THE INTERNAL BOND AND SHEAR STRENGTH OF HARDWOOD VENEERED PARTICLEBOARD COMPOSITES[1]

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ABSTRACT

The effects of several accelerated aging tests and weather exposures on hardwood reconstituted structural composite panels were evaluated. The results indicated that the internal bond and shear by tension loading strength reductions of the panels were affected by the exposure test method. The ranking of the effects of various exposure tests on strength values in an increasing order of severity was (1) 24-hour soak, (2) 1-hour boil, (3) 2-hour boil, (4) ASTM—6 cycles, and (5) WCAA—6 cycles. Both ASTM and WCAA tests had similar influences on IB and shear strength properties. Also, 4 cycles of either of these tests resulted in about the same degree of strength reduction as 6 cycles. In addition to test methods, a few construction variables were evaluated. The type of glueline, dry phenolic resin film and wet melamine-urea formaldehyde resin used to laminate the veneer over the core material yielded similar strength values. Other construction variables evaluated indicated that panels with an exterior particleboard core made from smaller particles as compared to wafers had higher IB values than waferboard core panels.

Keywords: Accelerated aging, adhesive, exterior particleboard, glueline, hard maple, hardwood composite, internal bond, red oak, shear strength, waferboard.

INTRODUCTION

The American Plywood Association has forecasted that the total demand for softwood plywood will increase from approximately 15.5 billion square feet (⅜-inch) basis in 1975 to about 22 billion square feet after 1985 (Mahoney 1975). In order to relieve any anticipated shortage of softwood plywood and extend future supplies of wood construction panels, wood products of other species may be required. The U.S Forest Service reported that the nation has a substantial volume of hardwood growing stock, but more than one-third of the hardwood inventory in 1970 consisted of oaks, hard maple, and poplar (U.S. For. Serv. 1973). Many studies related to the feasibility of making construction plywood and veneered composite panels from hardwoods have been reported (Chow 1972; Chow and Janowiak 1983; Chow and Redmond 1981; Jokerst et al. 1976; Lutz

and Jokerst 1974; Biblis and Lee 1984). One reason for not commercializing other structural panels has been inadequate data related to their properties and structural performance.

The objective of this study was to determine the effect of several variables (veneer species, glueline type, and core material) on the internal bond and shear strength of a hardwood veneer composite panel with veneer faces and particleboard cores.

MATERIALS AND PROCEDURE

The construction variables consisted of (1) veneer species (red oak and hard maple), (2) core material (exterior particleboard and a wafer type flakeboard), and (3) glueline type (dry and wet form). The properties were evaluated using (1) 24-hour water soak, (2) 1-hour boil, (3) 2-hour boil, (4) ASTM D1037 six-cycle accelerated aging test, and (5) the West Coast Adhesive Manufacturers Association (WCAMA or WCAA—6-cycle test) accelerated aging test.

In order to achieve the ½-inch panel thickness, ⅜-inch thick eastern pine exterior particleboard (5% phenolic content) and aspen waferboard (3% powder phenolic resin content) core material were purchased from commercial manufacturers. The ½-inch thick panels were also purchased. They have an average density of 42 lb/ft^3 and 41 lb/ft^3, respectively, based on oven-dry weight and air-dry volume at about 6% moisture content. Also, the ¹⁄₁₆-inch thick No. 2 face grade red oak and hard maple veneers were obtained from a manufacturer in the Midwest. The ¹⁄₁₆-inch veneer was used with the ⅜-inch core material to obtain a ½-inch composite. Because of the platen size of the hot press, the veneers, particleboards, and waferboards were cut into 20- by 24-inch pieces for lamination.

The lamination process consisted of gluing face veneers to particleboard and flakeboard cores with one of two different types of adhesives selected for evaluation. The two adhesives were a melamine-urea formaldehyde resin (wet form) and a thin, dry film (0.004 inch thick) of phenolic resin. The adhesive suppliers claimed that both of these resins meet the requirements of U.S. Products Standard P51-74 for exterior glue bond (National Bureau of Standards 1974).

