Effects of Seven Variables on Properties of Southern Pine Plywood: Part I

Maximizing Wood Failure

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THE DURABILITY of plywood bonds in exterior exposure is commonly measured indirectly by failing wetted specimens in shear; a high percentage of wood failure is accepted in the industry as evidence that the gluebond will be durable.

As raw material for plywood, southern pine sapwood is characterized by high permeability and wide bands of resinous late wood. Experience of the Douglas-fir plywood industry indicates that these characteristics increase the difficulty of getting gluebonds that consistently yield high wood failure. The studies reported here examined the interrelationships of seven variables affecting gluebond quality. Loblolly pine (*Pinus taeda* L.) was chosen because it is the predominant species in the areas of likely plant location.

Abstract

This paper is the first of a series of four that explores the interacting effects of seven variables—wood specific gravity, rate of tree growth, tightness of peel, resin content of glue, type of secondary extender, gluespread, and assembly time—on the properties of exterior plywood made from loblolly pine. The three following papers will consider strength of wet specimens on rolling shear, strength properties at 11-percent moisture content, and means of minimizing face checking.

Wood failure, as determined on thoroughly soaked shear specimens, was maximized at 99 percent by: 1) using veneer of low specific gravity cut from slow-growing trees; 2) peeling the veneer cold and loose (as contrasted to hot and tight); 3) increasing the percent of phenol-formaldehyde resin solids in the wet gluemix (levels considered were 21 and 26 percent); 4) using only wheat flour as a secondary extender (as contrasted with no secondary extender or with blood-plus-wheat flour extender; and 5) increasing the amount of gluespread on the core (levels considered were 65 and 75 pounds per 1,000 square feet of core).

With low-density wood, assembly times of 32 or 24 minutes were preferable to 13 minutes; with high-density wood, the shortest assembly time was necessary.

Rate of tree growth, nonsignificant in analysis of variance, had a weak but significant regression relationship with wood failure.

Veneer from fast-grown dense trees—the most difficult to glue—when peeled cold and loose yielded 91 percent wood failure if: 1) the wet gluemix contained 26 percent resin solids and wheat flour only was the secondary extender; 2) glue was spread at 75 pounds per 1,000 square feet of core; and 3) assembly time was held to 13 minutes.

In the three-ply construction used, 78 percent of the shear failures occurred at the loose-to-loose interface. When panels were pressed two to the opening, 54 percent of the failures occurred at the cooler glueline, that is, most distant from the platen, and 46 percent at the line near to the platen. Wet shear specimens pulled "open" developed 11 percent more wood failure than did specimens pulled "closed." Characteristically, frequency of lathe checks increased as depth decreased.

Conspicuous by their absence from the variables are drying temperature and percent of extractives. These factors will be considered in a follow up study. The adverse effect of aged wood surfaces on subsequent gluing processes[2] was also omitted.

Procedure

Selection of Trees

Eight loblolly pines in the range from 14 to 20 inches diameter at breast height were selected from natural stands in central Louisiana. A

[1] The author appreciatively acknowledges the assistance of: Georgia-Pacific Corporation of Fordyce, Ark.; R. K. Stensrud and James Klein of Reichhold Chemicals, Inc.; the American Plywood Association in Tacoma, Wash.; B. S. Bryant and Chung Yun Hsi of the University of Washington, Seattle; I. J. Nicholas of the Kisatchie National Forest; John Lutz, Curt Peters, John McMillen, R. F. Blomquist, and E. W. Kuenzi of the U. S. Forest Products Laboratory in Madison, Wis.; and Tom Dell, statistician at the Southern Forest Experiment Station in New Orleans.

[2] Stumbo, D. A. 1964. Influence of surface aging prior to gluing on bond strength of Douglas-fir and redwood. For. Prod. Jour. 14 (12):582–89.

This paper was presented at Session 8—Glues and Gluing—of the 19th Annual Meeting of the Forest Products Research Society, June 29, 1965, in New York City.

pair was chosen in each of four categories:

1) Fast growth and low density—less than 6 rings per inch and specific gravity of less than 0.5 (ovendry weight and green volume).

2) Fast growth and high density—less than 6 rings per inch and specific gravity above 0.5.

3) Slow growth and low density—more than 6 rings per inch and specific gravity less than 0.5.

4) Slow growth and high density—more than 6 rings per inch and specific gravity above 0.5.

One 10-foot length was cut from each tree. Ring counts and specific gravity determinations were made on disks cut from the top and bottom of each green length; these measurements were restricted to peripheral portions of the disks—that is, the area representing the part of the bolt that would be peeled for veneer.

