Reprinted from: Proc. Eleventh Particleboard Symp., Wash. State Univ., Pullman, Wash. 1977, p. 313-332.

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Basic Properties of Full-Size Structural Flakeboards Fabricated with Flakes on a Shaping Lathe

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Abstract

Structural exterior flakeboards manufactured in 4 by 8 ft (1.22 by 2.44 m) size with phenolic resin and flakes produced on a shaping-lathe headrig were evaluated for plate shear modulus, internal bond, bending properties, and 24-hour water soak stability. Both mixed and single species flakeboards were produced. Panels with mixed flakes had 20% by weight of hickory, white oak, red oak, sweetgum, and southern pine. The variables in fabricating these panels were as follows:

1. Two densities of aligned face and core flakes in panel thicknesses of 1/2 in. (12.7 mm) and 5/8 in. (15.9 mm).
2. Two densities of random face and core flakes in panel thicknesses of 1/2 in. (12.7 mm) and 5/8 in. (15.9 mm).

Single-species boards of one density class, 1/2 in. (12.7 mm) thick were fabricated with randomly oriented flakes of either yellow-poplar or loblolly pine.

Experimentally determined regression equations for the mixed species panels indicated that at 46 lbs/ft^3 density, a shear modulus of 192,000 psi (1323 MPa) would be obtained for the oriented panels. Random panels of this density would have 35% larger shear modulus. Based on specimen's initial dimensions, 60% of the bending strength was retained, while the modulus of elasticity increased after accelerated aging exposure. Initial bending properties depended on panel direction tested and on flake orientation. Oriented panels stressed along the 8 ft (2.44 m) axis

had the highest bending strength [5,412 psi (37.3 MPa) for 1/2 in. (12.7 mm) panels]; bending strength across the 4 ft (1.22 m) width was lower (3,346 psi or 23.1 MPa).

Modulus of elasticity reflected panel directional properties more than the bending strength; there was a modulus of elasticity of 967,000 psi (6667 MPa) along the 8 ft (2.44 m) axis and 377,400 psi (2602 MPa) across the panel. Random panels stressed along the 8 and 4 ft (2.44 and 1.22 m) axes had bending strengths of 5,034 psi (34.7 MPa) and 4,214 psi (29.1 MPa) and moduli of elasticity of 710,400 psi (4898 MPa) and 554,000 psi (3819 MPa) respectively. When bending strength and modulus of elasticity were averaged over both directions, the oriented panels averaged higher than the random panels. Internal bond of all panels after accelerated aging exposure decreased from the initial acceptable internal bond [greater than 700 psi (0.48 MPa)] to below 30 psi (0.21 MPa).

Introduction

The Forest Service is concentrating part of its research effort on using forest residues for structural flakeboard (Schaffer 1974). The Southern Forest Experiment Station's contribution is focused on currently under-utilized hardwoods growing on southern pine sites. Hse et al (1975) indicated that two methods of constructing three-layer pressed boards made from flakes produced on a shaping-lathe headrig could probably meet use requirements. In the first of these constructions, flakes are randomly oriented throughout the board; in the second, flakes on face and back are aligned with one axis of the board, while core flakes are randomly placed. Test panels 18 in. (457 mm) square and 1/2 in. (12.7 mm) thick were fabricated in the laboratory according to the specifications proposed by Hse et al. The panels' strength properties are tabulated below.

Board property	Oriented	Random
Board density, lbs/ft^3	45.5	47.5
(SG)	(0.73)	(0.76)
Modulus of elasticity (MOE), psi	,090,000	800,000
(MPa)	(7515)	(5516)
Bending strength, psi	6.600	5.300
(MPa)	(41.4)	(36.5)
Internal Bond (IB), psi	82	83
(MPa)	(0.57)	(0.57)

Small test panels were fabricated with relative ease; it is more difficult, however, to lay up and press commercial 4 by 8 ft (1.22 by 2.44 m) panels. Research indicated that the larger panels could be fabricated; but, a small percentage decrease in strength properties should be expected (Price 1975). Commercial production therefore might call for heavier or thicker boards to compensate.

In this study 4 by 8 ft (1.22 by 2.44 m) panels of various densities and thicknesses were fabricated. Plate shear, bending, IB, and 24 hr water soak specimens were cut from the 4 by 8 ft (1.22 by 2.44 m) boards and evaluated.

Experimental Procedure

Fabrication

Using a flake mixture of 20% each by weight of hickory (*Carya* sp.), white oak (*Quercus alba* L.), southern red oak (*Q. falcata* var. *falcata*), sweetgum (*Liquidambar styraciflua* L.), and southern pine (*Pinus* sp.) and the flake and panel specifications in Table 1, 4 by 8 ft (1.22 by 2.44 m) panels were manufactured with: a) random face and core flakes; and b) oriented face and core flakes. Also, 4 by 8 ft (1.22 by 2.44 m), single-species, random-flake panels were fabricated using either yellow-poplar (*Liriodendron tulipifera* L.) or loblolly pine (*Pinus taeda*). Mixed species panels were made 1/2 (12.7 mm) and 5/8 in. (15.9 mm) thick: single species, only in 1/2 in. (12.7 mm) thickness.

