Properties of Flakeboards From Hardwoods Growing on Southern Pine Sites

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Abstract

Boards 0.5 inch thick were made from 3-inch-long flakes of 9 species of southern hardwoods commonly found on pine sites. The main effects of species were due to variation in wood density; low-density species compacted readily when pressed, and the resulting good flake contact improved bonding and gave boards of high strength. With species having specific gravities above 0.6, it was difficult to form stiff boards without increasing density unduly. In black tupelo, cross-grained flakes yielded boards of exceptionally low MOE, even though wood specific gravity was below 0.6. In white oak boards, substantial delamination occurred after a 5-hour-boil test. Within the range of the experiment, all species except white oak and post oak yielded boards of acceptable dimensional stability at board densities of 44.5 pounds per cubic foot or less.

IN SOUTHERN FORESTS, hardwoods occupy large acreages that would be more productive if stocked with pine. Hardwoods grow slowly on these sites, and are of small average size. For lack of economical manufacturing processes, they have gone largely unutilized.

One likely use of the trees is as flakes for structural panel products. This paper reports an initial study aimed at determining some of the important physical and mechanical properties of flakeboards manufactured from 9 species chosen for their basic wood properties and abundance. Oaks were given special attention, since they comprise nearly half the South's volume of pine-site hardwoods. All together, the 9 species represent about 72 percent of the total hardwood volume under consideration.

Experimental Procedure

Design of Experiment

The variables studied were:

1) Nine hardwood species	Percent of hardwood volume on pine sites
a) Sweetgun	21
b) Hickory	10
c) Black tupelo	9
d) Red oak	9
e) Post oak	9
f) White oak	8
g) Sweetbay	3
h) White ash	2
i) Red maple	1

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2) Board specific gravity (basis of volume and weight at moisture equilibrium with an atmosphere at 80°F and 50 percent RH).

a) 39.5 lb./cubic foot (pcf) – 0.633 grams/cubic centimeter (g/cc)

b) 44.5 pcf – 0.713 g/cc

c) 49.5 pcf – 0.793 g/cc

3) Four replications

The fabrication of 39.5 pcf panels was limited to the five low-density species: sweetgum, black tupelo, sweetbay, white ash, and red maple.

Board Manufacture

All boards were prepared in the laboratory with flakes 3 inches long, 3/8 inch wide, and 0.015 inch thick.

Flake preparation.—The flakes were from rotary-peeled veneer cut to thickness on a metal-working lathe and then accurately clipped to length and width. They were dried to an average moisture content (MC) of 3 percent before adhesive was added.

Blending.–To prepare each panel, flakes were weighed out and placed in a rotating drum-type blender. Phenolic resin, in amounts equal to 4 percent of the ovendry weight of flakes, was then weighed and applied by air-atomizing nozzles. The resin, prepared in the laboratory, was formulated at 46 percent resin solids and with a molar ratio of formaldehyde to phenol of 1.80. Average MC of the flakes after spraying was 11 percent.

Mat forming and hot pressing.—After blending, the randomly oriented flakes were carefully felted into a 19- by 20-inch box to form the mat. The mat was transferred immediately to a 20- by 20-inch single-opening hot press with the platen temperature regulated at 335°F. Sufficient pressure (about 550 psi) was applied so that the platens closed to 1/2-inch-thickness stops in approximately 45 seconds. Press time was 5 minutes after closure.

Sampling and testing.—All boards were conditioned in a chamber controlled at 50 percent relative humidity and 80°F before testing; ending MCs averaged 5.9 percent. After conditioning, each board was cut to yield two static-bending specimens, two water-resistance specimens (one each for vacuum-pressure-soak and 5-hour-boil test), two dimensional-stability specimens, and five specimens for tensile strength perpendicular to the face (internal bond).

The mechanical tests were performed in accordance with ASTM standards for evaluating the properties of wood-base fiber and particle panel materials (D 1037-64).

The dimensional-stability test measured changes in length, thickness, and weight when the strips were brought from equilibrium at 50 percent relative humidity (RH) at 80°F to equilibrium at 90 percent RH at 80°F.