This evaluation of the peelable portions of the green 10-foot bolts from these 8 trees is illustrated in Figure 1.

Veneer Manufacturing Technique

Each 10-foot green length was cut into a pair of bolts to yield a total of 16 bolts, each 51 inches long. Bolts ranged from 14 to 19½ inches in diameter, averaging 16 inches. The bolts were numbered and color-coded on the ends according to destination. One-half were sent to the Georgia-Pacific Corporation in Fordyce, Ark. to be peeled under production conditions. The matched half were peeled at the U.S. Forest Products Laboratory in Madison, Wis. Bolts were shipped with bark on, each sealed in polyethylene film.

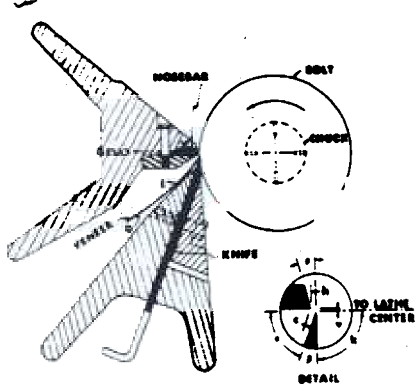

Figure 2.—Cross section of rotary veneer lathe. D is loose side of veneer; E is tight side.

The eight bolts shipped to Fordyce were barked and peeled cold and loose on a 4-foot lathe with a roller nosebar. The green veneer (0.130-inch-thick) was clipped into sheets 51 inches long and 26½ inches wide and dried in a modern steam-heated veneer dryer (not a jet dryer). Temperatures ranged from 275° F. at the green end to 315° F. at the dry end. Time in the heated zone was 19 minutes and 24 seconds. Final moisture content averaged 2 percent or less. The dry veneer was kept segregated according to bolt, wrapped in polyethylene film, and shipped to the University of Washington in eight crates, that is, one bolt per crate. At the Forest Products Laboratory, the bolts were heated in hot water (160° F.) for approximately 24 hours and then peeled hot on a core lathe having a fixed nosebar (Figure 2). Cutting data were:

cutting speed = 16 r.p.m., that is, less than 100 feet per minute

veneer thickness t_1 = 0.130 inch (assumed equal to undeformed thickness)

rake angle a = 69° 5′

sharpness angle β = 21°

knife angle K = 89° 55′

bevel (nosebar) θ = 15°

vertical opening v = 0.028 inch

horizontal opening b = 0.120 inch

nosebar clearance c = 0.122 inch $= [b + v\tan(90 - a)](\cos 90 - a)$

percent nosebar compression[3] $= 6.15 = \dfrac{(100)(t_1 - c)}{t_1}$

The green veneer was clipped to 26½-inch widths (Figure 3). Heartwood veneer was eliminated at the clipper with a color indicator made of equal parts of 10 percent sodium nitrite and benzedine.

The veneers were then dried in a single-deck, laboratory version of a conventional veneer dryer at 310° F. for 19 minutes and 24 seconds to a moisture content of 1 to 2 percent. Air circulation was longitudinal and more or less parallel to the plane of the veneer. Air velocity was approximately 600 feet per minute but turbulence around the top and bottom rolls made accurate measurement difficult. The dry veneer from each of the eight bolts was shipped to the University of Washington.

Steps Preparatory to Panel Assembly

The dry veneers were sawn to yield the maximum possible number of 12- by 12-inch defect-free pieces (Figure 4). Still segregated by bolt, the squares were sampled for moisture content (4.2 percent) and then placed on sticks in a lumber dry kiln for 96 hours at a dry-bulb temperature of 145° F. and a wet-bulb temperature of 100°. A sample of 32 pieces taken from throughout the kiln indicated an average moisture content of 2.6 percent at the conclusion of the equalization period. The range was from 1.3 to 4.3 percent.

The veneers from each bolt were sealed in polyethylene bags—one bag per bolt. Included in each bag were two moisture content specimens, that is, a total of 32 matched to those mentioned in the previous paragraph. At the conclusion of the pressing

