Bottomland hardwoods for structural flakeboards

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Abstract

Seven species found growing in bottomland hardwood sites were evaluated for their potential in being utilized in a structural flakeboard. The evaluation process consisted of three phases of investigation. Phase I investigated properties of flakeboards fabricated with several flake lengths and thicknesses using all seven species. In Phase II, properties of panels made with single species and mixtures such as all high-density species, all low-density species, and combinations of high- and low-density species were obtained. For Phase III, an alternative flaker disk was used to generate flakes for panel fabrication. Phase III panels were fabricated with flakes generated from both heated and ambient temperature conditioned bolts. Also, powder and liquid phenolic resins were used in the Phase III investigation. The data indicated a panel with acceptable properties is technically feasible using several fabrication arrangements.

Across the Southern United States, several areas are classified as bottomland hardwood sites. These areas are usually in the vicinity of major drainage systems. For instance, in Louisiana, the Mississippi, Red, and Atchafalaya river basins contain large sections of hardwood sites. Although these areas are often considered capable of producing pulpwood and a better quality of hardwood logs than upland sites, the bottomland sites often contain a mixture of low quality stems. Research efforts devoted to developing processes which would utilize mixtures of low grade hardwoods growing on upland sites to produce structural flakeboard appear to offer a solution for how to utilize bottomland hardwoods.

Southern Forest Experiment Station scientists (Hse, et al. (1) and Price (2)) have indicated that mixtures of upland hardwood species could be utilized to make structural flakeboard. Similar processes appear applicable for utilization of bottomland species mixtures. However, data necessary for industrial acceptance is lacking.

The objective of this study is to provide pertinent technical data necessary to assess the feasibility of producing an acceptable flakeboard made with a representative mixture of bottomland hardwood species from south-central Louisiana. To accomplish this objective, the study consists of three phases: 1) an investigation of the properties of flakeboards made with the commercial species mixture and several flake geometries; 2) an investigation of the properties of flakeboards made with single species and several mixtures using only one flake geometry; and 3) an investigation of the properties of panels made with disk cut flakes using different fabrication variables.

Procedure

South-central Louisiana timber companies indicated that a commercial bottomland hardwood species mixture for use in structural flakeboards would consist of sweetgum (*Liquidambar styraciflua*), hackberry (*Celtis* spp.), elm (*Ulmus* spp.), red oak (*Quercus* spp.), ash (*Fraxinus* spp.), white oak (*Quercus* spp.), and pecan (*Carya* spp.) (Table 1). Most likely the major species within these species groups would be American elm (*Ulmus americana*), southern red oak (*Q. falcata*), water oak (*Q. nigra*), green ash (*Fraxinus pennsylvanica*), and overcup oak (*Q. lyrata*). Therefore, these species and percentages (Table 1) were selected for analysis. Also, based on small diameter logs obtained in central Louisiana, this species mixture would have a wide initial moisture content and density range that should be considered when designing the fabrication procedures.

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TABLE 1 *Moisture content and density of species selected for flakeboard evaluations.*

Species	Percent of mixture	Moisture content	Density OD/green	Density OD/OD
			-(pcf) —	
Low-density group				
Sweetgum	32	129	29.6	33.1
Hackberry	18	84	30.7	33.4
Elm	5	89	33.1	37.7
High-density group				
Red oak	14	93	36.4	40.8
Ash	17	49	35.7	40.4
Overcup oak	5	101	36.9	43.3
Pecan	9	77	38.9	43.4
Weighted avg.		94	33.2	37.2

Species with a density less than 40 pounds per cubic foot (pcf) on an ovendry value basis were identified in a low-density species group, and those with a higher value in a high-density group. Thus, a flakeboard would require a 55:45 percent blend (by weight) of the low-density and high-density groups for total utilization.

Phase I. Flake geometry relationships. — Previous research (1) has indicated that decent panel properties are obtained with a face flake 3 inches long by 0.015 inch thick and random width (approximately 3/8-in. width is most desirable). Core flakes should be slightly thicker, 0.025 inch. A fair panel also can be produced if a) heated bolts are flaked with sharp knives, b) half the board weight is comprised of the core layer, c) all flakes are randomly oriented, d) phenol-formaldehyde liquid resin is applied at a volume greater than 5 percent solids rate basis, e) mat moisture content is less than 12 percent, and f) press pressure is sufficient to reach the desired thickness within 45 seconds. Additionally, the compaction ratio (panel density to average species density) should be approximately 1.2.