The vacuum-pressure-soak test (VPS) consisted of soaking 3- by 9-inch specimens in water under vacuum (30-in. Hg) for 30 minutes and then under 65 psi pressure (at room temperature) for 24 hours. Weights, thicknesses, and lengths were measured before and after soaking.

For the boil test, 3- by 9-inch specimens were soaked in boiling water for 5 hours. Weights, thicknesses, and lengths were measured before and after soaking.

Results

Average physical and mechanical properties of the flakeboards are summarized in Table 1. Effects of panel density and wood species were evaluated by analysis of variance at the 0.05 level of probability, and all differences discussed were significant at that level.

Bending strength (MOR).—Average MOR values ranged from 3,914 psi for white oak boards at 0.702 g/cc panel density to 10,080 psi for the sweetbay boards at 0.738 g/cc panel density (Table 1).

As expected, MOR increased with board density. Averages for three panel densities were:

Panel Weight	Five low-density species	Nine species
Pcf	———psi———	
39.5	6,314	
44.5	7,477	6,189
49.5	8,492	7,591

By analysis of variance, the MOR values differed significantly with wood species. Values were highest for sweetbay, followed in decreasing order by red maple, black tupelo, sweetgum, white ash, red oak, hickory, post oak, and white oak. The effects of species were due mainly to the wide variation in wood density. It is generally accepted that the low-density species permit inclusion of a greater volume of wood in each board, with resulting gain in strength both from the additional wood and from better contact between the flakes (even though resin coverage per unit of surface is slightly lower).

Panel density interacted with species to affect bending strength. As shown in Table 2, the increase between 39.5 and 44.5 pcf was at least twice that between 44.5 and 49.5 pcf for all low-density species with the exception of sweetbay. As panel density increased from 44.5 to 49.5, however, the MOR values of high-density species increased more than 30 percent, while those of the low-density species increased less than 14 percent.

The effect of board and wood density on bending strength may best be expressed by their relation to compactness in the panel. Because high-density flakes required higher panel density to attain the same compaction as low-density flakes, the ratio between board density and wood density (i.e., the compaction ratio) was computed (Table 1, column 4) and related to bending strength.

By regression analysis, bending strength increased proportionately as compaction ratio increased.

Table 1 PHYSICAL AND MECHANICAL PROPERTIES OF FLAKEBOARD.

Species (1)	Actual board density[1] (2)	Wood density (3)	Compaction ratio (4)	Panel moisture content (5)	MOR[2] (6)	MOE[2] (7)	IB[3] (8)
	- - - g/cc - - -			%	- - - - - - -	psi	- - - - - - -
Sweetbay	0.633	0.481	1.3155	5.4	8,342	935,232	109
	.708		1.4715	7.2	8,883	953,922	260
	.738		1.5339	6.6	10,080	1,032,808	236
Red maple	.648	.538	1.2044	5.9	6,601	717,017	97
	.755		1.3988	5.0	8,319	821,349	284
	.788		1.4648	6.0	8,521	876,874	315
Sweetgum	.638	.547	1.1659	5.5	5,693	679,191	81
	.723		1.3213	5.8	7,005	759,127	171
	.793		1.4493	6.1	7,783	824,975	196
Black tupelo	.625	.518	1.2075	4.9	5,808	504,222	113
	.721		1.3920	4.8	7,424	612,954	239
	.783		1.5118	6.0	8,190	618,142	385
White ash	.633	.646	.9793	5.0	5,129	624,466	83
	.708		1.0954	5.2	5,754	753,167	148
	.800		1.2386	6.0	7,888	838,695	273
Red oak	.705	.667	1.0577	5.0	5,357	939,955	55
	.788		1.1815	6.6	6,968	880,370	146
Hickory	.708	.702	1.0079	5.0	4,511	707,220	65
	.810		1.1539	6.3	7,228	853,022	107
Post oak	.703	.733	0.9584	7.0	4,533	675,226	58
	.790		1.0779	6.8	6,374	721,236	119
White oak	.702	.762	0.9211	6.9	3,914	513,048	51
	.795		1.0428	5.8	5,285	676,626	88

[1]Volume and weight at equilibrium in atmosphere held at 80°F and 50 percent RH. Nominal values for the three board densities were 0.633, 0.713, and 0.793.

