Effect of species and panel density on durability of structural flakeboard

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Abstract

Structural flakeboard panels made with species of sweetgum, hickories, red oaks, white oaks, and southern pines, and with a 20 percent mixture of each species group, were subjected to a series of exposure conditions. One of the exposure conditions consisted of a Xenon arc lamp with an intermittent water spray from conventional weatherometer test equipment. Other exposure conditions were the APA six-cycle and the ovendry-vacuum-pressure soak exposures. Mechanical and physical properties were determined and compared to commercial waferboard. At 50 percent RH, sweetgum, red oak, hickory, pine, and the mixed species panels all had properties similar to the commercial waferboard at a similar density (42 pcf). However, after the APA six-cycle exposure and the ovendry-vacuum-pressure soak exposure, only sweetgum retained physical properties equal to waferboard. Experimental panels of all species groups with higher panel densities than waferboard had similar property retentions as waferboard when exposed to the conditions in this study. None of the experimental panels performed as well as the commercial waferboard in the weatherometer tests. White oak panels were unacceptable after all exposures.

The quantity of low-grade hardwoods growing in the South continues to increase. These hardwoods are on sites more suitable to pines and on hardwood sites that are not properly managed. Until the forest sites are stocked with quality trees and properly managed, the quantity of low-grade hardwoods will continue to increase. This trend can be reversed if the fiber presently occupying these sites can be economically removed. Structural particleboard or flakeboard may provide sufficient economic return to the landowner to convince him to remove this low-quality fiber.

Our objective was to determine if a structural panel with properties comparable to the available commercial waferboaru could be produced from these low-grade hardwoods. We were also interested in property retentions of both waferboard and the experimental panels after several exposure conditions.

The difficulty encountered in evaluating a structural composite for long-term durability is the lack of good correlation between laboratory accelerated aging tests and in-use exposure conditions. Many laboratory exposure conditions are used to evaluate the property retention or durability of structural panels but none have become established as the best test. Some widely used conditions are the ASTM D 1037 (2), variations of the vacuum-pressure soak test (6) including ovendrying prior to soak, multiple vacuum-pressure and soaking times and temperatures (3, 4, 5, 7, 9, 10), and the APA test method S-6 after D-5 exposure (1). None of these tests accurately simulates the type of exposure encountered by most structural panels in service.

Also, for purposes of process control in the plant, these tests, with the possible exception of the vacuum-pressure soak and its variations, are all too time consuming. The structural panel industry is in need of a quick test for durability which can be used to maintain quality in the manufacturing process. This study did not address this need; the ovendry-vacuum-pressure soak and the APA six-cycle D-5 procedure were the two exposure conditions arbitrarily chosen for this study. Efforts should continue to be expended to develop an appropriate test procedure suitable for process control for the manufacturers.

Materials and methods

Five southern species groups, sweetgum, hickory, red oak, white oak, and southern pine, were used to

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make flakeboard panels at three different densities per species group. A sixth panel type, consisting of equal portions of the previous five species, also was made at three different panel densities. Table 1 contains the species, species density, nominal panel target densities, and the calculated compaction ratios for each panel density. Four replicate panels were produced from each species-panel density combination for a total of 72 panels. Also, for comparative purposes, commercial waferboard was purchased and evaluated.

The laboratory panels (Table 1) were produced with the following manufacturing parameters:

1. Panel size (trimmed)	- 36 by 32 inches
2. Nominal thickness	- 0.5 inch
3. Press temperature	- 350°F
4. Press time	- 8 minutes
5. Liquid phenolic resin	- 5.5 percent resin solids based on OD wood weight
6. Flakes	- produced on shaping lathe; length of approximately 3 inches, random width, thicknesses of 0.025 inch for core and 0.015 inch for face
7. Panel construction	- random flake orientation with 50 percent of panel weight in core and 25 percent of panel weight in each face
8. Time to stops	- 5 seconds to 1 minute dependent on species and panel density
9. Maximum press pressure	- 340 to 600 psi dependent on species and panel density