For this study, an experiment with six replications was implemented using the combination of two panel densities (42 and 45 pcf) and four flake types. Panels for three of the flake types consisted of 0.015-inch face flakes and 0.025-inch core flakes but different flake lengths. The flake lengths were 1) 3-inch face and core, 2) 3-inch face and 1.5-inch core, and 3) 1.5-inch face and core. The fourth panel type contained flakes 3 inches long by 0.020 inch thick for both face and core. All flakes were cut on a laboratory prototype shaping lathe and each panel layer contained the seven-species mixture.

Panel manufacturing conditions were as follows:

- Panel size: 7/16 inch thick by 42 inches by 22 inches
- Binder: a 42 percent phenol-formaldehyde liquid resin at 5.5 percent of solid rate basis
- Mat construction: random flake distribution with 25, 50, and 25 percent of the board weight in the face-core-face layers.
- Mat moisture content: less than 10 percent
- Press requirements: 340°F, 20 seconds to thickness, 5.5 minutes total press time.

A group of panels was also made with 2.5 percent powder resin but without wax. The panels were made with 0.015-inch face and 0.025-inch core flakes and pressed with a 395°F press temperature for 5.5 minutes.

Phase II. Species mixtures. — Recognizing that fabricating four groups of flakes (thin, low-density face flakes; thin, high-density face flakes; thicker, low-density core flakes; and thicker, high-density core flakes) and maintaining the given species mixture could be cumbersome in production, data of panels made with different species mixtures and one flake thickness was undertaken. Previous work (3) and Phase I indicated an acceptable flakeboard seems feasible with many species if the flakes are 2.5 to 3 inches long and 0.020 inch thick. Therefore, panels 7/16 inch thick by 21 inches by 16 inches were fabricated with manufacturing conditions established in Phase I.

Fabrication variables consisted of a six-panel replication of two density levels for 12 species mixtures. The 12 mixtures consisted of single species (seven panel types), all low-density species, all high-density species, and one low-density species combined with one or two high-density species (three panel types).

Phase III. Disk flakes. — Although Price and Lehmann (3) illustrated for several single species that flakes cut on a disk or lathe flaker produced an acceptable flakeboard, additional data were needed to assess properties of panels made with disk cut flakes and the species mixture of Phase I. Also, additional data were desired on the effect of conditioning the wood in hot water prior to flaking and resin type (liquid or powder). Therefore, to provide the needed data, five panel types (7/16 by 21 by 16 in.) were made with disk cut flakes (3 in. long by 0.020 in. thick) of the seven-species mixture. The panel types consisted of flakes produced with green wood:

1. Unconditioned with two levels of liquid resin (5.5% and 4.5%) with no wax and two levels of powder resin (3% and 2%) with 1.5 percent wax — four panel types.
2. Conditioned in hot water, 5.5 percent liquid resin — one panel type.

All panel types were made at two density levels and a four-panel replication.

For this study, a small disk flaker capable of flaking 6-inch-long bolts was used. Selection of this machine was based on accessibility and the desire to use a disk flaker. Just because a shaping lathe and a disk flaker were employed for the flake procurement, it should not be assumed that these flakers are the only machines acceptable for producing a flakeboard made with southern hardwoods. In any event, a good quality flake is vital.

Bending properties, internal bond (IB), and dimensional stability properties were obtained for panels fabricated in each phase. For durability evaluations, an ovendry to vacuum pressure soak (ODVPS) was employed with the following constraints: 1) dried at 217° ± 4°F for 24 hours; 2) placed in a pressure cylinder and flooded with tap water, 3) vacuumed in 27 ± 2 inches of mercury for 1 hour, and put under 90 ± 10 psi for 2 hours. The procedure was developed by the American Plywood Association and designated as APA Test

Method P-1 for linear expansion (LE) evaluation. LE and thickness swell values are based on the change from the ovendry condition to the end of the ODVPS cycle. Bending and IB ODVPS specimens received the additional treatment of drying in an oven for 24 hours followed by at least 1 week of conditioning at 50 percent relative humidity (RH) before evaluation.

Bending and IB specimens were also evaluated according to ASTM D1037-72, except that bending specimens were 3 inches wide and tested by center point loading over a 15-inch span. From the larger panels in Phase I, six bending, two bending ODVPS, two LE for 30 to 90 percent RH, and two LE ODVPS specimens were obtained. For the smaller panels, only two specimens were obtained from each panel per test. Two IB specimens were obtained from every bending specimen. Therefore, Phase I had more bending and IB evaluations per fabrication variable than the other phases.