[2]Each value is the average of 8 observations.

[3]Each value is the average of 20 observations.

Table 2. — PERCENTAGE INCREASE (BY WOOD SPECIES) IN MOR FOR VARIOUS PANEL DENSITY INCREMENTS.

	Panel density increments	
Species	39.5 to 44.5 pcf	44.5 to 49.5 pcf
Low density (<0.6)		
Sweetbay	6.5	13.5
Sweetgum	23.0	11.1
Black tupelo	27.8	10.3
Red maple	26.0	2.4
High density (>0.6)		
White ash		37.1
Red oak		30.1
Hickory		60.2
Post oak		40.6
White oak		35.0

Equation B in Figure 1 accounted for 86 percent of the variation in MOR. This equation predicts relationships among MOR, wood density, and board density regardless of wood species. The USDA Forest Service's Task Group on Panel Product Specifications has set a minimum of 4,500 psi as the target MOR value for structural particleboard to be used as roof, wall, and floor sheathing. Within the range of compaction ratios in this study, and assuming a 95 percent tolerance limit, lower limit line B indicates that a ratio of 1.200 would be required to attain this value.

Stiffness (MOE).–Average MOE ranged from 504,222 psi for black tupelo boards at 0.625 g/cc panel density to 1,032,808 psi for sweetbay boards at 0.738 panel density (Table 1, col. 7). As did MOR, MOE increased as board density increased. Average MOE values were:

Panel density	Five low-density species	Nine species
pcf	------psi	
	692,025	
	785,104	728,996
	838,298	813,638

The most interesting result in the effects of species on MOE was with black tupelo. While MOR was close to the average for the low-density species, the black tupelo panels had exceptionally low MOE values. Black tupelo has about the same wood density as red maple, but is inherently cross-grained and thus inferior in many wood-strength values. The following

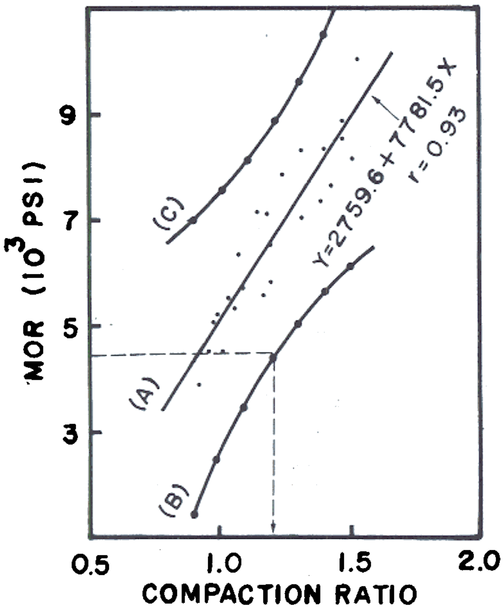

Figure 1. — Relationship of compaction ratio to MOE. Curved lines B and C show 95 percent tolerance limits. Dashed lines indicate the compaction ratio corresponding to an attainable minimum of 4,500 psi MOR.

tabulation compares strength properties of the wood and flakeboard panels of the two species:

(1)	Red maple (2)	Black tupelo (3)	Percent by which black tupelo is weaker than red maple (4)
		-------MOE (psi)-------	
Wood[1]	1,640,000	1,200,000	27
Panels[2]	805,080	579,272	28
		-------MOR (psi)------	
Wood[1]	13,400	9,600	28
Panels[2]	7,814	7,141	9

[1]Wood values are from the Forest Products Laboratory's *Wood Handbook*. 1955. USDA Handb. 72, 528 pp.

[2]Panel values are averages for all board densities.

As shown in column 4, strength properties for wood and panels of black tupelo were inferior to those of red maple by about the same percentages (27 percent for wood and 28 percent for panels). But whereas MOR of black tupelo wood was 28 percent less than that of red maple wood, the decrease for panel MOR was only 9 percent. These results indicate that densification of the panel did not change the effect of cross grain on stiffness of black tupelo boards, but did significantly improve panel MOR.