Random panels were batch formed with a commercial resin at the U.S. Forest Products Laboratory, Madison, Wis. The panels were pressed two at a time in a single-opening press 20 ft (6.1 m) long. Both 1/2 in. (12.7 mm) and 5/8 in. (15.9 mm) boards were pressed at 350°F (177°C) and 575 psi (3.96 MPa). Press time for the 1/2 in. (12.7 mm) board was 7.5 minutes; for the 5/8 in. (15.9 mm), 9.5 minutes. The FPL press had a 15 to 20 second pause between the time of contact of the top platen with the mat and the time pressure commenced. Because of this pause, a top caul was used to retard heat transfer and precure.

Oriented panels were fabricated with specially formulated resin (Hse 1975) in the pilot plant of Potlatch Corp. at Lewiston, Idaho. The panels were made in a double-opening press 8.5 ft (2.59 m) long. The 1/2 in. (12.7 mm) and 5/8 in. (15.9 mm) panels were pressed for the same amount of time as the random panels, 7.5 and 9.5 minutes, but at lower temperature and specific mat pressure—340°F (171°C) and 450 psi (3.10 MPa).

Table 1. Flake and panel fabrication specifications for 4 by 8 ft (1.22 by 2.44 m) structural flakeboards

Property	Specifications
Flake generation	From 6 in. (152 mm) bolt on shaping lathe
Flake length	3 in. (76.2 mm)
Core flakes	0.025 in. (0.635 mm) thick, milled for width reduction
Face flakes	0.015 in. (0.381 mm) thick, random bolts heated to 160°F (71°C) oriented bolts at ambient temperature.
Flake moisture content	3% to 4%
Mat construction	Layered with each face 1/4 of total weight
Surface treatment	Sprayed 4.32 g of water sq/ft of surface area
Resin binder	6% liquid phenol-formaldehyde resin[1]
Wax	1% wax solids from wax emulsion

[1]Hse, C. Y. Formulation of an economical fast-cure phenolic resin for exterior hardwood flakeboard. Ninth Particleboard Proceedings. April 1975.

Density

Panel density depended on the method of fabrication, flake orientation, and species mixture. Panel density, in pounds per cubic foot (lbs/ft^3), was based on weight and volume at approximately 6% moisture content. Twenty-eight random panels were fabricated at each of the following densities.

	Panel Thickness	
	1/2 in. (12.7 mm)	5/8 in. (15.9 mm)
Species	lbs/ft^3 (SG)	
Mixed species	47, 49 (0.75), (0.79)	45, 47 (0.72), (0.75)
Yellow-poplar	43.5 (0.70)	
Loblolly pine	45. (0.72)	

Because the equipment used to form the oriented panels caused substantial variation [as high as 10 lbs/ft^3 (0.16 SG)] among the panels, each thickness group was sorted into two average density classes containing 27 panels.

Thickness–in. (mm)	Density–lbs/ft^3 (SG)
1/2	46.6, 51.3
(12.7)	(0.75), (0.82)
5/8	45.6, 47.9
(15.9)	(0.73), (0.77)

The densities of specimens cut from panels and used in the tests are reported on ovendry basis and are somehwat less than the densities of the full-size panels.

Tests

From each density group, eight panels were chosen at random and cut into two 4 ft (1.22 m) square sections. One section was reserved for tests that will be reported later. The other 4 ft (1.22 m) section was dissected into small-size test specimens (Figure 1).

Plate shear specimens, 17.5 in. (445 mm) square, were tested according to ASTM D 3044-72 (ASTM 1974). Bending, IB, and 24 hr water soak tests were conducted according to ASTM D 1037-72 (ASTM 1974), with the addition of a modified aging test.

Four sets of three bending specimens were taken from each 4 by 4 ft (1.22 by 1.22 m) section of panel (Figure 1). From each set, an original-condition [65% relative humidity (RH) at 72°F (22°C)], accelerated-aging, and modified aging specimen was randomly selected. Fifteen in. (381 mm) test spans were used for 1/2 in. (12.7 mm) thick bending specimens and 18 in. (457 mm) spans, for 5/8 in. (15.9 mm) specimens.

IB specimens used for the 65% RH, accelerated aging, and modified aging tests were removed from bending specimens. IB samples used for the 50% RH test were cut from the 4 by 4 ft (1.22 by 1.22 m) sections of panel (Figure 1).

The modified-aging regime consisted of three complete cycles of:

1. Immersing in water at 120° ±3°F (49° ±0.7°C) for 6 hours.
2. Heat in dry air at 210° ±3°F (99° ±0.7°C) for 18 hours.

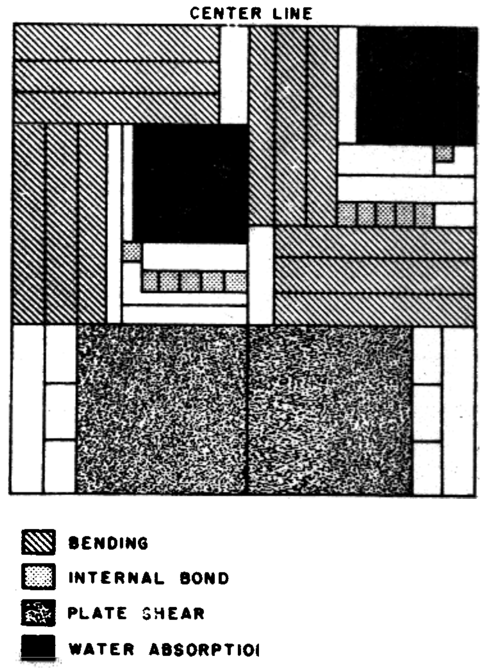

Figure Specimen locations on 4 by 4 ft (1.22 by 22 m) half of 4 by 8 ft (1.22 by 2.44 m) panel.