Results

Phase I

For panels made with liquid resin, an increase in panel density generally resulted in increased bending and IB properties (Table 2, Fig. 1). The change in mechanical properties such as modulus of elasticity (MOE), modulus of rupture (MOR), and IB, as related to density change (slope of the lines in Fig. 1), was similar for all flake types.

Comparing flake length, the panels made with 1.5-inch face and core flakes to panels made with .015 by 3-inch face and .025 by 3-inch core flakes, the shorter flakes resulted in higher IB, lower MOR, and lower MOE panel properties (Fig. 1).

The thin face flakes over thick core flakes compared to the panels with a constant flake thickness of 0.020 inch, all flakes 3 inches long, resulted in a panel with a higher MOR and MOE but a lower IB (Table 2).

Except for ODVPS data for panels with 3-inch face and 1.5-core flakes, the LE decreased a very small amount with an increase in density (Table 3).

Powder phenolic resin bonded panels did not attain desirable properties (Table 2). Although the panels did have a low average panel density, the panels were substantially lower in quality than panels made with a liquid resin at the low density.

To evaluate panel durability, mechanical properties based on initial panel thickness of specimens subjected to the ODVPS treatment were obtained for comparison to untreated specimens. Panels made with 0.015-inch-thick face flakes maintained panel stiffness (MOE) after ODVPS treatment while panels with thicker (0.020 in.) face flakes had a 10 to 20 percent decrease in stiffness. Even though panels with both flake thicknesses had a decrease in bending strength and IB, the thinner face flake panels retained the higher percentage of their initial mechanical properties (Table 2). The thicker core flakes could also have contributed to this higher retention.

Based on these fabrication procedures, species mixtures, and data, a company may attempt to make a prudent selection among these flake types for industrial

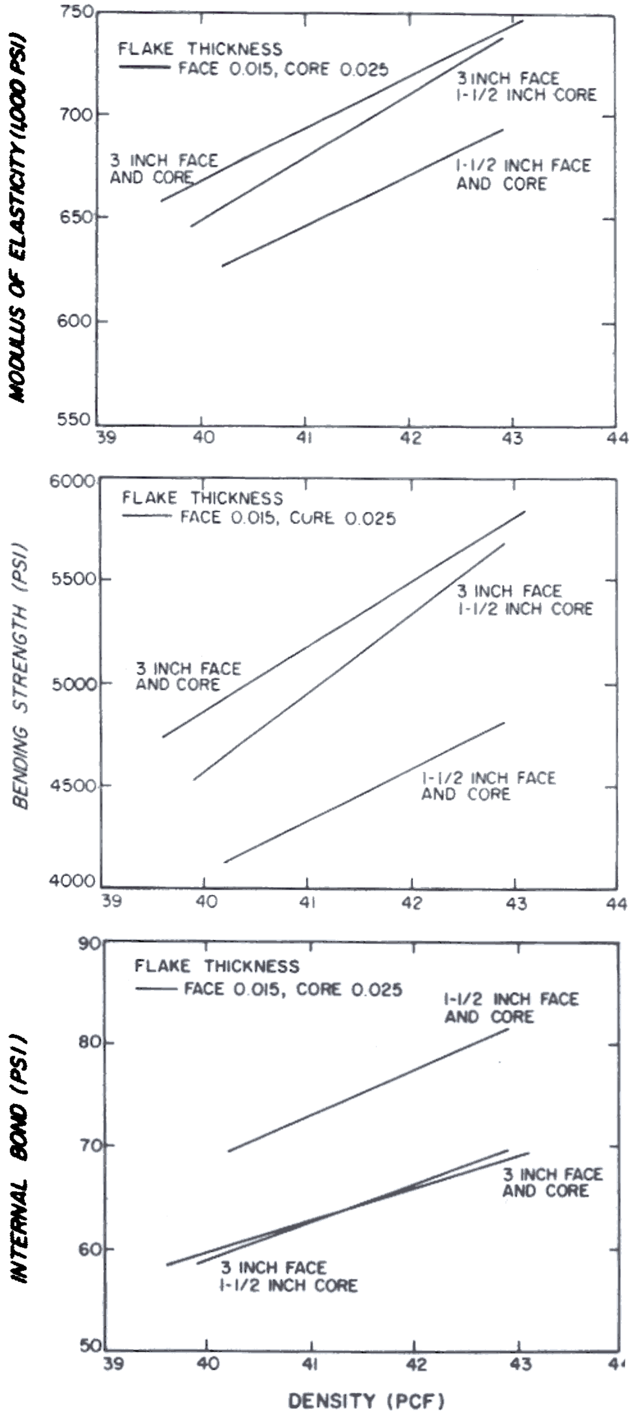

Figure 1. — Mechanical properties of panels fabricated with a seven-species mixture of bottomland hardwoods as related to density and flake geometries.