As with MOR, sweetbay yielded flakeboards with highest MOE. Only minor differences in MOE values were noticed among sweetgum, red maple, white ash, hickory, and red oak. Both post oak and white oak yielded flakeboards of substantially lower MOE.

MOE proved to be significantly related to compaction ratio. Because of black tupelo's unusual grain properties, one regression analysis was made with data for this species included and another with the data omitted. Figure 2 shows the relationship with black tupelo omitted. To attain the target value of 800,000 psi recommended by the Forest Service Task Group, the minimum compaction ratio would be 1.240.

Internal bond (IB).–Average IB strengths ranged from 51 psi for white oak at a board density of 0.702 g/cc to 385 psi for black tupelo at 0.782 g/cc (Table 1). Bond strength increased with panel density for all species except sweetbay.

As expected, IB for the four densest species (i.e., hickory and the oaks) was significantly lower than for the other species, even though the resin coverage was greater. At 44.5 pcf all four species yielded panels with IB values less than the target level of 70 psi. As panel density was increased to 49.5 pcf, however, satisfactory bond strength was obtained.

On average, for the 44.5- and 49.5-pcf boards, black tupelo flakeboards had the highest IB strengths (312 psi) and were followed in decreasing order by red maple (299 psi), sweetbay (248 psi), white ash (209 psi), sweetgum (183 psi), red oak (100 psi), post oak (89 psi), hickory (87 psi), and white oak (69 psi).

High IB strength, coupled with low MOE, suggests that, of the species studied, black tupelo may provide the best core material for three-layer board construction.

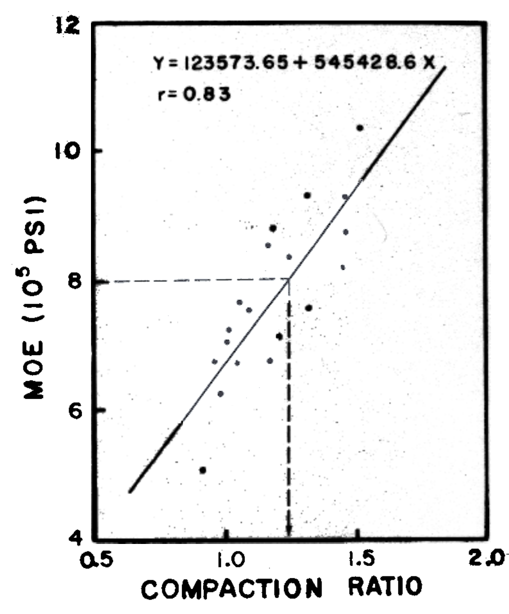

Figure 2. — Relationship of compaction ratio to panel MOE. Dashed lines indicate the compaction ratio corresponding to an attained average of 800,000 psi MOE.

By regression analysis, IB strength increased as the compaction ratio increased (Fig. 3). To attain target IB value of 70 psi, the corresponding minimum compaction ratio would be 1.012.

The minimum compaction ratios required to attain the target specification for structural flakeboard were not the same for IB, MOR, and MOE. Since the MOE required the greatest compaction (i.e., a ratio of 1.240 to yield a satisfactory panel), it appears to be the controlling factor. Equally apparent is that the required panel density may differ substantially among species, since hardwoods vary widely in wood density.

Dimensional Stability

Table 3 summarizes average water absorption, linear expansion, and thickness swelling for each combination of species and panel density.