Before testing, material was conditioned at a temperature of 72° ±3°F (22° ±0.7°C) and a RH of 65% ±1% for at least 1 week.

Statistical Analyses

Linear regressions were used for comparing board constructions and thickness. All differences were statistically significant at the 0.005 level of probability. When comparing properties that have a significant linear relationship with density, comparisons are made at 46 lbs/ft^3 (0.74 SG) densities for mixed-species panels and 42 lbs/ft^3 (0.67 SG) for single-species panels.

Results

Plate shear

At a density of 46 lbs/ft^3 (0.74 SG), the shear modulus of the random panels, 259,000 psi (1789 MPa), is 35% higher than that of the oriented panels, 192,000 psi (1323 MPa). The regression slopes of panel density on shear modulus are statistically equivalent for both 5/8 in. (15.9 mm) panels and the 1/2 in. (12.7 mm) random panel (Table 2). Since the slope of the 1/2 in. (12.7 mm) oriented panels was not equivalent to the other three, at higher or lower densities the 35% difference in shear moduli will not be maintained when compared to the 1/2 in. (12.7 mm) random panel.

Bending

Based on regressions calculated for a density of 46 lbs/ft^3 (0.74 SG) (Table 3), oriented panels have better bending properties than random panels if both the 8 ft (2.44 m) and 4 ft (1.22 m) directions are averaged, even though oriented panels were pressed at lower pressure and cold-cut flakes were used. However, in the 8 ft (2.44 m) direction, oriented panels have better bending properties than random panels; in the 4 ft (1.22 m) direction random panels have the better bending properties (Table 4). The directional effects held for both 1/2 in. (12.7 mm) and 5/8 in. (15.9 mm) thicknesses even though bending properties of 1/2 in. mixed species panels were lower than those for 5/8 in. panels.

When directional property ratios (DPR), that is, the bending strength or modulus for the 8 ft (2.44 m) direction divided by that for the 4 ft (1.22 m) direction, equals 1.0. complete randomization is achieved. The higher the ratios, the better the orientation. The DPR of 5/8 in. (15.9 mm) panels was greater than that of 1/2 in. (12.7 mm) panels indicating an increase in directional property difference with increased thickness.

Random mixed species panels showed DPR's of 1.15 in bending strength (σ), and 1.21 in MOE. Single-species panels averaged 1.21 and 1.26 for σ and MOE. These DPR's indicate that the forming system at FPL allowed for a small degree of orientation.

Oriented panels had a DPR of 1.79 in bending strength and 2.70 in MOE. so Potlatch's orienting equipment was successful in orienting the flakes. Visual analysis indicated that the oriented panel's DPR was influenced by two factors. First. the alignment mechanism for core

Table 2. Summary of shear modulus and regression equations.

Flakeboard panel type	Number of test specimens	Moisture content %	Density[1] ρ lbs/ft^3 (SG)	Shear modulus G thousand psi (MPa)	Linear regression, $G = a + b\rho$			
					a	b	R^2	$Sy \cdot \rho$
1/2 in. (12.7 mm) oriented mixed species	16	10.34	42.55 (0.68)	173.84 (1199)	-90.157	6.131	0.840	8.395
	16	9.78	46.85 (0.75)	193.95 (1337)				
1/2 in. (12.7 mm) random mixed species	16	10.24	46.31 (0.74)	261.57 (1803)	-122.291	8.302	0.670	3.213
	16	10.17	48.00 (0.77)	276.80 (1909)				
5/8 in. (15.9 mm) oriented mixed species	16	10.02	41.09 (0.66)	155.41 (1072)	155.924	7.573	0.861	9.855
	16	10.30	45.48 (0.73)	188.40 (1299)				
5/8 in. (15.9 mm) random mixed species	16	10.01	42.60 (0.68)	235.94 (1627)	-91.683	7.622	0.777	12.601
	16	9.99	45.46 (0.73)	252.52 (1741)				
	8	10.20	49.48 (0.79)	288.24 (1987)				
/2 in. 2.7 mm) random pine	16	10.66	41.95 (0.67)	266.89 (1840)	N.S.			
1/2 in. (12.7 mm) random yellow-poplar	16	9.50	42.25 (0.68)	301.30 (2077)	N.S.			

[1] Density based on OD weight and volume at test.

Table 3. Regression relationship between density and bending properties (English Measure).