Prior to lamination, all core panels were sanded slightly with 60 grit sandpaper to eliminate uneven surfaces and to improve the gluebond property. Panels laminated with the phenolic film were hot pressed at a pressure of 225 psi and 300 F temperature. The press times were 6 minutes for ½-inch thick composite panels. Panels laminated with melamine-urea formaldehyde liquid resin (100 parts powder resin, 60 parts water, and 5 parts catalyst) were hot pressed at 265 F and 200 pounds per square inch. Adhesive was applied to the core using a spread rate of 80 pounds per thousand square feet of double glueline. The press time was 6½ minutes for the ½-inch thick panels. The moisture content of veneers and cores before bond was maintained at between 5 and 8%. For all of the panels, the grain direction of the veneer overlays was parallel to the 24-inch length of the core material.

After being pressed, all panels were trimmed to specimen dimensions as specified in ASTM D 1037-72a (American Society for Testing and Materials 1981). All specimens were coded and conditioned at a relative humidity of 65% and a temperature of 68 F. For comparison purposes, matched specimens were cut from commercial ½-inch exterior particleboard and aspen waferboard. Matched

unaged control specimens were also cut from all materials. A commercial ½-inch thick, CDX grade Douglas-fir plywood material was also purchased and tested in this experiment. It had an average density of 36 lb/ft³.

Accelerated aging tests

Six accelerated aging regimes were selected for evaluation. The test procedures were:

1. ASTM D 1037-72a, 6 cycles, 12 days to complete (American Society for Testing and Materials 1981, National Particleboard Association 1980)
   a. Soaked in water at 120 F for 1 hour
   b. Steamed at 200 F for 3 hours
   c. Frozen at 10 F for 20 hours
   d. Dried at 210 F for 3 hours
   e. Steamed at 200 F for 3 hours
   f. Dried at 210 F for 18 hours
2. WCAA, 6 cycles, 6 days to complete (West Coast Adhesive Manufacturers Association 1966)
   a. Submerged in water at 70 F with 27-inch vacuum for 30 minutes
   b. Boiled in water at 210–212 F for 3 hours
   c. Dried at 220 F for 20 hours
3. 24-hour soak test (American Society for Testing and Materials, D-1037, 1981)
   a. Specimens were submerged in water at room temperature, approximately 75 F
   b. Specimens were removed after 24 hours
4. 1-hour boil test
   a. Specimens were submerged in boiling water 210–212 F
   b. Specimens were removed after 1 hour
5. 2-hour boil test (Shen and Wrangham 1971)
   a. Specimens were submerged in boiling water 210–212 F
   b. Specimens were removed after 2 hours

For the ASTM test, a set of specimens was removed at the end of each cycle. Similarly, specimens were removed from the WCAA test at the end of cycles 2, 4, and 6. This permitted comparison of strength reductions due to the number of exposure cycles for the two test procedures.

Strength properties tests

After completing the accelerated aging regimes, specimens were conditioned with the unexposed control group specimens in a climate chamber maintained at a relative humidity of 65% and a temperature of 68 F.

The IB and shear by tension tests were performed on each core material and composite panel type exposed to the aging tests, and the conditioned control specimens using a Universal testing machine and a plywood shear tester. The IB tests were performed according to ASTM D 1037-72 (American Society for Testing and Materials 1981), while the shear test specimens were tested according to methods described in ASTM D 906-64 (Reapproved 1976), standard methods of evaluating strength properties of adhesive in plywood type construction in shear by tension loading (American Society for Testing and Materials 1982). Specimens

TABLE 1. *Internal bond of unexposed control specimens and percent of value retained after five aging tests.*[1]