implementation. Yet the data were not explicit toward the selection. For instance, if the panel stiffness with the 0.020-inch-thick flakes had been higher, a selection of the panel with 0.020-inch-thick flakes would be easily justified. Likewise, if the IB of the 0.015-inch face and 0.025-inch core flakes had been larger than the 0.020-inch-thick flakes, panels with different flake

TABLE 2. — *Strength properties of flakeboards made with a seven-species mixture of bottomland hardwoods.*[a]

Flake length				Bending strength		MOE		IB	
Face	Core	Density[b]	MC	Initial	ODVPS[c]	Initial	ODVPS[c]	Initial	ODVPS[c]
---------- (in.) ----------		(pcf)	(%)	(psi)	(%)	(1,000 psi)	(%)	(1,000 psi)	(%)
Panels made with 0.015-inch face flakes, 0.025-inch core flakes, and 5% liquid phenolic resin									
1-1/2	1-1/2	40.2	5.0	4163	85	627.2	97	69.7	34
1-1/2	1-1/2	42.9	4.8	4812	78	694.0	98	81.6[d]	35
3	1-1/2	39.9	5.8	4533	81	647.2	97	58.4	39
3	1-1/2	42.9	5.7	5698	77	737.3	99	69.8	34
3	3	39.6	5.8	4731	91	655.9	102	58.4	39
3	3	43.1	5.5	5845	80	746.2	110	69.4	38
Panels made with 0.015-inch face flakes, 0.025-inch core flakes, and 2.5% powder phenolic resin									
3	3	38.7	3.1	2262		525.1		14.2	
3	3	39.7	3.2	1987		487.9		7.3	
Panels made with 0.020-inch flakes and 5.5% liquid phenolic resin									
3	3	39.0	4.7	4181	65	565.9	79	64.9	25
3	3	42.2	4.7	4878	72	612.3	89	71.7	32

[a]The seven species in order of increasing density and percent of the total mixture were sweetgum (32%), hackberry (18%), elm (5%), red oak (14%), ash (17%), overcup oak (5%), and pecan (9%). All panels were made at 7/16-inch thickness, flakes randomly oriented, and pressed for 5-1/2 minutes. For panels with different face and core flake thicknesses, one quarter of the board weight was in each face and half of board weight was in the core. Panels with liquid resin consisted of a six-panel replication and a press temperature of 340°F. Panels with powder phenolic resin consisted of a three-panel replication and a press temperature of 395°F.
[b]Based on ovendry weight and volume at test.
[c]ODVPS = ovendry to vacuum-pressure soak test method P-1 of the American Plywood Assoc. Specimens were redried to approximately 7% MC before testing.
[d]After gluing the specimen to the IB blocks, a few specimens from the panel with the lowest average (64.5) were dropped and the edges were exposed to water. The other five panels averaged 85.1 psi with a range of 82.3 to 87.8 psi.

TABLE 3. — *Dimensional stability properties of flakeboards made with a seven-species mixture of bottomland hardwoods.*[a]

Face length			ODVPS[c]				30% to 90% RH			
			MC				MC			
Face	Core	Density[b]	Initial	Final	LE	TS	Initial	Final	LE	TS
---------- (in.) ----------		(pcf)	---------- (%) ----------							
Panels made with 0.015-inch face flakes, 0.025-inch core flakes, and 5.5% liquid phenolic resin										
1-1/2	1-1/2	40.2	0	124.9	.211	27.9	7.06	19.0	.055	14.9
1-1/2	1-1/2	42.9	0	114.0	.206	29.1	7.04	18.5	.049	14.6
3	1-1/2	39.9	0	125.2	.167	26.2	7.07	18.5	.061	13.8
3	1-1/2	42.9	0	115.0	.191	27.5	7.06	18.4	.057	14.1
3	3	39.6	0	128.6	.185	28.0	7.08	18.8	.068	14.6
3	3	43.1	0	117.8	.148	28.6	7.06	18.8	.034	16.2
Panels made with 0.020-inch flakes and 5.5% liquid phenolic resin										
3	3	39.0	0	132.6	.206	35.3	6.67	17.1	.093	12.8
3	3	42.2	0	116.3	.182	34.4	6.82	16.9	.067	11.9