The following properties and exposure conditions were evaluated for each panel type:

1. Static bending and internal bond (ASTM D 1037 test procedures, 3- by 14-in. specimen)
   a) Control conditioned at 50 percent RH, 72°F (two specimens per panel). Internal bond determined on 2- by 2-inch non-failed portion of specimen.
   b) Tested wet after ovendry-vacuum-pressure soak (two specimens per panel). Unable to determine internal bond because of rough surfaces.
   c) Tested after APA six-cycle D-5 exposure (two specimens per panel). Unable to determine internal bond because of rough surfaces.
2. Dimensional properties
   a) Linear expansion and thickness swelling from equilibrium at 50 percent RH to equilibrium at 90 percent RH (one 3-in. by 30-in. specimen per panel).
   b) Linear expansion and thickness swelling from ovendry to vacuum-pressure soak (two 3-in. by 30-in. specimens per panel).
3. Bending of 1- by 5-inch specimen on edge, APA S-6 test procedure
   a) Control conditioned at 50 percent RH and 72°F (four specimens per panel).
   b) Tested after APA six-cycle D-5 exposure (four specimens per panel).
   c) Tested after equalization at 50 percent RH and 72°F following D-5 exposure (four specimens per panel).

TABLE 1. — *Species, density, nominal target density, and calculated target compaction ratio for experimental panels.*

Species	Species density[a]	Target panel density[b] and compaction ratio[c]		
Hickory	43.0	43/1.00	46/1.07	54/1.26
Pine	30.7	38/1.34	43/1.40	46/1.50
Red oak	36.7	43/1.17	46/1.26	49/1.34
Sweetgum	29.0	36/1.24	43/1.48	46/1.59
White oak	40.1	43/1.07	46/1.15	50/1.35
Mixture	35.9	43/1.20	46/1.28	49/1.36

[a]Ovendry weight, green volume (pcf).
[b]Ovendry weight, test volume (pcf).
[c]Compaction ratio = panel density/wood density.

In addition, two specimens per panel, approximately 3 by 10 inches, were exposed in a weatherometer to continuous irradiation with a Xenon arc lamp at a wavelength of 340 nm. An irradiance level of 0.55 W/m² was used and a total irradiation level of 500 kj/m² was chosen as the endpoint instead of total hours of irradiation. This minimized the effect of normal aging characteristics in the Xenon burner on the level of irradiance for the five duplicate runs required to expose all the samples. The unit was programmed to automatically shut down when the irradiation level reached 500 kj/m², which required approximately 910 hours. Specimens were subjected to a water spray on the irradiated surface for 18 minutes every 2 hours. Qualitative evaluation of appearance and percent thickness swelling were determined after exposure.

Results and discussion

Static bending and internal bond (ASTM)

The density, modulus of rupture (MOR), apparent modulus of elasticity (MOE), and internal bond (IB) results for specimens conditioned to 50 percent RH at 72°F and for specimens subjected to ovendry-vacuum-pressure soak and the APA D-5 exposures are presented in Table 2. The MOR and MOE values were determined with test specimen dimensions at the time of testing in all cases. The IB test was not conducted on samples exposed to the two accelerated aging exposures. Duncan's multiple range test was used to determine significant differences in MOR, MOE, and IB between densities within species.

The decrease in density from the conditioned samples to the two exposure tests reflects the thickness swelling upon exposure. The exceptionally low density of the white oak specimens after exposure is due to the large thickness swelling evident in panels with this species.

Figure 1 provides a graphical comparison of the MOR data of Table 2. The average MOR for conditioned specimens of all species-density combinations except the low densities of pine and white oak produced MOR values equal to or exceeding those of the commercial waferboard. Sweetgum was the best performer; at a density comparable to the waferboard it had twice the MOR value.

