Gluability of Southern Pine Earlywood and Latewood

Abstract

The gluability and glue-bond durability of southern pine earlywood and latewood were investigated with two-ply, cross-laminated, 1/2-inch-square specimens comprised entirely of earlywood or latewood. A commercial exterior phenolic resin was used.

Glue-bond quality, as tested wet and dry in tension, was best with earlywood to earlywood and poorest with latewood to latewood; earlywood to latewood was intermediate. Optimum closed assembly time for latewood to latewood was zero minutes, while the optimum for earlywood to earlywood was 15 minutes. When these optima were exceeded by 30 minutes, the decrease in bond strength and percentage of wood failure was 90 percent for latewood-to-latewood bonds but less than 3 percent for earlywood-to-earlywood. Furthermore, latewood-to-latewood bonds showed a sharp increase in percentage of delamination (after exterior exposure) with increase in assembly time; the range tested was zero to 120 minutes.

Earlywood cells in the vicinity of the glue line were compressed and impregnated with resin. These cells formed a transition layer between glue line and the undeformed wood substrate. The dense, thick-walled latewood showed no such cell deformation, and resin impregnation was confined to the cells immediately adjacent to the glue line.

At any given percentage of wood failure, the bond strength was proportional to wood density. Percentage of delamination was not correlated with bond strength or percentage of wood failure.

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VENEERS FROM SOUTHERN PINE SAPWOOD are very permeable and typically contain wide bands of latewood and earlywood. With phenol formaldehyde adhesives the gluability of latewood is distinctly different from the gluability of earlywood. This difference creates difficulty in controlling glue-bond quality in southern pine plywood; as a practical matter, latewood-to-latewood bonds are the most difficult to make.

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To gain information on the specific nature of the bonding problem, the study reported here examined the gluability of veneers composed entirely of latewood or earlywood. An attempt was also made to determine how the interaction between wood substrate and assembly time was related to bond quality.

Procedure

Veneer Preparation

All veneers were from mill-run southern pine bolts being peeled at a plywood plant in Natchitoches, La. The 1/8-inch veneers were dried for 10-1/2 minutes in a six-section jet dryer at temperatures ranging from 340° to 380°F. Final moisture content averaged 4 percent or less. The dried veneers were sawn to yield 12- by 12-inch pieces. These pieces were randomly matched in two-ply, cross-laminated panels arranged with tight side to tight side, in order to minimize the effects of lathe checks.

The panels were pre-assembled without glue and conditioned to 3 percent moisture content. Prior to the conditioning, pilot holes were drilled in three corners of each panel to insure matching of the veneers in the hot press. The latewood and earlywood zones on the inner faces of the veneers were mapped on tracing paper with the pilot holes as references. To facilitate recovery of the desired test specimens after gluing, those zones were in-

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Table. 1 — AVERAGE BOND STRENGTH, PERCENTAGE OF WOOD FAILURE, AND PERCENTAGE OF DELAMINATION.

Primary variables	Unexposed				Exposed		
	Strength		Wood failure		Delamination	Strength	Wood failure
	Wet	Dry	Wet	Dry			
(1)	(2)		(4)	(5)	(6)	(7)	(8)
	P.s.i.		%				%
Type of wood substrate[a]							
E/E	213	425	88	83	1	336	64
E/L	138	330	39	55	40	219	38
L/L	55	266	8	19	80	61	5
Assembly time, minutes							
0	212	503	67	82	8	343	61
15	184	395	63	64	29	272	50
30	117	316	39	54	46	183	34
60	98	300	39	45	55	147	27
120	66	187	15	17	66	82	7

[a]E/E = earlywood to earlywood; E/L = earlywood to latewood; L/L = latewood to latewood.

dicated on the outer faces of each panel. Following conditioning, the veneer pairs were randomly sorted into five groups for tests of five assembly times. Veneers were sealed in polyethylene bags to minimize change in moisture content.

Panel Preparation

The only experimental variable in panel preparation was closed assembly time, i.e., zero, 15, 30, 60, and 120 minutes.

An exterior-grade phenol formaldehyde resin supplied by the Borden Chemical Co. was used. It was mixed according to the manufacturer's recommendations and spread on one face of one panel of each pair at the rate of 37.5 pounds per thousand square feet of single glue line. After the glue was spread, a wooden dowel was inserted in each hole of the two-ply panel to insure accurate matching.