[a]The seven species in order of increasing density and percent of the total mixture were sweetgum (32%), hackberry (18%), elm (5%), red oak (14%), ash (17%), overcup oak (5%), and pecan (9%). All panels were made at 7/16-inch thickness, flakes randomly oriented, and pressed for 5-1/2 minutes. For panels with different face and core flake thicknesses, one quarter of the board weight was in each face and half of board weight was in the core. Panels with liquid resin consisted of a six-panel replication and a press temperature of 340°F. Panels with powder phenolic resin consisted of a three-panel replication and a press temperature of 395°F.
[b]The density is the density based on ovendry weight and volume at test of the bending specimen.
[c]ODVPS = ovendry to vacuum-pressure soak test method P-1 of the American Plywood Assoc.

thickness for the face and core flakes would be easily defendable.

Since one flake geometry did not produce all the best panel properties, other factors such as production procedures must be considered. Before the tests, a decision was made that the given percentage of high- and low-density species must be maintained in both the face and core layers. To obtain the mixture, segregation of these density groups followed by controlled metering at a given fabrication stage will be required. The metering and mixing could occur prior to flake drying, resin application, or at the forming bins. If two flake thicknesses, i.e., 0.015-inch-thick face and 0.025-inch-thick core flakes, are also required, then the green storage areas and flaking operations would be doubled. Therefore, to enhance industrial acceptance, a panel may require minimal flake-type considerations. Thus, additional data for panels with 3-inch-long by 0.020-inch-thick flakes were undertaken as Phase II.

Phase II

Properties of panels made with the individual species and five different species combinations were obtained (Table 4). The five combinations consisted of

TABLE 4. — *Properties of flakeboards made with 0.020-inch-thick by 3-inch-long flakes and 5.5% liquid resin.*[a]

Panel species and mixture[b]	MC	Density[c]	Bending strength	MOE	IB	ODVPS[d] LE	TS	MC	ODVPS - Bending specimens[e] MC	Density	Bending strength	MOE
		(pcf)	(psi)		(psi)	——— (%)				(pcf)	(psi)	
Sweetgum 32, hackberry 18,	4.7	39.0	4181		64.9	.205	36.3	132.6	6.4	37.5	2702	
elm 5, red oak 14, ash 17,	4.7	42.2	4878		71.7	.182	34.4	116.3	6.6	40.6	3524	
overcup oak 5, pecan 9		*42.0*	*4840*		*71.0*	*.186*				*42.0*	*3910*	
Sweetgum 55, red oak 20,	5.6	41.7	3982		96.3	.214	28.3	121.8	6.3	42.0	3532	
ash 25	5.5	44.5	4863		116.1	.232	28.7	104.2	6.7	45.8	4389	
		42.0	*4080*		*98.1*	*.216*				*42.0*	*3532*	
Hackberry 55, pecan 45	5.3	41.1	3630		111.6	.204	25.9	123.9	6.3	39.7	2986	
	4.3	44.5	4996		113.5	.240	28.0	112.9	6.0	41.9	3497	
		42.0	*3990*		*112.0*	*.214*				*42.0*	*3500*	
Hackberry 55, overcup oak 45	5.8	40.2	3722		95.6	.262	31.7	130.7	5.8	39.8	2583	
	5.5	43.4	3878		125.4	.277	32.6	114.6	5.8	42.7	3104	
		42.0	*3810*		*112.5*	*.270*				*42.0*	*2980*	
Sweetgum 58, hackberry 33	5.8	42.2	3992		82.8	.061	30.6	117.4	6.6	41.9	3806	
elm 9	5.7	44.3	5050		96.8	.106	26.6	107.7	6.5	44.8	4423	
		42.0	*3870*		*79.0*	*.079*				*42.0*	*3820*	
Red oak 31, ash 38, overcup	5.5	40.8	3220		104.6	.292	27.9	121.3	5.6	41.1	2463	
oak 11, pecan 20	5.3	43.6	3885		117.0	.303	27.7	111.0	5.8	42.9	2552	
		42.0	*3500*		*110.0*	*.296*				*42.0*	*2510*	
Sweetgum 100	5.1	41.9	4099		105.6	.105	29.6	127.0	6.4	42.4	3419	
	5.3	44.5	4678		120.4	.139	29.1	116.8	6.8	44.3	3983	
		42.0	*4120*		*106.0*	*.122*				*42.0*	*3300*	
Hackberry 100	5.0	40.4	4044		106.1	.260	32.4	133.9	6.1	40.9	3780	
	5.1	44.2	4859		121.2	.196	28.0	113.8	6.6	43.4	4338	
		42.0	*4380*		*112.4*	*.228*				*42.0*	*4230*	
Elm 100		42.7	3414		102.4	.120	23.1	114.2	6.5	42.4	3080	
		44.7	4259		101.4	.149	22.3	101.9	6.3	45.6	4340	
		42.0	*3100*		*101.0*	*.108*				*42.0*	*2920*	
Red oak 100	5.0	41.7	3322		90.5	.280	28.8	124.5	5.5	40.9	2731	
	5.1	42.4	3805		84.6	.243	29.3	114.2	5.6	43.6	3321	
		42.0	*3520*		*88.0*	*.265*				*42.0*	*2970*	
Ash 100	5.4	40.8	4001		120.8	.231	18.5	108.6	5.7	41.2	3611	
	5.0	44.3	4564		138.9	.278	20.8	96.4	6.0	44.4	4205	
		42.0	*4190*		*126.9*	*.247*				*42.0*	*3760*	
Overcup oak 100	5.5	41.2	2840		78.7	.407	41.3	140.0	5.8	40.5	1629	
	5.3	42.9	3154		85.6	.409	37.6	125.9	6.0	42.2	1923	
		42.0	*2990*		*81.8*	*.408*				*42.0*	*1890*	
Pecan 100	4.8	42.1	3133		113.1	.261	23.5	112.6	6.5	41.1	2616	
	4.8	45.0	4188		130.2	.297	23.1	103.3	6.5	44.5	3112	
		42.0	*3020*		*112.5*	*.260*				*42.0*	*2750*	

