.)	47.5	45.5
IB (psi)	83	82
MOE (psi)	800,000	1,090,000
MOR (psi)	5,300	6,625

Relationships of IB, MOE, and MOR to panel density are plotted in Figures 17, 18, and 19 (from which the foregoing tabulation was constructed). The target IB of 70 psi was attained in both aligned and random boards at a panel density of 44.7 lb./cu. ft. (Fig. 17). Target MOE of 800,000 psi required a random panel density of 47.5 lb./cu. ft., however, at which density IB was 83 psi (Fig. 18). The board with aligned faces had an MOE of 1,090,000 at density of 45.5 lb./cu. ft., at which density IB was 82 psi. At all densities, MOR of the aligned board was well above that of the random board (Fig. 19).

The flakes for the panels just described were cut with sharp knives from wood heated in water to 160°F. Subsequent experimentation showed a loss of a few percentage points in MOR and IB in panels made from the same mix of flakes cut from wood at 72°F. Another slight loss in values was discernible when knives were allowed to become substantially dull. In future work, flakes will be cut at ambient temperature and attention will be focused on keeping knives sharp.

Discussion

From Figure 17 it is clear that the target IB of 70 psi imposed a definite lower limit on panel density, i.e., 44.7 lb./cu. ft. for the species mix used. In production, panel densities may need to be somewhat greater to insure an IB of 70 psi at 5.5 percent resin content.

It is also clear that alignment of face flakes yields boards with higher MOE than random boards of the same weight.

Ancillary data from McMillin and Koch and from Hse (in press) indicate that the panels described by Figures 17, 18, and 19 will have a thickness swell, when cycled from 30 to 90 percent RH, considerably greater (16 to 17 percent with no wax additive) than the target value of 8 percent.

Linear expansion should be about 0.15 percent, which is less than the target value of 0.25 percent. Nail withdrawal, nailhead pullthrough, and lateral nail resistance will all be substantially greater than target values. Hardness of these panels, while permitting the hand driving of nails, will be about twice the upper target value of 1,200 lb.

Intensive tests are being made of 4- by 8-foot panels fabricated essentially as described under this and the previous heading. These tests will yield data on creep, thickness swell, linear stability, impact strength, racking strength, water absorption, interlaminar and edgewise shear strength, hardness, nailability, modulus of rigidity, and fire resistance as well as the MOE, IB, and MOR with which this paper has been chiefly concerned.

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