The panels were not prepressed. Each two-ply panel was given the scheduled closed assembly time and all panels were pressed for 6-1/2 minutes in a two-opening hot press at a temperature of 285°F., and a specific pressure of 175 p.s.i. As the panels were removed, they were immediately placed in a hot-stack box where they remained overnight.

After the panels were fabricated, 1/2-inch squares were sawn to yield latewood-to-latewood, latewood-to-earlywood, and earlywood-to-earlywood specimens. Specimens were sized and edges smoothed by sanding lightly. A total of 450 specimens was prepared. They were then divided into three equal groups for tests of dry strength in tension, wet strength in tension, and delamination in exterior exposure.

Tests of Joints

Each two-ply, crosslap specimen (except those given exterior exposure) was glued with epoxy resin between the ends of a pair of steel bars each 1/2-inch square and 2-1/2 inches long. The bar and specimen assemblies were aligned in an inclined wood trough and secured with rubberbands while curing overnight. After curing, the assemblies were removed from the trough and aged for 7 days.

The dry-strength assemblies were then placed in an atmosphere held at 50 percent R.H. and 72°F. until the plywood specimens reached equilibrium, and the wet-strength assemblies were sub-

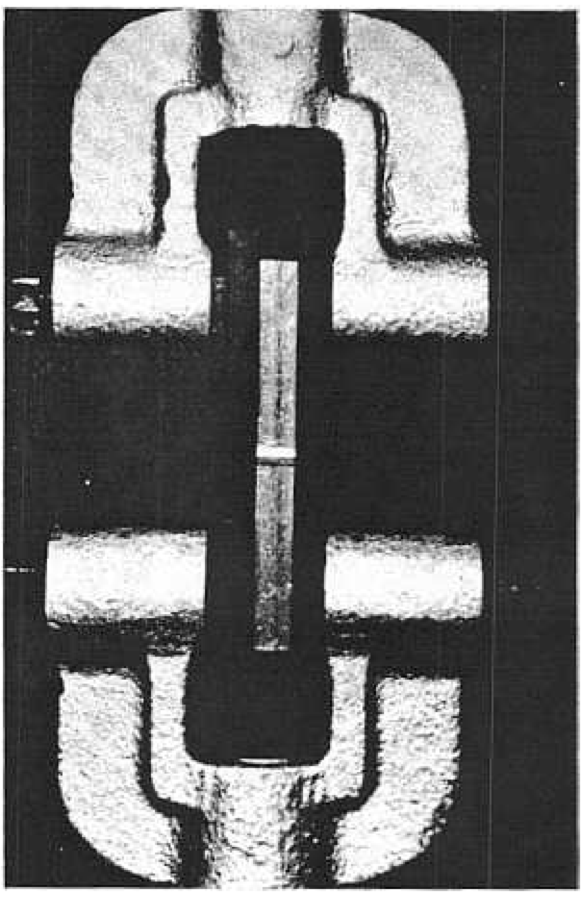

Figure 1. — Specimen glued between two steel bars for evaluation of tensile strength perpendicular to the glue line.

Table 2. — PERCENT OF DECREASE IN WET BOND STRENGTH AND WOOD FAILURE AS RELATED TO ASSEMBLY TIME.

Type of wood substrate	Assembly time	Bond strength	Decrease in bond strength	Cumulative decrease in bond strength	Percent of wood failure	Decrease in percent of wood failure	Cumulative decrease
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Min.	P.s.i.	%	%	%	%	%
Earlywood	0	202	—	—	100	—	—
to	15	235	—	—	100	—	—
Earlywood	30	233	0.8	0.8	100	0	—
	60	227	2.6	3.4	97	3	3
	120	168	25.1	28.5	42	55	58
Latewood	0	182	—	—	25	—	—
to	15	73	59.9	—	13	48	—
Latewood	30	18	30.2	90.1	2	44	92
	60	3	8.2	98.4	0	8	100
	120	0	1.6	100.0	0	0	100

jected to the vacuum-pressure soak cycle for exterior glue lines (PS-1-66). After conditioning, each assembly was placed in the tension grips of an Instron Universal Testing Machine (Fig. 1) and a tensile load was applied at a crosshead speed of 0.01 inch per minute. Strength values were determined at failure, and percent wood failure was measured.