[a]The number in italics is estimated for a 42 pcf panel based on a linear relationship.
[b]Number after species is percent mixture.
[c]Density is based on OD weight and volume at test of the bending specimens.
[d]Values obtained from specimens subjected to the ovendry to vacuum-pressure soak (ODVPS), test method P-1 of the American Plywood Assoc. LE = linear expansion, TS = thickness swell, MC = moisture content.
[e]Bending specimens were subjected to the ODVPS test method P-1 and ovendried. Specimens were then conditioned to 50% RH and evaluated. Density is based on OD weight and volume prior to ODVPS cycle.

100 percent high-density species (red oak 31%, ash 38%, overcup oak 11%, and pecan 20%), 100 percent low-density species (sweetgum 58%, hackberry 33%, and elm 9%), a three-species mixture (sweetgum 58%, red oak 20%, and ash 25%), and two combinations with a two-species mixture (hackberry 55% and pecan 45%; hackberry 55% and overcup oak 45%). A species percentage within a mixture was based on the species availability in relationship to the other species in the mixture and density groups and is in an increasing density order.

Previous experience (1, 3) had indicated that for equivalent panel densities, low-density species usually had higher bending properties than the high-density species mixture. Also, a panel composed of a mixture of the high- and low-density species would have properties between the high- and low-density panels. Comparing the estimated properties for a 42 pcf density panel, the panel in Phase I with a seven-species mixture yielded bending properties higher than the three-species mixture of low-density species and five-species mixture of high-density species. Since Phase I contained more test specimens and panels, the result may be totally an experimental error or statistically not significantly different. However, changes in the panel density profile and individual species influence within a group could be contributing factors. For instance, panels made with the low-density species, elm, had lower bending properties than the two high-density species, red oak and ash. Replacing the high-density red oak and ash with elm may result in lower bending properties.

A reason a species may yield bending properties lower than anticipated could be related to anatomical characteristics. Elm and hackberry sometimes have interlocking grain that could result in a flake with low tensile strength. Panel property differences between the two panels composed of a low-density, three-species mixture (sweetgum, hackberry, and elm) compared with the one low-density species (sweetgum) plus two high-density species (red oak and ash) could be related to interlocking grain occurring in elm and hackberry. The same influence could explain the panel composed of all low-density species having low initial bending properties.