After the ovendry-vacuum-pressure soak exposure only the white oak panels failed to produce MOR values

TABLE 2. — *Average test density, modulus of rupture, modulus of elasticity, and internal bond after conditioning and after two exposure treatments for all species density combinations.*[1]

Species	Conditioned at 50% RH, 72°F				OD-VPS exposure			D-5 exposure		
	Density (pcf)	MOR[2] (psi)	MOE[2] (1000 psi)	IB[2] (psi)	Density (pcf)	MOR[2] (psi)	MOE[2] (1000 psi)	Density (pcf)	MOR[2] (psi)	MOE[2] (1000 psi)
Hickory	42.0	2677 A	434 A	43 A	29.1	483 A	73.6 A	26.6	405 A	49.3 A
	46.0	3636 B	509 B	50 A	30.6	585 A	76.6 A	29.0	550 A	57.8 A
	50.7	4450 C	590 C	115 B	36.7	1161 B	147.7 B	33.9	1268 B	124.5 B
Pine	37.5	2167 A	468 A	23 A	27.5	471 A	83.8 A	26.2	515 A	77.6 A
	42.4	3506 B	630 B	38 B	31.6	810 B	132.8 B	29.7	818 B	119.6 B
	45.2	4213 C	731 C	53 C	32.2	795 B	121.6 B	31.1	967 B	129.0 B
Red oak	42.2	3473 A	540 A	64 A	30.5	844 A	123.4 A	28.0	739 A	94.0 A
	46.1	4857 B	668 B	101 B	32.8	1149 B	161.6 B	30.6	1264 B	140.2 B
	49.3	5492 B	727 B	92 AB	34.8	1200 B	171.3 B	31.2	1128 B	125.5 B
Sweetgum	35.9	3387 A	602 A	49 A	28.4	928 A	149.1 A	27.3	1334 A	178.2 A
	42.9	5193 B	677 B	68 B	31.4	1250 B	167.9 A	30.2	1590 A	207.2 A
	44.1	4950 B	658 B	88 C	33.0	1356 B	181.4 A	31.5	1600 A	189.6 A
White oak	42.5	2524 A	477 A	30 A	23.1	165 A	26.3 A	17.9	70 A	6.2 A
	45.0	2843 AB	521 AB	38 A	25.1	228 B	32.8 A	19.8	113 B	9.6 B
	47.3	3217 B	548 B	59 B	26.5	299 C	42.5 B	20.9	137 C	11.5 C
Mixture	41.7	3404 A	543 A	40 A	29.3	666 A	102.5 A	28.3	757 A	90.1 A
	46.0	4013 AB	615 AB	64 B	31.5	789 A	113.5 A	27.8	709 A	73.1 B
	47.6	4676 B	678 B	80 B	34.5	1091 B	153.5 B	30.7	1092 B	118.8 C
Waferboard[3]	42.0	2618	486	82	30.4	654	129.6	31.3	1154	132.5

[1]Averages based on two specimens from each of four replicate panels. MOR, MOE, and density values are based on specimen dimensions at time of test.
[2]Averages within species per test condition followed by common letter are not significantly different at 0.0005 level.
[3]Average of four specimens.

equal to waferboard. Hickory required a conditioned panel density higher than waferboard to produce MOR values equal to waferboard after this exposure.

The MOR results for the experimental panels after the six-cycle APA D-5 exposure were generally not as good as the waferboard at equivalent densities. Sweetgum was the only species with an average MOR value equal to that of waferboard at the same or lower conditioned panel density. Hickory and red oak required substantially higher conditioned panel densities to obtain MOR values comparable to waferboard after OD-VPS exposure.

None of the experimental panels at densities comparable to the waferboards had internal bonds as high as the waferboard. Substantially higher panel densities than waferboard were required with all species before IB values were equal to those in waferboard. This is a reflection of the much higher compaction ratio of the waferboard as compared to the panels made in this study. None of the experimental panels had compaction ratios approaching the 1.8 to 1.9 ratio of the aspen-based waferboard. Most IB samples failed in the cores; those that failed in the face layer were randomly distributed between all species-density combinations.