Panel, ½-inch		Glueline type	Unexposed control	24-hour soak	1-hour boil	2-hour boil	ASTM— 6 cycles	WCAA— 6 cycles
Faces, ¼ in.	Core, ¾ in.							
			Psi		— % retained from control —			
Red oak, 43 pcf	Exterior particle-board, 42 pcf	Dry[2]	86 (11)[4]	92.7	73.9	64.3	64.5	41.0
		Wet[3]	81 (15)	88.0	79.3	71.2	42.4	51.3
Red oak, 43 pcf	Waferboard, 41 pcf	Dry	73 (15)	97.0	33.3	26.9	22.0	27.0
		Wet	82 (13)	94.0	43.6	32.3	15.0	19.2
Hard maple, 42 pcf	Exterior particle-board, 42 pcf	Dry	91 (15)	81.3	71.3	36.0	34.9	36.6
		Wet	82 (13)	73.0	61.0	49.0	37.0	33.0
Hard maple, 42 pcf	Waferboard, 41 pcf	Dry	48 (2)	108.3	26.0	19.3	—[5]	—
		Wet	85 (6)	64.4	37.8	29.1	—	—
½ in. waferboard, 41 pcf			72 (11)	113.0	58.2	37.3	6.7	7.0
½ in. exterior particleboard, 42 pcf			84 (6)	97.0	77.2	65.0	50.4	36.1
½ in. D. F. plywood sheathing, 36 pcf			180 (36)	97.8	79.3	83.9	47.6	45.6

[1] All specimens were conditioned at 65% RH and 68 F prior to the test.
[2] Dry glueline—a dry sheet of phenol formaldehyde resin (0.004-inch thick).
[3] Wet glueline—liquid form of melamine-urea formaldehyde resin.
[4] Each value is an average for eight tests. Values in parentheses represent standard deviation.
[5] Glueline delamination occurred to some specimens during aging test.

of ½-inch thick particleboard and waferboard were prepared and tested in the same manner as those of the composite panels and the plywood.

EXPERIMENTAL DESIGN

In this experiment, analysis of variances (AOV) was conducted through the use of a completely randomized design. Components of the composite panels were considered as separate factors: factor A—veneer species, 2 levels, red oak and hard maple; factor B—core material, 2 levels, particleboard and waferboard; factor C—glueline type, 2 levels, dry phenolic film resin and liquid melamine-urea resin; and factor D—accelerated aging method, 5 levels, 24-hour soak, 1-hour boil, 2-hour boil, ASTM—6 cycles, and WCAA—6 cycles. Thus the experiment was a 2 × 2 × 2 × 5 factorial design (Steel and Torrie 1980). The number of replications per variable was eight for both IB and shear tests. However, because of the occurrence of delamination of some waferboard cores, the number of replicates tested for some ASTM and WCAA type specimens was less. All data were statistically analyzed using the Statistical Analysis System (SAS) programming procedure on the IBM 360 system. Special analytical techniques were employed to consider the missing data due to glueline delamination in the Analysis of Variance (SAS 1981).

RESULTS AND DISCUSSION

Control condition

Tables 1 and 2 give the average IB and shear strength values for the control specimens that were not aged. No glueline failures were found between the red oak face veneer and core board in these unexposed veneered composite specimens. The average particleboard IB value was higher than that of the waferboard. This IB property difference also occurred for the composite panels. Most likely the

TABLE 2. *Shear by tension loading (ASTM D 906-64) strength of unexposed control specimens and percent of value retained after five aging tests.*[1]