Panel Type	Exposure condition	Panel direction Ft	[1]$\sigma = a + b\rho$, psi				[1]$E = a + b\rho$, thousand psi			
			a	b	R^2	$Sy \cdot \rho$	a	b	R^2	$Sy \cdot \rho$
1/2 in. oriented mixed species	65% RH	8	-4846	223	0.642	616	-633.78	34.80	0.746	74.95
		4	-2358	124	0.735	232	-67.90	9.68	0.536	27.98
	Modified aging	8	-7986	267	0.813	525	-125.27	45.88	0.931	51.15
		4	-4409	150	0.659	318	-750.92	24.15	0.355	96.91
	Accelerated aging	8	-6990	237	0.749	420	-138.43	48.71	0.943	52.40
		4	-2498	107	0.640	233	-321.13	14.44	0.455	45.80
1/2 in. random mixed species	65% RH	8	-8122	286	0.583	519	-870.64	34.37	0.633	56.03
		4	-800	109	0.317	542	42.62	11.12	0.292	58.89
	Modified aging	8	-8320	270	0.543	552	-608.47	27.45	0.389	76.86
		4	-5642	199	0.505	416	-744.03	27.77	0.666	41.48
	Accelerated aging	8	-7024	232	0.724	349	-112.67	39.01	0.750	54.70
		4	-4152	159	0.530	379	-764.09	28.29	0.765	39.70
5/8 in. oriented mixed species	65% RH	8	-8157	302	0.549	881	-906.85	42.02	0.596	111.08
		4	-2712	124	0.449	411	-141.28	10.49	0.413	37.62
	Modified aging	8	-9505	297	0.642	697	-147.26	50.60	0.574	137.10
		4	-3451	123	0.487	346	-315.06	13.57	0.558	32.99
	Accelerated aging	8	-5095	183	0.539	565	-105.57	38.66	0.520	123.27
		4	-2557	120	0.724	249	-157.31	9.29	0.286	37.37
5/8 in. random mixed species	65% RH	8	-4606	212	0.644	541	-226.39	20.91	0.542	66.52
		4	-4329	190	0.732	376	-444.06	23.29	0.583	64.59
	Modified aging	8	-4169	179	0.760	360	-515.52	26.16	0.774	50.48
		4	-4034	166	0.641	420	-693.51	28.20	0.712	59.21
	Accelerated aging	8	-2012	113	0.544	373	-337.90	15.48	0.269	91.93
		4	-1921	84	0.310	320	-419.01	16.49	0.291	86.71
1/2 in. random pine	65% RH	8	-5944	263	0.721	547	-583.99	31.02	0.856	42.45
		4	-1230	122	0.611	363	-222.20	18.76	0.798	35.21
	Modified aging	8	-2492	164	0.621	404	-708.69	33.53	0.694	70.25
		4	-3286	171	0.725	352	-371.91	22.22	0.711	47.46
	Accelerated aging	8	-5037	225	0.643	570	-649.18	31.94	0.774	58.79
		4	N.S.				-502.53	25.39	0.528	64.87
1/2 in. random yellow-poplar	65% RH	8	-3196	217	0.729	637	-448.91	30.96	0.831	67.16
		4	-7728	310	0.804	351	-583.76	30.02	0.742	40.92
	Modified aging	8	-3537	221	0.561	757	-733.93	38.26	0.744	87.18
		4	-5642	255	0.634	526	-580.75	30.21	0.594	67.85
	Accelerated aging	8	-5140	262	0.694	757	-1054.43	48.53	0.829	96.04
		4	-4741	230	0.568	536	-619.80	31.70	0.649	62.24

[1]σ = bending strength; ρ = density based on OD weight and volume at 65% RH; E = modulus of elasticity

Table 3. Regression relationship between density and bending properties (SI Measure).