The MOE for the experimental panels conditioned to 50 percent RH at 72°F were all equal to or greater than the waferboard at similar densities, except for hickory. After the OD-VPS exposure, the white oak and

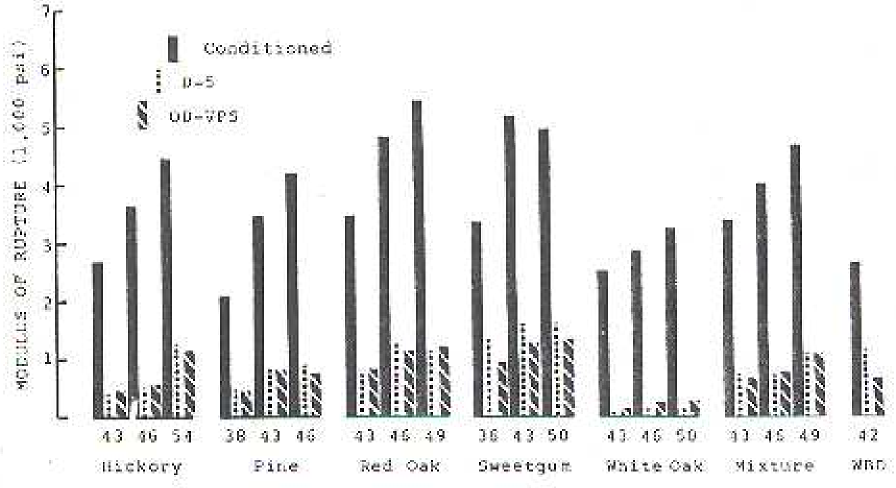

Figure 1. — MOR of conditioned samples and after OD-VPS and D-5 exposures for all species-density combinations and waferboard.

hickory panels with conditioned densities similar to waferboard had lower MOE values than waferboard. The extremely low MOE values for all densities of the white oak illustrate the extremely low resistance of these panels to the exposure tests. Only the sweetgum and, marginally, the pine had MOE values comparable to the waferboard at similar conditioned densities after the APA six-cycle D-5 exposure.

The above results with the static bending test on conditioned and exposed samples indicate that a phenolic-bonded flakeboard made from sweetgum flakes at the same density as commercial waferboard will have comparable property retentions to those of waferboard. Panels of most species with density comparable to waferboard produced bending strength properties similar to waferboard for unexposed, conditioned samples; however, after exposure to accelerated aging conditions, the bending properties were lower than those of similarly exposed waferboard.

Dimensional properties

Linear expansion (LE) and thickness swelling (THSW) were determined between equilibrium conditions at 50 percent and 90 percent RH and from ovendry to vacuum-pressure soak conditions. One specimen from each of four replicate panels per species-density combination was used for the 50 to 90 percent RH exposure, and two specimens per species-density combination were used for the OD to VPS exposure.

50 to 90% RH.—Table 3 presents the density and equilibrium moisture content at 50 and 90 percent RH as well as the LE and THSW between 50 and 90 percent RH for all species-density combinations. All experimental panels, with the exception of the white oak, had substantially lower LE values between 50 and 90 percent RH than the waferboard. The sweetgum panels had the lowest LE; in fact, the average LE values for the two higher sweetgum densities were negative and are omitted. However, the THSW of the experimental panels was in all cases, except for the lowest density sweetgum, higher than the waferboard, with the white oak having the largest THSW. Again, this is probably the result of compaction ratio differences. In general, there was no significant effect of panel density on either LE or THSW.