The relationship between the IB strength and panel types composed of more than one species generally paralleled the bending property relationship (Table 4). For instance, the low-density species mixture had a lower IB, 79 psi, than the high-density species mixture, 110 psi. For panels made with single species, oak yielded the lowest IB, while the high-density species ash yielded the highest value. The other four single-species panels yielded similar IB values.

An advantage of using a low-density species instead of a high-density species is evident in the LE and bending strength data of specimens subjected to the ODVPS regime. The low-density panels, single species and mixtures, generally had a lower LE and percent decrease in bending strength than high-density species panel types (Table 4).

For instance, panels with a mixture of all four low-density species, seven-species mixture, and all three high-density species had LE values of 0.079 percent, 0.186 percent, and 0.296 percent, respectively, for an estimated 42 pcf panel. Also, the percent retention of bending strength and MOE for the three panels were 99 and 105 percent for low-density panel types, 81 and 97 percent for the all-species mixture, and 72 and 81 percent for the high-density mixture. The single-species panel that performed the worst under ODVPS was the high-density overcup oak.

Although maintaining production in a plant with the given percentages of each density group may be feasible, maintaining the exact seven-species mixture may not be possible. Based on this analysis of the data, a facility producing an acceptable panel with the seven-species mixture would still produce an acceptable panel with changes in the species mixtures. A few changes that should be avoided are 1) an increase in the percentage of high-density group unless the increase is ash, 2) an alteration of the high-density group so that it contains only oak species, and 3) an alteration of the low-density group to contain all elm. Therefore, if a production superintendent desires to control the percent per species, major efforts should be directed toward decreasing overcup oak and elm.

Phase III

An acceptable panel was obtained with the flakes produced on the disk flaker and the liquid phenolic resin (Tables 5 and 6). Heating the bolts prior to flaking and changing either resin content or resin type did affect panel properties. At 42 pcf density, panels made with flakes procured from heated bolts had approximately an 11 percent higher bending strength and MOE but an 11 percent lower IB than panels made with flakes from nonheated bolts. Although no measurements were obtained, the lower IB could have resulted from the heated bolt flakes having a larger width. A wide flake could have an increase in the number of folded flakes and in adequate resin coverage. However, differences in surface characteristics may also have influenced the IB.

TABLE 5. — *Properties of flakeboards made with flakes of a seven-species mixture. Flakes were approximately 0.020 inch thick, 3 inches long, and produced on a disk flaker.*[a]

Resin[b] Type	Resin[b] Content	Flaking condition	Panel density[c]	MC	Bending strength	MOE	IB
	(%)		(pcf)	(%)	(pcf)	(1,000 psi)	(psi)
Liquid	5.5	Hot	41.2	5.3	4635	687.7	83.0
			45.2	4.8	5750	715.0	115.4
			42.0[a]		*4858*	*693.0*	*89.5*
	5.5	Cold	41.5	5.0	4366	617.6	90.9
			43.4	5.2	4336	645.3	126.5
			42.0		*4358*	*625.0*	*100.3*
	4.5	Cold	41.1	4.8	2905	516.1	60.9
			42.7	4.7	3609	596.3	76.4
			42.0		*3302*	*561.0*	*69.6*
Powder	3	Cold	37.1	3.0	1706	421.0	37.4
			40.0	2.4	2213	504.0	58.0
			42.0		*2560*	*561.0*	*72.2*
	2.25	Cold	37.2	2.1	1289	392.1	27.0
			[illegible]	[illegible]	1774	478.1	47.7
							62.5

[a]Number in italics is an estimate for a 42 pcf panel based on a linear relationship.
[b]Powder resin panels also contained 1.5% wax.
[c]Based on ovendry weight and volume at test.

TABLE 6. — *Properties of flakeboards subjected to ovendry vacuum-pressure soak conditions. Panels consisted of a seven-species mixture of flakes approximately 0.020 inch thick, 3 inches long, and produced on a disk flaker.*[a]