Water absorption.–The range of data in water absorption is summarized as follows:

50-90 percent RH	13-16 percent
5-hour boil	68-125 percent
VPS	75-116 percent

As panel density increased, percentage of water absorbed declined in all but two species (sweetbay and

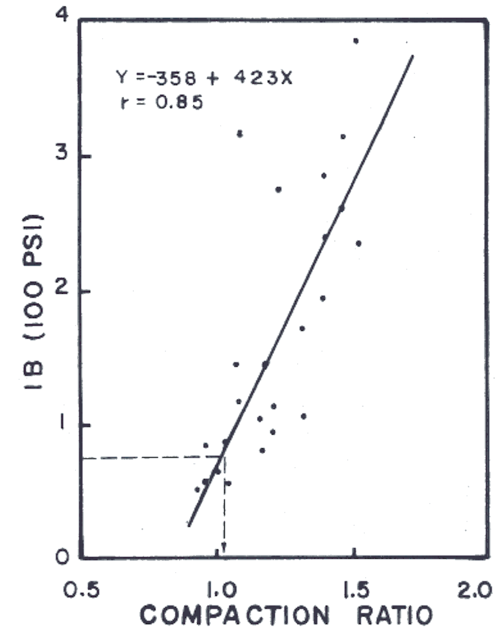

Figure 3. — Relationship of compaction ratio to IB. Dashed lines indicate the compaction ratio corresponding to an attainable average of 70 psi IB.

Table 3. DIMENSIONAL STABILITY PROPERTIES OF FLAKEBOARD AS MEASURED BY VACUUM-PRESSURE-SOAK, 5-HOUR-BOIL, AND RH TESTS.

Species	Board weight	Vacuum-pressure soak: Water absorption	Vacuum-pressure soak: Thickness swelling	Vacuum-pressure soak: Linear expansion	5-hour-boil: Water absorption	5-hour-boil: Linear expansion	50-90% RH: Water absorption	50-90% RH:	50-90% RH: Linear expansion
		-	-	-	-	-		-	-
Sweetbay	39.5	116	27.8	0.127	125	0.067	15.2	20.3	0.094
	44.5	88	29.3	.047	110	.061	14.9	16.4	.088
	49.5	96	30.1	.214	114	.168	14.0	21.1	.153
Red maple	39.5	116	20.3	.134	97	.145	14.2	13.3	.156
	44.5	92	27.1	.027	95	.053	14.3	13.9	.090
	49.5	87	27.8	.144	95	.146	14.0	20.8	.176
Sweetgum	39.5	112	23.6	.059	113	.095	15.9	21.6	.068
	44.5	104	31.9	.093	104	.045	15.2	20.8	.083
	49.5	101	42.6	.126	117	.164	16.1	31.8	.195
Black tupelo	39.5	104	22.3	.130	109	.128	15.2	15.4	.154
	44.5	91	23.4	.222	88	.177	14.2	14.6	.219
	49.5	88	25.7	.225	86	.199	15.4	21.6	.252
White ash	39.5	110	21.2	.198	97	.194	14.0	13.7	.204
	44.5	95	21.4	.149	91	.181	14.0	13.5	.174
	49.5	82	24.6	.227	91	.204	13.9	22.2	.259
Red oak	44.5	88	20.7	.171	88	.173	13.9	14.9	.169
	49.5	86	27.4	.253	86	.175	14.0	23.2	.251
Hickory	44.5	80	22.1	.245	80	.238	14.5	15.7	.212
	49.5	75	23.0	.171	68	.213	14.3	16.0	.172
Post oak	44.5	93	27.5	.296	91	.241	13.6	14.6	.270
	49.5	84	28.0	.306	86	.189	13.8	18.0	.268
White oak	44.5	95	48.5	.376	95	.314	13.3	20.1	.296
	49.5	94	56.8	.480	84	.443	14.6	25.6	.351

sweetgum) during the 5-hour-boil and declined in all but one species (sweetbay) during the VPS. On average, high-density species (hickory, red oak, post oak, and white oak) absorbed a slightly lower weight percentage of water. In the 50-90 percent RH exposures, species and panel densities had no significant effect on moisture gain.

Thickness swelling.—Ranges of average thickness swelling in the three exposure tests were:

50-90 percent RH	13-32 percent
5-hour boil	20-112 percent
VPS	20-57 percent

The amount of thickness swelling varied from test to test. The 5-hour-boil consistently resulted in the greatest thickness swelling, followed in order by the VPS and 50 to 90 percent RH exposure test.

In 5-hour-boil and VPS tests, thickness swelling for all species increased as panel density increased. This result was anticipated, since increase in density is achieved essentially by increasing the degree of compaction.