One possible reason for the substantially higher LE of the waferboard may be the thickness of the wafers. It has been widely reported (8) that linear expansion increases with increased particle thickness. The wafers of the waferboard were most likely substantially thicker than the 0.025- and 0.015-inch-thick flakes used in the experimental panels. Two other, less likely explanations, could be the orientation of the wafers in the panel and the orientation of the grain in the wafers. If the wafers are inclined at an angle to the panel faces, thickness changes in the wafers would produce a linear change in the panel. This change would be larger than that produced solely by wafer width changes in a well-formed panel. In turn, the small longitudinal movement of the inclined wafers would slightly reduce the thickness swelling of the panel. On the other hand, if the wafers were parallel to the panel faces, but were cut at an angle to the grain, the effect on the linear expansion would be the same.

A significantly lower EMC at 50 and 90 percent RH was obtained for the waferboard (Table 3). The reduced hygroscopicity of the waferboard is probably due to

TABLE 3. — *Panel density and moisture content in equilibrium with 50 and 90 percent relative humidity and linear expansion from equilibrium at 50 to equilibrium at 90 percent relative humidity.*[1]

Species	Density (pcf)[2] @ 50% RH	Density (pcf)[2] @ 90% RH	Moisture content (%) @ 50% RH	Moisture content (%) @ 90% RH	Linear expansion (%)[3] 50-90% RH	Thickness swelling (%)[3] 50-90% RH
Hickory	40.3	31.3	8.15	23.49	0.021 AB	28.7 A
	43.4	34.5	7.92	22.58	0.002 A	25.7 A
	49.5	39.8	8.16	22.63	0.044 B	24.4 A
Pine	37.9	31.0	7.85	21.10	0.017 A	22.1 A
	43.4	34.9	7.86	21.45	0.005 A	24.0 A
	46.0	36.7	7.89	21.48	0.012 A	26.4 A
Red oak	42.9	35.8	7.56	20.31	0.015 A	19.5 A
	45.0	37.1	7.62	21.20	0.011 A	21.1 AB
	47.9	38.3	7.76	21.37	0.029 B	24.9 B
Sweetgum	35.3	30.3	7.76	21.55	0.002 A	16.4 A
	41.7	34.2	7.85	22.76	—	22.1 B
	44.0	35.9	7.61	22.41	—	22.5 B
White oak	40.3	30.1	7.87	20.91	0.171 A	33.0 A
	42.8	31.8	7.77	21.29	0.186 A	34.0 A
	47.1	34.8	8.25	21.67	0.194 A	34.9 A
Mixture	42.9	34.9	7.65	21.06	0.036 A	22.5 A
	44.4	36.2	8.03	21.01	0.044 A	22.4 A
	47.3	38.2	7.82	21.58	0.030 A	23.7 A
Waferboard[4]	42.5	35.2	5.84	17.37	0.197	20.1

[1]Average of one sample from each of four replicate panels.
[2]Ovendry weight, test volume.
[3]Averages within species followed by common letter are not significantly different at 0.0005 level
[4]Average of two samples.

inherent differences in the drying or pressing temperatures in the commercial process as opposed to the experimental panels. Even though the experimental panels had no wax, the wax in the waferboard is not believed to be effective in reducing the hygroscopicity of the wood.

Ovendry to vacuum-pressure soak.—Table 4 presents the average moisture content, THSW, and LE for samples subjected to OD-VPS exposure for all species-density combinations and for the commercial waferboard.

As the density increased within a species, the panel void volume decreases and the average moisture content after soaking decreases, as shown in Table 4. There is no consistent increase in THSW within species as either the density or the compaction ratio increases. The LE of all species-density combinations, with the exception of the white oak, was less than that of waferboard. The thickness swelling of the waferboard was less than most of the experimental panels. The trend of these dimensional changes duplicates that of the 50 to 90 percent RH exposure, perhaps again reflecting the compaction ratio effect and the flake thickness differences.

With the exception of white oak, the experimental panels, compared to waferboard, had similar THSW and significantly lower LE when evaluated by either 50 to 90 percent RH or OD-VPS exposure. However, 20 to 25 percent THSW from 50 to 90 percent RH may be excessive for a structural panel material.