Panel, ½-inch		Glueline type	Unexposed control	24-hour soak	1-hour boil	2-hour boil	ASTM— 6 cycles	WCAA— 6 cycles
Faces, 1/16 in.	Core, ⅜ in.							
			Psi		*% retained from control*			
Red oak,	Exterior particle-	Dry[2]	155 (28)[4]	95.6	82.0	85.2	57.1	63.2
43 pcf	board, 42 pcf	Wet[3]	146 (25)	98.4	87.6	95.0	75.7	62.0
Red oak,	Waferboard, 41 pcf	Dry	139 (10)	106.1	86.5	60.8	61.0	61.0
43 pcf		Wet	147 (24)	92.7	70.4	61.5	30.0	38.5
Hard maple,	Exterior particle-	Dry	166 (52)	97.0	92.0	62.0	32.0	50.0
42 pcf	board, 42 pcf	Wet	155 (28)	87.0	84.0	81.0	42.0	45.0
Hard maple,	Waferboard, 41 pcf	Dry	148 (24)	86.0	70.0	60.0	—[5]	—
42 pcf		Wet	141 (21)	88.3	78.8	87.7	—	—
½ in. waferboard, 41 pcf			145 (11)	92.1	49.2	39.5	20.1	5.2
½ in. exterior particleboard, 42 pcf			163 (9)	85.1	86.4	53.7	62.8	25.6
½ in. D. F. plywood sheathing, 36 pcf			332 (40)	106.6	106.9	56.3	84.9	89.5

[1] All specimens were conditioned at 65% RH and 68 F prior to the test.
[2] Dry glueline—a dry sheet of phenol formaldehyde resin (0.004-inch thick).
[3] Wet glueline—liquid form of melamine-urea formaldehyde resin.
[4] Each value is an average for eight tests. Values in parentheses represent standard deviation.
[5] Glueline delamination occurred to some specimens during aging test.

difference is due to variation in the gluing properties of smaller particles relative to large flakes or wafers.

It is interesting to see that plywood specimens were found to have higher IB and shear strengths than specimens made from particleboard or waferboard core, although IB is not a property used to evaluate plywood products.

Accelerated aging test

The percent of IB and shear strength reductions based on values obtained at unexposed control conditions were tabulated for replications that had no delaminated specimens (Tables 1 and 2).

Except for the ASTM—6-cycle test compared with the WCAA—6-cycle test, the IB means obtained by any two test methods were significantly different at the 1% level (Table 3). For the shear strength values, the two 6-cycle test methods were statistically equivalent as well as the 24-hour soak versus the unexposed control.

TABLE 3. *Least significance difference (LSD) analysis of average IB and shear values between two different accelerated aging tests.*

	Properties	
Difference between two test models	IB	Shear
Control vs. 24-hour soak	**	NS
1-hour boil vs. 2-hour boil	**	**
2-hour boil vs. ASTM—6 cycles	**	**
2-hour boil vs. WCAA—6 cycles	**	**
WCAA—6 cycles vs. ASTM—6 cycles	NS	NS

** Difference significant at 1% level.
NS—Difference not significant at 5% level.

TABLE 4. *Factorial analysis for two strength properties of veneered composite panels.*

Source	F ratio	
	IB	Shear
A (veneer species)	**	NS
B (core)	**	NS
C (glue type)	NS	NS
D (aging test)	**	**
AB	NS	**
AD	**	NS
BC	NS	NS
CD	**	*
CA	NS	NS

* Difference significant at 5% level.
** Difference significant at 1% level.
NS—Difference not significant at 5% level.

Factorial analysis

Both IB and shear values were statistically analyzed using analysis of variance (AOV). The results of the AOV (Table 4) show that (1) factor A (veneer species) significantly affected the IB values; (2) factor B (core material) significantly influenced the IB values; (3) factor C (glueline type) did not have any effect on either strength value; and (4) factor D (accelerated aging tests) had a significant effect on both strength values.

On the basis of this analysis, several conclusions can be stated. First, composite panels made with the particleboard cores had a superior IB property, and resisted the degrading effects of the exposure conditions better than panels made with waferboard cores. Second, the 2-hour boil tests created the greatest average thickness swelling of all hardwood veneered composite panel specimens (Table 5). Finally, the exposure condition greatly affected the amount of strength reduction based on the unexposed specimens:

	Average strength retention %	
	IB	Shear
24-hour soak	92	94
1-hour boil	58	81
2-hour boil	47	68
ASTM 6-cycle	36	52
WCAA 6-cycle	33	49

ASTM—6-cycle versus WCAA—6-cycle test

Two of the most widely used accelerated aging tests are ASTM and WCAA cyclic tests. Both of these test methods resulted in a large percentage of strength reduction for all materials evaluated. For this reason, special attention was given to a comparison between these two tests and the effect of the number of cycles.