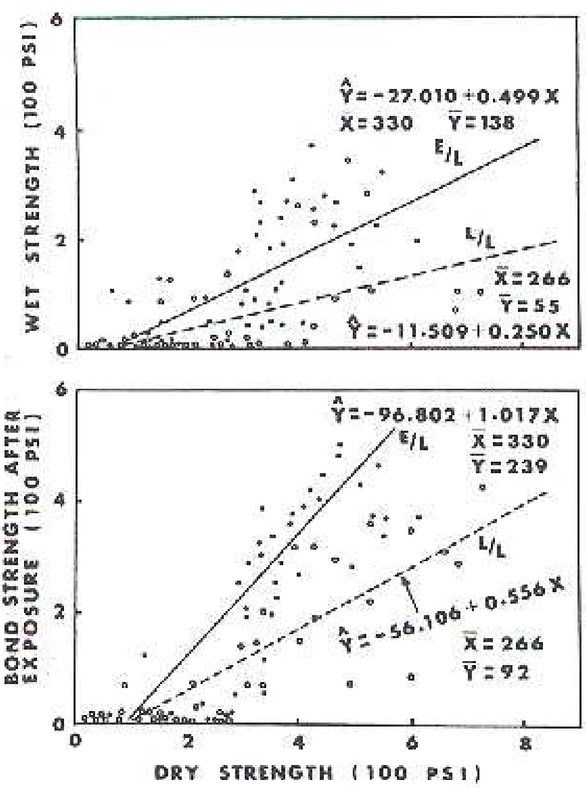

Figure 2. — Regressions of strength perpendicular to the glue line. Matched specimens were tested dry, wet after vacuum-pressure cycle, and dry after exterior exposure.

In the delamination test, the specimens were lightly held in individual metal cages mounted on a plywood base fixed on a south-facing, 45 degrees, exterior exposure deck. The specimens, together with the plywood base, were removed as a unit and submerged in water daily (at noon) for five minutes to accelerate delamination.

At the end of three months, the delamination in each glue line was measured by the method described by Koch (3). In this method, a round-end blade 1/8 inch wide and 0.006 inch thick is inserted into the deteriorating glue line at sufficient points to allow mapping of the delamination on 1/10-inch grid paper. Delamination was expressed as a percentage of total glue line area.

The specimens were then epoxied to 1/2 inch square steel bars in the same manner described previously for the wet and dry specimens, and were tested in tension to determine strength and percent of wood failure.

Results

By analysis of variance, bond strength, percentage of wood failure, and percentage of delamination differed significantly with changes in type of wood substrate and with each assembly time (Table 1). The interaction of the primary variables also proved significant — at the 0.005 level (Table 2).

Glue-bond quality as evaluated by bond strength, percentage of wood failure, and percentage of delamination, was best with earlywood to earlywood and poorest with latewood to latewood; earlywood to latewood was intermediate (Table 1). After three months on the exposure deck, the percentage of delamination in glue lines of earlywood to earlywood was one percent, as compared with 40 percent for earlywood to latewood and 80 percent for latewood to latewood (Table 1, column 6).

On the average, bond strength and percentage of wood failure decreased with increased assembly time, and percentage of delamination increased.

As expected, the specimens subjected to the vacuum-pressure cycle (Table 1, column 2), or to exterior exposure (column 7), had strengths considerably less than those tested dry (column 3). Regression analyses were made of the relation between dry strength and the strength measured after the vacuum-pressure cycle, and also the strength measured after exterior exposure. The regressions were significant (0.005 level) in the specimens composed of earlywood to latewood or latewood to latewood but were not significant in the specimens of earlywood to earlywood. The significant relationships are plotted in Figure 2.

The type of wood substrate interacted with assembly time to affect glue-bond quality (Table 2). The mean values of bond strength and percentage of wood failure are plotted against assembly time in Figures 3a, b, c, d, and e. In all comparisons the earlywood-to-earlywood bonds were the least sensitive to assembly time, and the latewood-to-latewood bonds were most sensitive.

Percentage of delamination is plotted against assembly time in Figure 3f. The latewood-to-latewood bonds showed a sharp increase in delamination with increase of assembly time. The earlywood-to-earlywood bonds were notably unaffected. The significantly higher percentage of delamination in latewood-to-latewood bonds and the interaction with assembly time support the results obtained by Northcott (4) and Koch (3).