Panel Type	Exposure condition	Panel direction m	[1]$\sigma = a + b\rho$, psi				[1]$E = a + b\rho$, thousand psi			
			a	b	R^2	$Sy \cdot \rho$	a	b	R^2	$Sy \cdot \rho$
12.7 mm oriented mixed species	65% RH	2.44	-33.41	96.10	0.642	4.25	-4,369.9	14,996.6	0.746	516.8
		1.22	-16.26	53.44	0.735	1.60	-468.2	4,171.5	0.536	192.9
	Modified aging	2.44	-55.06	115.06	0.813	3.62	-863.7	19,771.4	0.931	352.7
		1.22	-30.40	64.64	0.659	2.19	-5,177.6	10,407.1	0.355	668.2
	Accelerated aging	2.44	-48.20	102.13	0.749	2.90	-954.5	20,991.0	0.943	361.3
		1.22	-17.22	46.11	0.640	1.61	-2,214.2	6,222.7	0.455	315.8
12.7 mm random mixed species	65% RH	2.44	-56.00	123.25	0.583	3.58	-6,003.1	14,811.3	0.633	386.3
		1.22	-5.52	46.97	0.317	3.74	-293.9	4,792.0	0.292	404.0
	Modified aging	2.44	-57.37	116.35	0.543	3.81	-4,195.4	11,829.2	0.389	529.9
		1.22	-38.90	85.76	0.505	2.87	-5,130.1	11,967.1	0.666	286.0
	Accelerated aging	2.44	-48.43	99.98	0.724	2.41	-776.9	16,810.9	0.750	377.2
		1.22	-28.63	68.52	0.530	2.61	-5,268.4	12,191.2	0.765	273.7
15.9 mm oriented mixed species	65% RH	2.44	-56.24	130.14	0.549	6.07	-6,252.7	18,108.0	0.596	765.5
		1.22	-18.70	53.44	0.449	2.83	-974.1	4,520.5	0.413	259.4
	Modified aging	2.44	-65.54	127.99	0.642	4.81	-1,015.4	21,805.4	0.574	945.3
		1.22	-23.79	53.01	0.487	2.39	-2,172.3	5,847.8	0.558	227.5
	Accelerated aging	2.44	-35.13	78.86	0.539	3.90	-727.9	16,660.0	0.520	849.9
		1.22	-17.63	51.71	0.724	1.72	-1,084.7	4,003.4	0.286	257.7
15.9 mm random mixed species	65% RH	2.44	-31.76	91.36	0.644	3.73	-1,560.9	9,010.0	0.542	458.7
		1.22	-29.85	81.88	0.732	2.59	-3,061.8	10,036.5	0.583	445.4
	Modified aging	2.44	-28.75	77.14	0.760	2.48	-3,554.5	11,273.3	0.774	348.1
		1.22	-27.81	71.54	0.641	2.90	-4,781.8	12,152.4	0.712	408.3
	Accelerated aging	2.44	-13.87	48.70	0.544	2.57	-2,329.8	6,670.9	0.269	633.9
		1.22	-13.25	36.20	0.310	2.21	-2,889.1	7,106.2	0.291	597.9
12.7 mm random pine	65% RH	2.44	-40.98	113.34	0.721	3.77	-4,025.6	13,367.7	0.856	292.7
		1.22	-8.48	52.57	0.611	2.50	-1,532.1	8,084.4	0.798	242.8
	Modified aging	2.44	-17.18	70.67	0.621	2.79	-4,886.4	14,449.3	0.694	484.4
		1.22	-22.66	73.69	0.725	2.43	-2,564.3	9,575.4	0.711	327.2
	Accelerated aging	2.44	-34.73	96.96	0.643	3.93	-4,476.1	13,764.1	0.774	405.4
		1.22	N.S.				-3,464.9	10,941.5	0.528	447.3
12.7 mm random yellow poplar	65% RH	2.44	-22.04	93.51	0.729	4.39	-3,095.2	13,341.8	0.831	463.1
		1.22	-53.28	133.59	0.804	2.42	-4,025.0	12,936.7	0.742	282.1
	Modified aging	2.44	-24.39	95.24	0.561	5.22	-5,060.5	16,487.7	0.744	601.1
		1.22	-38.90	109.89	0.634	3.63	-4,004.3	13,018.6	0.594	467.8
	Accelerated aging	2.44	-35.44	112.91	0.694	5.22	-7,270.3	20,913.4	0.829	662.2
		1.22	-32.69	99.12	0.568	3.70	-4,273.5	13,660.7	0.649	429.1

σ = bending strength; ρ = density based on OD weight and volume at 65% RH; E = modulus of elasticity.

Table 4. Calculated bending properties of panels pressed to a density of 46 lbs/ft^3 (0.74 SG).

Panel type	Panel direction	Exposure Condition: 65% RH	Modified aging	Accelerated aging
		BENDING STRENGTH, psi (MPa)		
1/2 in. (12.7 mm) oriented mixed species	8 ft (2.44 m)	5412 (37.3)	4296 (29.6)	3912 (27.0)
	4 ft (1.22 m)	3346 (23.1)	2491 (17.2)	2424 (16.7)
1/2 in. (12.7 mm) random mixed species	8 ft (2.44 m)	5034 (34.7)	4100 (28.3)	3648 (25.2)
	4 ft (1.22 m)	4214 (29.1)	3512 (24.2)	3162 (21.8)
5/8 in. (15.9 mm) oriented mixed species	8 ft (2.44 m)	5735 (39.5)	4157 (28.7)	3323 (22.9)
	4 ft (1.22 m)	2992 (20.6)	2207 (15.2)	2963 (20.4)
5/8 in. (15.9 mm) random mixed species	8 ft (2.44 m)	5146 (35.5)	4065 (28.0)	3186 (22.0)
	4 ft (1.22 m)	4411 (30.4)	3602 (24.8)	1943 (13.4)
1/2 in. (12.7 mm) random pine	8 ft (2.44 m)	5102 (35.2)	4396 (30.3)	4413 (30.4)
	4 ft (1.22 m)	3894 (26.9)	3896 (26.9)	
1/2 in. (12.7 mm) random yellow-poplar	8 ft (2.44 m)	5918 (40.8)	5745 (39.6)	5864 (40.4)
	4 ft (1.22 m)	5292 (36.5)	5068 (34.9)	4919 (33.9)
		MODULUS OF ELASTICITY, thousand psi (MPa)		
1/2 in. (12.7 mm) oriented mixed species	8 ft (2.44 m)	967 (6668)	1985.21 (13688)	2102 (14495)
	4 ft (1.22 m)	377 (2602)	359.98 (2482)	343 (2366)
1/2 in. (12.7 mm) random mixed species	8 ft (2.44 m)	710 (4898)	1871.17 (12902)	1682 (11596)
	4 ft (1.22 m)	554 (3821)	533.39 (3678)	537 (3708)
5/8 in. (15.9 mm) oriented mixed species	8 ft (2.44 m)	1026 (7075)	2180.34 (15033)	1673 (11534)
	4 ft (1.22 m)	341 (2353)	309.16 (2132)	270 (1862)
5/8 in. (15.9 mm) random mixed species	8 ft (2.44 m)	735 (5071)	687.84 (4742)	374 (2580)
	4 ft (1.22 m)	627 (4325)	603.69 (4162)	340 (2341)
1/2 in. (12.7 mm) random pine	8 ft (2.44 m)	719 (4956)	699.57 (4824)	692 (4773)
	4 ft (1.22 m)	565 (3901)	561.33 (3870)	564 (3888)
1/2 in. (12.7 mm) random yellow-poplar	8 ft (2.44 m)	851 (5870)	872.99 (6019)	984 (6784)
	4 ft (1.22 m)	677 (4669)	688.07 (4744)	712 (4906)