To determine the effects of the number of cycles of both ASTM and WCAA accelerated aging procedures on the strength properties of composite panel, specimens were evaluated for 2, 4, and 6 cycles and compared statistically using the Duncan's Multiple Range Test. For both accelerated test methods, IB and shear properties both showed no significant difference between 2 and 4 exposure cycles

TABLE 5. *Average percent thickness swell of ½-inch thick, composite panel for various exposure ditions.*[1]

Panel materials	Thickness swelling (%)				
	24-hour soak	bour boil	2-hour boil	ASTM–6 cycles	WCAA–6 cycles
			percent		
½″ plywood sheathing (CDX)	2	3	2	2	2
½″ ext. particleboard	2	7	22	13	17
½″ waferboard	4	7	25	28	24
Red oak/pt. bd. core	6	14	19	17	14
Red oak/wf. bd. core	6	18	32	30	28
Hard maple/pt. bd. core	6	15	20	25	15
Hard maple/wf. bd. core	8	27	32	—[2]	—

[1] Each value is an average for eight specimens on plywood, pt. bd., and waferboard; and is an average for 16 specimens of four veneered composite panels. All specimens were conditioned at 65% RH and 68 F prior to the measurements.
[2] Glueline delamination occurred to some specimens during aging process.

or 4 and 6 cycles except the shear values for ASTM cyclic test (Table 6). The result of this analysis suggests that hardwood composite panel specimens subjected to four cycles of either ASTM or WCAA aging test could achieve the same degree of strength reduction as specimens subjected to six cycles.

It was found that the most drastic reduction of IB and shear was observed from the first to second cycle of exposure for the ASTM procedure. A gradual decline of IB and shear after the third cycle was also shown for both ASTM and WCAA test methods.

CONCLUSIONS

On the basis of this experimental design and its results, several conclusions can be stated.

1. Shear by tension strength for plywood was superior to any of the hardwood composites or core materials tested. Based on the degree of core delamination, adhesive bond of red oak face veneer to core material is stronger than the coherence of chips or flakes in the core material.

2. The 24-hour soaking test had the least amount of strength reduction and caused the least amount of thickness swelling. The WCAA accelerated aging method resulted in the greatest observed average reduction for the two strength properties examined. However, statistical analysis showed that there is no real

TABLE 6. *Comparison of strength properties for different number of cyclic exposures for ASTM and WCAA accelerated aging test method.*

Strength property	No. of cycles	ASTM, mean[1]	WCAA, mean
		psi	
IB	2	40A	37A
	4	35AB	34AB
	6	32 B	31 B
Shear	2	123A	102A
	4	100 B	97AB
	6	105 B	89 B

[1] The same capital letters within a strength property test method group indicate no real difference between two strength values based on Duncan's Multiple Range test and 0.05% level.

difference between WCAA and ASTM, in reducing both values. Significant differences are noted between 1-hour boil and 2-hour boil; between 2-hour boil and WCAA 6-cycle; and between 2-hour boil and ASTM 6-cycle test in reducing both IB and shear by tension loading properties.

3. Significant differences were observed between control condition and 24-hour soak for IB property, while both IB and shear values were significantly different for 1-hour boil and 2-hour boil.

4. A drastic reduction occurred in both IB and shear strength between the first and second exposure cycles for either ASTM or WCAA test method. However, no significant differences in most of the strength values were found between 4-cycle and 6-cycle tests.

5. Internal bond was significantly influenced by the core material. The maximum IB value for a composite panel was obtained using a particleboard core.

6. Red oak veneered composite panels demonstrated better gluability characteristics than hard maple veneered panels.

7. Part of the decreased strength properties due to accelerated aging test in hardwood composite panels may be attributed to a lower density as a result of thickness swelling and the deterioration of the glue bond.

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