Resin		Flaking			Bending					Final
Type	Content	condition	Density[b]	MC[c]	strength	MOE	IB[d]	LE	TS	MC
	(%)		(pcf)	(%)	(psi)	(1,000 psi)	(psi)	----------	(%)	----------
Liquid	5.5	Hot	40.6	5.7	3926	609.7	31.4	.194	21.9	126.6
			45.4	5.8	4950	780.6	34.4	.214	24.2	128.8
			42.0		*4225*	*660.0*	*32.3*	*.200*		
	5.5	Cold	41.3	5.6	2900	517.6	33.1	.259	30.5	126.2
			46.2	5.7	3485	687.4	29.7	.183	29.7	128.5
			42.0		*2980*	*542.0*	*32.6*	*.248*		
	4.5	Cold	41.8	5.2	1891	423.6	8.7	.265	37.2	132.0
			43.4	5.4	2563	570.9	13.2	.268	40.8	137.3
			42.0		*1975*	*442.0*	*9.3*	*.265*		
Powder	3	Cold					0.5	.345	45.6	135.5
							1.3	.393	44.6	137.6
	2.25	Cold					0.0	.284	66.9	131.1
							0.4	.393	55.9	138.7

[a]Number in italics is an estimate for a 42 pcf panel based on linear relationship.
[b]Density is based on ovendry weight and volume prior to ovendrying the bending specimens.
[c]Moisture content of the bending specimens at time of test.
[d]Internal bond specimens obtained from the linear expansion specimens.

TABLE 7. — *Properties of several types of flakeboard fabricated at 42 pcf density based on ovendry weight.*

Species mixture[a]	Flake type	Resin[b]	Bending strength	MOE	IB	LE[c]
			(psi)	(1,000 psi)	(psi)	(%)
7 species	Lathe 0.015 face 0.025 core Hot	L - 5.5	5500	716	66	.16
7 species	Lathe 0.020 Hot	L - 5.5	4840	610	71	.19
SG (55) RO (20) A (25)	Lathe 0.020 Hot	L - 5.5	4080	640	98	.22
HA (55) PE (45)	Lathe 0.020 Hot	L - 5.5	3990	600	112	.21
HA (55) OC (45)	Lathe 0.020 Hot	L - 5.5	3810	541	113	.30
SG (58) HA (33) E (9)	Lathe 0.020 Hot	L - 5.5	3870	574	79	.08
RO (31) A (38) OC (11) PE (20)	Lathe 0.020 Hot	L - 5.5	3500	568	110	.33
7 species	Disk 0.020 Hot	L - 5.5	4850	691	87	.20
7 species	Disk 0.020 Cold	L - 5.5	4350	624	103	.25
7 species	Disk 0.020 Cold	L - 4.5	3300	560	69	.27
7 species	Disk 0.020 Cold	P - 3	2550	560	72	.42
7 species	Disk 0.020 Cold	P - 2.25	2125	498	62	.47

[a]The seven species and percentages are sweetgum (SG), 32; hackberry (HA), 18; elm (E), 5; red oak (RO), 14; ash (A), 17; overcup oak (OC), 5; and pecan (PE), 9.
[b]The letter abbreviation implies liquid (L) or powder (P) phenolic resin. The number gives the percentage based on OD weight of panel.
[c]Ovendry to vacuum-pressure soak test method P-1 of the American Plywood Assoc.

Mechanical properties of panels made with flakes produced from hot bolts compared to unheated bolts exhibited smaller decrease after ODVPS conditioning (Table 6). Panels with heated flakes lost 13 percent and 5 percent in bending strength and MOE, respectively, while the unheated panel type lost 32 percent and 13 percent. The IB also had a smaller decrease for the panels made with heated bolts resulting in both panel types having similar values.

Decreasing the resin content to 4.5 percent or changing to a powder resin as high as 3 percent resulted in substantial decreases in panel properties. The most noticeable effects were reflected in the bending strength and IB. Therefore, utilization of the powder resin or liquid resin content less than 5 percent did not prove feasible for this mixture and fabrication procedure.

The IB for the panels made with flakes produced from unheated bolts was higher than those from heated bolts; the LE was larger and exhibited a slight decrease with increasing density.

Discussion

Assuming a linear relationship for panel properties over the density range investigated, properties for a 42 pcf panel were obtained for different species mixtures and flake types (Table 7). For this species mixture and fabrication procedure, a panel with properties exceeding 4,000 psi bending strength, 600,000 psi MOE, and 70 psi IB and an LE of less than 0.25 percent as measured by ODVPS methods was obtained. A panel with these properties consisted of flakes 0.020 inch thick produced on either the lathe or disk flaker and with a liquid phenolic resin. If the bolts are heated prior to flaking, an increase in bending strength and MOE resulted but there was a decrease in initial IB. Additional bending properties were obtained for panels with face flakes 0.015 inch thick and core flakes 0.025 inch thick. Panels with other combinations of species mixture but a 55:45 ratio of low-density species to high-density species were also successfully fabricated.

Literature cited

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