As shown in Figure 3a, dry strengths varied widely, all assembly times considered. The values for latewood to latewood ranged from 550 to 70 p.s.i., and for earlywood to earlywood from 495 to 330 p.si. The specimens subjected to the vacuum-pressure cycle averaged from 182 to zero p.s.i. for latewood to latewood and 235 to 168 p.s.i. for earlywood to earlywood (Fig. 3b).

In earlywood-to-earlywood bonds subjected to the wetting cycle, 100 percent wood failure was developed at zero assembly time; the decrease in wood failure was moderate as assembly time was extended (Fig. 3e). Latewood-to-latewood bonds treated similarly showed only 25 percent wood failure at zero assembly time; this proportion decreased sharply to zero with increased assembly time.

Discussion

One of the significant findings of the study was the difference between earlywood and latewood in response to assembly time. The glue-bond quality curve, as evaluated by bond strength and percentage of wood failure, was concave for latewood to latewood and convex for earlywood to earlywood (Fig. 3).

Of the times tested, and for the adhesive used, optimum assembly time was 15 minutes for earlywood to earlywood and zero minutes for latewood to latewood. The longer assembly time for early-

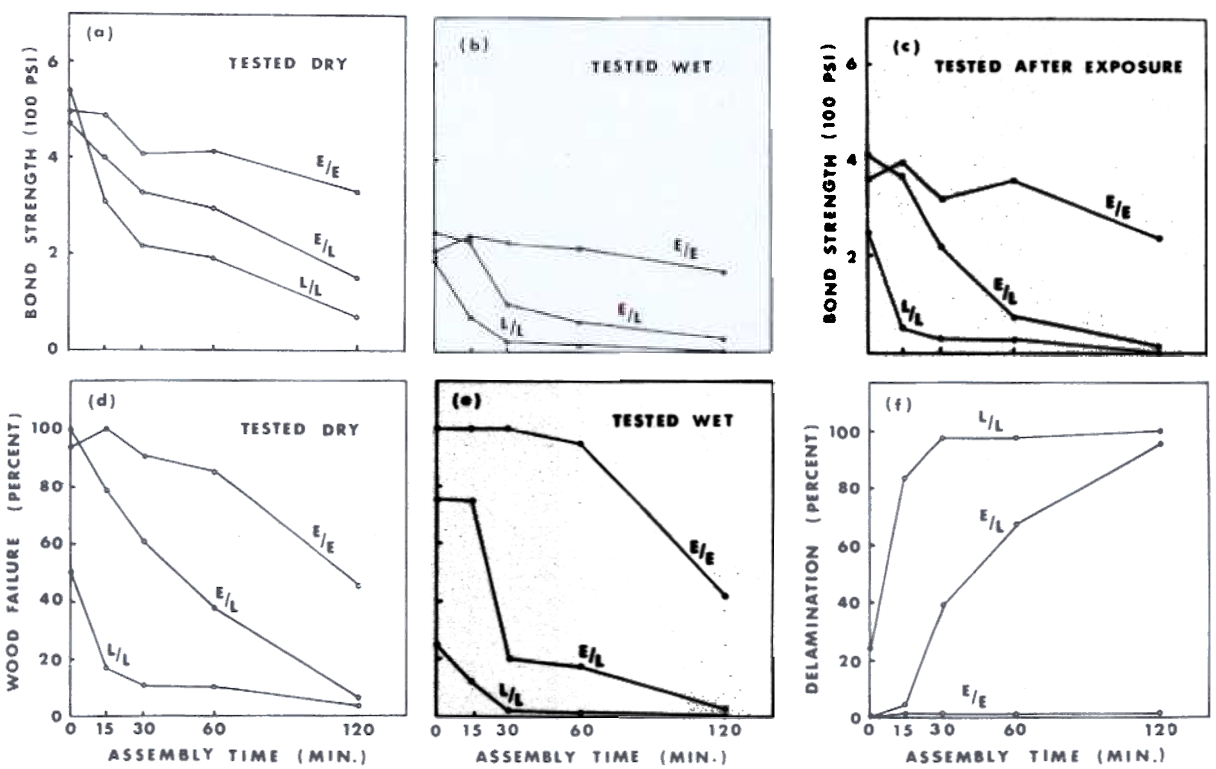

Figure 3. — Interactions of wood failure, delamination, and bond strength perpendicular to the glue line with substrate and assembly time. L/L means latewood to latewood, E/L means earlywood to latewood, and E/E means earlywood to earlywood.