[1]Density based on ovendry weight and volume at 65% RH.

flakes functioned better than the mechanism for face flake alignment. Second, a consistent feed rate at the mat forming station could not be obtained, resulting in an unbalanced core-face ratio.

In general, modified aging did not reduce bending properties as much as the ASTM accelerated aging (Table 5). For the mixed-species panels at 46 lbs/ft^3 (0.74 SG), 60% and 78% of the bending strength was retained after accelerated and modified aging, respectively. Single-species panels retained 93% and 95% of their bending strength after aging exposures.

Since σ and MOE after aging are based on the specimen's original dimensions, substantial swelling during aging may indicate either a loss or gain in strength and stiffness, which is reflected mostly in the MOE values (Table 5).

Internal Bond

The IB at 46 lbs/ft^3 (0.74 SG) was not affected by the orientation of the flakes (Table 6). IB was affected by thickness and was the only property tested for which 1/2 in. (12.7 mm) boards had better values than 5/8 in. (15.9 mm) boards. However, IB of the 5/8 in. (15.9 mm) boards could be improved by a longer press time and greater pressure. Also, face densification of all panels could have been improved by greater pressure.

The pressing schedules used did not significantly densify the face of the panels, which yielded a uniform density profile throughout the panel thickness. Most IB failures of mixed-species panels, regardless of exposure condition and panel thickness, occurred in the face flakes (Table 7). Because of the uniform density profile, sanding before testing would probably not have decreased the incidence of face flake failures. The experimentally determined linear relations (Table 6) indicated that to obtain an IB strength of 70 psi (0.48 MPa), density of 1/2 in. (12.7 mm) mixed-species must exceed 43 lbs/ft^3 (0.69 SG) and 5/8 in. (15.9 mm) panels must exceed 47 lbs/ft^3 (0.75 SG).

As exposure induced weathering or moisture increased, IB decreased (Table 8). Increasing RH from 50% to 65% decreased IB an average of 7.6 psi (0.05 MPa) because of moisture increase or density decrease or both. Modified aging and accelerated aging reduced IB strength drastically. The average modified aging strength [13.5 psi (0.09 MPa)] is only 21% of the 65% RH average. Accelerated aging reduced the IB an additional 8%. For the mixed-species panels, only 10% of the 65% RH strength was retained after accelerated aging, but the single-species panels retained 28%. An improvement in aged IB should improve other properties and may decrease the property differences discernible after modified and accelerated aging exposure.