Small specimen bending (APA S-6)

One- by five-inch specimens were tested as a beam (1 in. dimension loaded as the beam depth) by midpoint loading across a 4-inch span. Twelve samples were prepared from each of the four replicate panels of each species-density combination. Four of these samples were conditioned to 50 percent RH at 72°F prior to testing; another four were subjected to the APA six-cycle D-5 accelerated aging exposure and tested immediately; the remaining four samples, prior to testing, were reconditioned to 50 percent RH at 72°F after the D-5 exposure. The average breaking loads for all species-density combinations for the three conditions tested were obtained (Table 5). The density and moisture content were also determined for the two accelerated aging tests.

All species-density combinations tested after conditioning to 50 percent RH at 72°F, in which the panel density was at least equal to that of waferboard, had average breaking loads equal to or greater than the waferboard. Within species, the average breaking load increased as the density increased and the high density panels of hickory, red oak, sweetgum, and the mixture all had at least twice the breaking load of the waferboard.

The average breaking load and density for all species-density combinations decreased substantially after D-5 accelerated aging. Using the species-density combinations which had exposed densities similar to that of exposed waferboard, red oak, sweetgum, and the mixture had average breaking loads equal to or better than waferboard. Hickory and pine are marginally comparable to waferboard; only the white oak was a total failure.

Samples reconditioned to 50 percent RH at 72°F after the D-5 exposure had substantially higher moisture content than those tested immediately after D-5 exposure since the last step of the D-5 test is a 15-hour drying step at 180°F. Again, the waferboard had a lower EMC at 50 percent RH than the experimental panels, duplicating the earlier results at 90 percent RH. All species-density combinations, except white oak, had breaking loads equal to or better than waferboard at similar test densities. Also, all species-density combinations had marginally higher breaking loads after reconditioning; the waferboard average breaking load was essentially the same in both cases.

TABLE 4. — *Average of moisture content, thickness swelling, and linear expansion for specimens subjected to ovendry to vacuum-pressure soak exposure.*[1]

Species	Moisture content[2] (%)	Linear expansion[2] (%)	Thickness swelling[2] (%)
Hickory	126.4 A	0.29 AB	46.1 A
	113.9 B	0.28 A	45.8 A
	87.6 C	0.31 B	39.0 B
Pine	144.8 A	0.19 A	42.3 A
	123.6 B	0.17 A	45.2 AB
	115.7 C	0.19 A	47.9 B
Red oak	122.8 A	0.18 A	38.0 A
	106.8 B	0.19 A	36.6 A
	102.1 C	0.22 B	38.6 A
Sweetgum	153.0 A	0.13 A	33.2 B
	123.5 B	0.14 A	35.6 A
	114.9 D	0.17 A	41.5 A
White oak	143.2 A	0.46 A	74.2 A
	134.7 AB	0.47 A	68.8 B
	126.9 B	0.47 A	68.0 B
Mixture	131.3 A	0.24 AB	42.6 A
	116.2 B	0.25 A	45.3 B
	105.5 C	0.22 B	40.7 A
Waferboard[3]	112.0	0.39	37.2

[1]Average based on two specimens from each of four replicate panels.
[2]Within species averages with common letter are not significantly different at the 0.0005 level.
[3]Average of four specimens.

Weatherometer

The average thickness swelling and moisture content were determined for each species from samples subjected to a total irradiation of 500 kj/m² in the weatherometer. There were no major differences in either moisture content or thickness swelling between panel densities within species or between species, except for the white oak.