In the 50 to 90 percent RH test, there was little difference in thickness stability between panel densities of 39.5 and 44.5 pcf. The thickness swelling increased slightly as panel density increased to 49.5 pcf.

White oak panels swelled significantly more than those of other species. They were also notable for their substantial interparticle delamination after the 5-hour boil. In no species could a relationship be found between initial bond strength and thickness stability.

Linear expansion.—Ranges for average linear expansion in the three exposure tests were:

50-90 percent RH	0.068-0.351 percent
5-hour boil	0.045-0.443 percent
VPS	0.027-0.480 percent

On average, the low-density species were slightly more stable than the high-density ones. As in the test of thickness swelling, white oak panels were the least stable.

All 49.5-pcf boards, except hickory and post oak, expanded more than either 44.5 or 39.5-pcf boards of the same species. Red maple, sweetbay, and sweetgum were the most stable of the 44.5-pcf boards. Among 39.5-pcf boards, sweetgum and sweetbay were the most stable.

The Forest Service Task Group specified a maximum of 0.250 percent linear expansion as determined by a 30 to 90 percent RH exposure test. In the three exposure tests reported here, all 39.5-pcf boards met the specification. In the 44.5-pcf class, post oak and white oak failed. In the 45.5-pcf group, five species failed—post, white, and red oak, white ash, and black tupelo.

Discussion

The purpose of this research was to provide basic information about the performance of pine-site hardwoods in flakeboard.

The data indicate that three of the species tested—sweetbay, red maple, and sweetgum—can be manufactured into boards meeting the requirements of the Forest Service Task Group on Panel Specifications. Board weight would be about 40 pcf or 52 pounds for a sheet of standard 4- by 8-foot dimensions.

With the other six species, dimensional stability was not attained at board densities meeting strength requirements. In addition, boards of minimum MOE are so heavy—in excess of 50 pounds per cubic foot—that transportation would be costly and on-site handling onerous. Table 4 summarizes study findings in terms of minimum board densities at which specifications can be met.

Table 4. — BOARD DENSITIES[1] AT WHICH DATA INDICATE TARGET SPECIFICATIONS FOR MECHANICAL PROPERTIES AND DIMENSIONAL STABILITY CAN BE MET.

Species	Minimum for 4,500 psi MOR (95 percent tolerance limit)	Minimum for 800,000 psi MOE	Minimum for 70 psi IB	Maximum, beyond which 0.25% linear[2] expansion is exceeded
	- - - - - - - - pcf - - - -			
Sweetbay	35.9	37.2	30.4	49.5
Red maple	40.0	41.6	33.9	49.5
Sweetgum	40.9	42.3	34.5	49.5
Black tupelo	38.8	>49.5[3]	32.7	44.5
White ash	48.3	50.0	40.8	49.5
Red oak	49.9	51.6	42.1	44.5
Hickory	52.5	54.3	44.3	49.5
Post oak	54.8	56.7	46.3	<44.5[4]
White oak	57.1	59.0	48.1	<44.5[4]

[1]Based on volume and weight at equilibrium at 80°F and 50 percent RH (i.e., at an MC of about 5.9%).

[2]In 30-90 percent RH exposure test.

[3]Indicates undetermined value larger than 49.5.

[4]Indicates undetermined value smaller than 44.5.

About 55 percent of the South's volume of pine-site hardwoods is in species that have a wood density of 0.6 or less and are otherwise suitable for manufacture of commercial boards. Rigorous separation of flakes by species is not likely in commercial practice, and in many situations a mixture of light and dense flakes would probably yield an acceptable board. Conversely, flakes of refractory species might be concentrated in the middle layers of three-layer boards.

The present boards were manufactured from accurately sized flakes made from rotary-peeled veneer. Results with these near-perfect flakes probably differ somewhat from those attainable with flakes made under production conditions. On the other hand, no special techniques were applied in manufacture of the experimental boards. It seems likely that resin additives or post-treatment with steam would improve dimensional stability, and that steam shock treatment or alignment of flakes in the surface layers would increase MOE considerably.