'able 5. Summary of bending properties

Panel type	65% RH Test Condition: Moisture content %	65% RH Test Condition: Density[1] at test lbs/ft^3 (SG)	65% RH Test Condition: Bending strength psi (MPa)	65% RH Test Condition: Modulus of elasticity Thousand psi (MPa)	After Modified Aging[2]: Density %	After Modified Aging[2]: Bending strength %	After Modified Aging[2]: Modulus of elasticity %	After Accelerated Aging[2]: Density %	After Accelerated Aging[2]: Bending strength %	After Accelerated Aging[2]: Modulus of elasticity %
8 FT (2.44 M) DIRECTION										
1/2 in. (12.7 mm) oriented mixed species	10.86	42.68 (0.68)	4831 (33.3)	867 (5978)	79.9	77.9	87.8	73.8	67.8	81.5
	10.39	47.75 (0.76)	5676 (39.1)	1010 (6964)	79.5	76.9	86.3	72.5	70.1	87.7
1/2 in. (12.7 mm) random mixed species	10.68	43.13 (0.69)	4314 (29.7)	610 (4206)	80.4	76.8	100.1	73.4	68.8	90.4
	10.66	45.68 (0.73)	4852 (33.5)	701 (4833)	78.2	84.2	91.7	71.3	71.6	91.2
5/8 in. (15.9 mm) oriented mixed species	10.64	42.82 (0.69)	4655 (32.1)	776 (5351)	77.3	68.0	87.0	72.2	54.1	74.5
	10.33	46.33 (0.74)	5999 (41.4)	1060 (7309)	75.2	72.3	85.0	65.8	55.0	58.0
5/8 in. (15.9 mm) random mixed species	10.91	39.10 (0.63)	3748 (32.7)	606 (4178)	83.5	75.2	83.9	77.7	61.7	39.6
	10.79	41.69 (0.67)	4026 (27.8)	640 (4413)	81.0	77.7	87.7	74.6	63.6	55.1
	10.58	45.78 (0.73)	5526 (38.1)	737 (5082)	80.3	78.4	95.0	73.1	60.4	41.5
1/2 in. (12.7 mm) random pine	11.27	39.28 (0.63)	4384 (30.2)	634 (4371)	88.0	91.8	101.5	83.5	83.8	92.7
1/2 in. (12.7 mm) random yellow-poplar	10.68	39.44 (0.63)	5375 (37.1)	772 (5323)	83.8	96.6	100.3	84.4	91.5	105.0
4 FT (1.22 M) DIRECTION										
1/2 in. (12.7 mm) oriented mixed species	10.63	42.67 (0.68)	2909 (20.1)	347 (2393)	79.5	76.9	83.4	73.9	69.3	81.6
	10.43	47.32 (0.76)	3554 (24.5)	389 (2682)	79.2	84.1	102.2	72.4	69.3	89.9
1/2 in. (12.7 mm) random mixed species	10.63	44.13 (0.71)	4043 (27.9)	530 (3654)	79.7	87.7	92.9	74.4	69.2	86.0
	10.56	46.15 (0.74)	4300 (29.6)	573 (3951)	78.5	79.4	92.5	71.2	67.0	88.2
5/8 in. (15.9 mm) oriented mixed species	10.76	42.48 (0.68)	2440 (16.8)	302 (2082)	77.0	71.9	86.3	72.2	63.7	75.1
	10.41	45.65 (0.73)	3027 (20.9)	340 (2344)	75.0	76.5	93.0	65.5	64.7	78.9
5/8 in. (15.9 mm) random mixed species	10.90	39.39 (0.63)	3274 (22.6)	484 (3337)	83.4	76.2	87.6	78.5	64.3	41.5
	10.88	42.04 (0.67)	3611 (24.9)	550 (3792)	80.5	75.7	83.4	74.6	62.8	52.4
	10.66	45.47 (0.73)	4274 (29.5)	574 (3957)	80.4	90.6	12.5	73.4	72.5	55.0
1/2 in. (12.7 mm) random pine	11.64	39.54 (0.63)	3594 (24.8)	519 (3579)	86.3	101.5	02.3	82.8	127.2	100.2
1/2 in. (12.7 mm) random yellow-poplar	10.74	39.39 (0.63)	4493 (31.0)	598 (4123)	82.8	100.5	03.9	78.0	2.6	06.8

[1] Density based on OD weight and volume at test.
[2] Average percent retention of the initial values.

Table 6. Regression equation relating density to IB strength of mixed-species panels[1] (English Measure).

Panel types and exposure conditions	IB at 46 lbs/ft^3	Linear regression, IB = a + bρ, psi			
		a	b	R^2	Sy · ρ
1/2 in. oriented					
50% RH	91.8	-170.36	5.70	0.508	13.50
65% RH	83.0	-112.03	4.24	0.442	16.03
1/2 in. random					
50% RH	84.2	-223.55	6.69	0.505	7.98
65% RH	79.2	-59.74	3.02	0.176	18.77
5/8 in. oriented					
50% RH	74.1	-241.05	6.85	0.572	14.54
65% RH	64.1	-158.10	4.83	0.442	16.70
5/8 in. random					
50% RH	75.1	-206.43	6.12	0.598	12.56
65% RH	67.4	-99.56	3.63	0.466	13.03

[1] Density based on OD weight and volume at test.

Table 6. Regression equation relating density to IB strength of mixed-species panels[1] (SI Measure).

Panel types and exposure conditions	IB at 0.74 SG	Linear regression, IB = a + bρ, kPa			
	kPa	a	b	R^2	Sy · ρ
12.7 mm oriented					
50% RH	633	,175	2,456	0.508	93.1
65% RH	573	-772	1,827	0.442	110.5
12.7 mm random					
50% RH	581	,541	2,883	0.505	55.0
65% RH	546	-412	1,301	0.176	129.4
15.9 mm oriented					
50% RH	511	-1,662	2,952	0.572	100.3
65% RH	442	-1,090	2,081	0.442	115.1
15.9 mm random					
50% RH	519	,423	2,637	0.598	86.6
65% RH	465	-686	1,564	0.466	89.8

[1] Density based on OD weight and volume at test

Table 7. Percent IB failures occurring at designated locations for 1/2 in. (12.7 mm) panels conditioned at 50% RH

Board type and density (SG)	Failure location[1]			
	F	C	I	L
		%		
Oriented				
43.22 (0.69)	59.4	31.2	9.4	0
46.75 (0.75)	89.1	3.1	7.8	0
Random				
46.59 (0.75)	56.3	35.9	7.8	6.3
47.92 (0.77)	59.4	23.4	17.2	4.7
Pine				
43.38 (0.69)	28.1	64.	7.8	4.7
Yellow-poplar				
42.40 (0.68)	26.6	65.6	7.8	6.3

[1]F = face
C = core
I = face-core interface
L = large folded flake occupying at least 30% of failure surface

24-Hour Water Soak

Linear regressions on density of percent water absorption based on weight gain (WAW), and percent thickness swell per percent moisture content increase (TM) were significant for mixed-species panels. Comparisons among regressions (slopes) indicate that panel thickness did not affect the density relationships. But, flake orientation was significant. Combining the panel thicknesses for each flake orientation, linear regressions for WAW and TM on density (ρ) are

Panel type	Linear regression	R^2	$S_{y \cdot \rho}$
Random	$WAW = 70.37 - 1.12\rho$	0.663	2.651
	$TM = -3.78 + 0.183\rho$	.553	.546
Oriented	$WAW = 99.81 - 1.48\rho$	.537	4.267
	$TM = -2.35 + 0.136\rho$	.350	.608

Table 8. Summary of IB properties for flakeboard panels subjected to various exposures (English Measure).