Species	MC	THSW
	(%)	(%)
Hickory	50.6	56.5
Pine	47.8	46.8
Red oak	55.7	53.0
Sweetgum	48.1	43.3
White oak	67.6	99.7
Mixture	50.8	56.3
Waferboard	9.0	4.0

TABLE 6. — *Average density and breaking load for 1-inch by 5-inch bending specimen after initial conditioning, D-5 exposure, and reconditioning after D-5 exposure (Tested by APA S 6).*[1]

Species	Conditioned at 50% RH, 72°F		D-5 Exposure			Reconditioned at 50% RH, 72 F after D-5 exposure		
	Density[2] (pcf)	Breaking load[3] (lb.)	Density[2] (pcf)	MC (%)	Breaking load[3] (lb.)	Density[2] (pcf)	MC (%)	Breaking load[3] (lb.)
Hickory	40.3	203 A	25.4	3.13	62 A	25.9	9.42	85 A
	44.2	318 B	27.7	3.19	103 B	27.6	9.44	120 B
	50.4	511 C	32.1	2.96	199 C	31.6	9.19	224 C
Pine	36.9	214 A	26.5	1.88	61 A	35.1	9.14	87 A
	42.0	331 B	29.7	1.65	121 B	28.5	9.05	143 B
	45.8	398 C	31.7	1.88	163 C	39.7	9.16	165 C
Red oak	41.0	325 A	26.7	3.79	112 A	26.2	8.44	128 A
	45.5	443 B	29.7	3.65	168 B	29.2	8.41	190 B
	47.0	490 B	28.8	3.30	160 B	28.6	8.43	193 B
Sweetgum	35.4	299 A	27.6	2.56	190 A	27.5	8.72	229 A
	42.0	420 B	28.6	2.82	247 B	28.0	8.75	263 A
	44.8	499 C	29.7	2.83	279 B	30.0	8.74	318 B
White oak	40.9	196 A	18.9	3.04	18 A	18.6	9.36	23 A
	43.7	248 B	19.3	2.71	25 B	19.5	9.70	32 B
	47.2	323 C	19.6	2.39	28 B	20.3	9.67	35 B
Mixture	40.8	267 A	24.0	3.74	95 A	25.9	9.04	113 A
	45.1	402 B	26.9	4.04	117 B	27.9	9.11	145 B
	47.1	468 C	29.1	3.54	155 C	30.3	8.92	201 C
Waferboard[4]	41.8	237	29.5	1.94	145	28.1	7.72	136

[1]Average of four specimens from each of four replicate panels.
[2]Ovendry weight, test volume.
[3]Within species averages with common letter are not significantly different at the 0.0005 level.
[4]Average of eight specimens.

The waferboard performance was considerably better than any of the experimental panels. Most of this difference may be attributable to the absence of a sizing agent in the experimental panels. The white oak samples continued the pattern established with earlier tests of excessive thickness swelling and high moisture absorption. In addition, a black, viscous material migrated to the back face of the samples, away from the light source and the water spray. Possibly, this material is a water soluble extractive found only in white oak.

Conclusions

Several conclusions are obtained from these durability evaluations. First, there is very little difference in the effect on panel properties of the two exposure methods used in this study. The OD-VPS and the APA six-cycle D5 exposure both produced comparable reduction in the properties of all experimental panels and in the waferboard.

Second, based upon the results of this work, white oak does not appear to be an acceptable furnish for structural flakeboard.

Third, if the objective is to produce a panel at the same density as the commercial waferboard (approximately 42 pcf), sweetgum is the best possibility. Hickory, red oak, and the mixed species had bending strengths equal to or better than the waferboard in the dry state, but their properties were significantly lower than those of waferboard when they were subjected to an accelerated aging exposure. Experimental panels with densities higher than waferboard had properties comparable to waferboard. Consequently, a structural panel utilizing the species investigated in this study may require panels to be fabricated at a higher density to obtain acceptable panel properties.

Fourth, the commercial waferboard did not have exceptionally high property retention after accelerated aging exposures. The effective MOR and MOE values after the APA D-5 exposure and after OD-VPS exposure were only approximately 25 percent of the unexposed values, but the load at failure averaged approximately 50 percent of the control value. The other properties evaluated were similarly reduced by the various exposures. The weatherometer exposure was the only one in which the waferboard performance was not substantially altered.

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