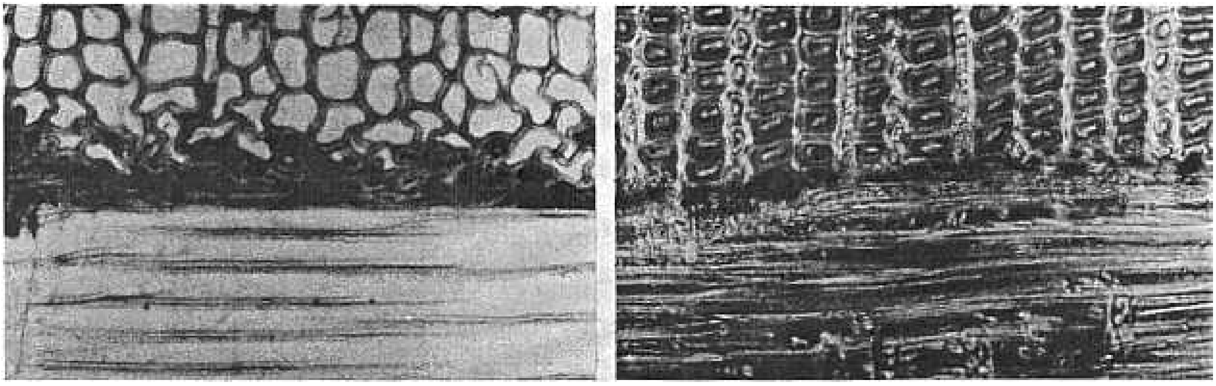

Figure 4. — Photomicrographs of glue lines. Left: Earlywood to earlywood bond. Earlywood cells were deformed near the interface, and resin penetrated deeply. Right: Latewood to latewood bond. Penetration into latewood was less evident, and cells near the interface were not deformed.

wood to earlywood is somewhat surprising because earlywood, being less dense than latewood, has higher gross porosity, and thus should develop a shorter optimum assembly time. The explanation may be that the glue was highly fluid when spread and that the application of pressure at zero assembly time probably caused considerable squeeze-out from the dense, hard latewood area to the adjoining softer earlywood area. This overabundant glue, with its low viscosity, may have penetrated the wood excessively before it cured. The result would have been a bond somewhat below maximum strength. The importance of the mobility of the adhesive has been previously stressed by Bryant and Garcia (1) in their study of factors affecting bleedthrough of phenolic resin adhesive in hardwood plywood.

Examination of the latewood specimens showed that the glue did not transfer adequately from the spread surface to the unspread. Latewood is less wettable than earlywood (2). It is possible that the increase in glue viscosity with increase in assembly time, combined with the loss of glue from the latewood area, may have critically affected wettability and significantly decreased glue transfer to the adjacent face. If this were the case, latewood bond strength would rapidly decrease with increased assembly time.

Figure 3 illustrates that latewood and earlywood differed substantially in the rate at which glue-bond quality decreased with assembly time once the optimum time had been exceeded. The cumulative decrease in a period of 30 minutes after optimum assembly time was 90 percent for the latewood-to-latewood bonds. For earlywood-to-earlywood bonds the corresponding loss was trivial (Table 2).

As shown in Table 1, the latewood-to-latewood bonds lost more strength and developed more delamination at the glue line than the earlywood-to-earlywood bonds. Because latewood is denser than earlywood, it shrinks and swells more with changes in moisture content. The resulting glue-line stresses accelerate delamination.

The glue lines were examined under a microscope in an effort to relate glue penetration to assembly time. From Figure 4, it can be seen that earlywood cells in the vicinity of the glue line typically were compressed and impregnated with resin. These cells formed a transition layer between the glue line and the undeformed wood substrate. The dense, thick-walled latewood, on the other hand, showed no such cell deformation, and impregnation was confined to the cells immediately adjacent to the glue line.

In earlywood the transition layer, with deep impregnation, may have changed the hygroscopic properties at the interface and improved its stability during changes in exposure. The densified layer may also have resulted in improved strength properties near the interface. Furthermore, the resin impregnation provided a gradual transition between the higher modulus of elasticity of the glue line to the lower modulus of the wood. Thus there was lower probability of stress concentration at the interface as the plywood changed moisture content. In earlywood-to-earlywood bonds, the increased strength and stability of zones near the interface, together with lower stress concentration and lower levels of stress due to moisture change, may have accounted for their greater durability.

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