Panel Types	50% RH Density[1] lbs/ft³	50% RH IB psi	65% RH Density[2] lbs/ft³	65% RH IB psi	Modified Aging Density[2] lbs/ft³	Modified Aging IB psi	Accelerated Aging Density[2] lbs/ft³	Accelerated Aging IB psi
1/2 in. oriented mixed species	43.22	77	42.67	71	43.24	13	42.46	8
	46.75	95	47.54	87	47.16	20	46.43	12
1/2 in. random mixed species	46.59	89	43.63	73	44.21	13	42.78	7
	47.92	96	45.92	82	45.98	14	45.36	8
5/8 in. oriented mixed species	43.72	57	42.65	44	42.56	6	42.43	4
	47.56	85	45.99	70	46.70	8	45.49	6
5/8 in. random mixed species	42.19	53	39.25	41	38.99	7	38.56	5
	44.61	66	42.35	54	41.77	8	41.20	5
	48.42	91	45.63	71	46.21	10	45.50	6
1/2 in. random pine	43.38	72	39.40	60	40.22	25	39.54	7
1/2 in. random yellow-poplar	42.40	68	39.41	65	39.62	26	38.58	17
Avg	45.16	77	43.21	65	43.33	14	47.57	9

[1] Density based on OD weight and volume at 50% RH.

[2] Density based on OD weight and volume at 65% RH.

Table 8. Summary of IB properties for flakeboard panels subjected to various exposures (SI Measure).

Panel Types	50% RH		65% RH		Modified Aging		Accelerated Aging	
	Density[1] SG	IB MPa	Density[2] SG	IB MPa	Density[2] SG	IB MPa	Density[2] SG	IB MPa
12.7 mm oriented mixed species	0.692	0.53	0.683	0.49	0.692	0.088	0.679	0.052
	0.748	0.66	0.761	0.60	0.755	0.134	0.743	0.080
12.7 mm random mixed species	0.745	0.61	0.698	0.50	0.707	0.090	0.684	0.046
	0.767	0.67	0.735	0.56	0.736	0.099	0.726	0.052
15.9 mm oriented mixed species	0.700	0.40	0.682	0.30	0.679	0.039	0.679	0.030
	0.761	0.59	0.736	0.48	0.747	0.052	0.728	0.038
15.9 mm random mixed species	0.675	0.36	0.628	0.29	0.624	0.046	0.617	0.034
	0.714	0.45	0.678	0.38	0.668	0.054	0.659	0.039
	0.775	0.63	0.730	0.49	0.739	0.072	0.728	0.044
12.7 mm random pine	0.694	0.49	0.630	0.41	0.644	0.172	0.633	0.118
12.7 mm random yellow-poplar	0.678	0.47	0.631	0.45	0.634	0.177	0.617	0.118
Avg	0.723	0.53	0.691	0.45	0.693	0.093	0.761	0.059

[1] Density based on OD weight and volume at 50% RH.
[2] Density based on OD weight and volume at 65% RH.

The dimensional stability was influenced by the fabrication variables. Random panels' linear expansion (LE) is larger in the 4 ft (1.22 m) direction, while the oriented panels have the largest LE's in the 8 ft (2.44 m) direction (Table 9). As previously discussed, equivalent layer orientation or randomization and balanced layer flake quantity was not obtained.

If the three layered mats had been fabricated with cores and faces of equal weight and equally well aligned, then the LE values would have been equal in both directions.

Table 9. Dimensional stability measured by 24-hour water soak.

Panel type and density lbs/ft^3 (SG)	Water absorption %	Thickness swell %	Thickness swell %/% M.C.[1]	Linear expansion 8 ft (2.44 m) direction %	Linear expansion 4 ft (1.22 m) direction %
1/2 in. (12.7 mm) oriented mixed species					
43.63 (0.70)	30.0	20.8	0.338	0.085	0.030
48.30 (0.77)	36.4	17.8	0.383	0.079	0.020
1/2 in. (12.7 mm) random mixed species					
43.95 (0.70)	21.4	13.2	0.454	0.055	0.090
45.68 (0.73)	21.0	13.2	0.445	0.062	0.101
5/8 in. (15.9 mm) oriented mixed species					
42.54 (0.68)	36.6	22.7	0.463	0.193	0.143
47.16 (0.75)	27.8	19.0	0.351	0.190	0.129
5/8 in. (15.9 mm) random mixed species					
38.77 (0.62)	26.7	13.3	0.342	0.058	0.116
42.03 (0.67)	22.5	12.0	0.383	0.028	0.057
47.07 (0.75)	17.1	9.6	0.428	0.065	0.085
1/2 in. (12.7 mm) random pine					
40.37 (0.64)	27.3	12.9	0.331	0.020	0.053
1/2 in. (12.7 mm) random yellow-poplar					
39.42 (0.63)	20.5	9.9	0.372	0.025	0.035

[1] The percent thickness swell per percent change in moisture content.

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