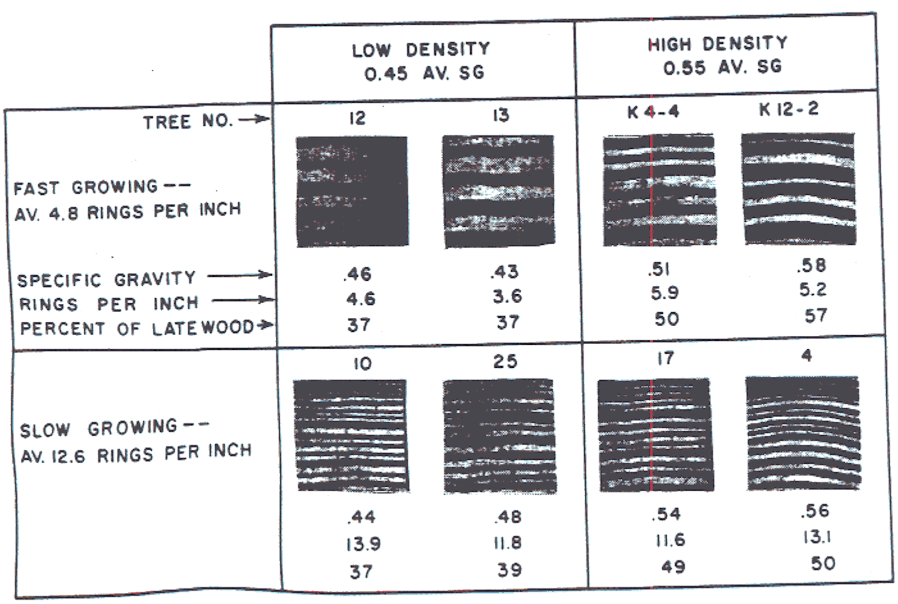

Figure 1.—Representative 1-inch-square cross sections from the eight loblolly pines. Trees in each box—for example, 12 and 13, K4-4 and K12-2—are considered replications of each other.

[3] Koch, P. 1964. Wood Machining Processes, Ronald Press Co., New York, N. Y. pp. 438–40.

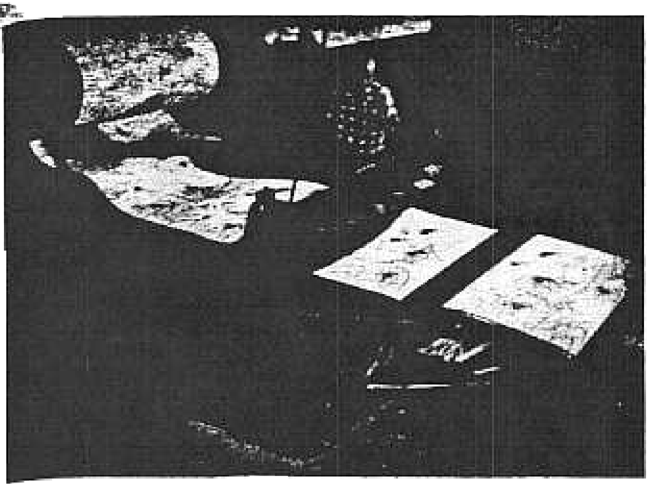

Figure 3.—The 0.130-inch-thick green veneer was clipped to 26½-inch-wide sheets.

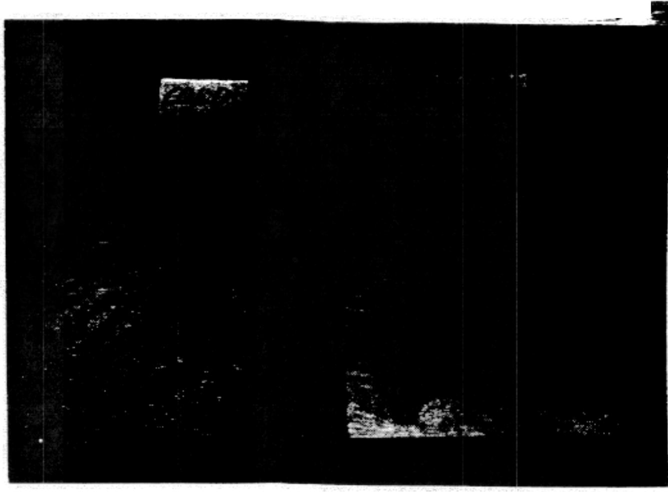

Figure 4.—Loose sides of typical 12-inch-square veneers. Cold peeling caused rough surface and deep lathe checks.

phase (5 to 8 days later, depending on the bolt), the moisture content of these strips averaged 3.7 percent. The range was from 1.5 to 6.7 percent.

Just prior to the gluespreading and pressing of any group of panels having a common adhesive mix and spread, the appropriate dry veneers were preassembled (in polyethylene bags) into sets of 24 panels, each panel comprised of three randomly selected veneers from a single bolt. The tight sides of the face and back veneers were placed outermost. The core was randomly arranged to have its tight side either up or down. The face of each preassembled panel was identified with a number. There were 12 gluemixes and spreads, replicated once. Thus the total number of sets was 24, each set comprised of 24 panels for a total of 576. Stated another way, 36 three-ply panels were made from each of 16 bolts.

For best gluebonds, elapsed time between veneer peeling and panel pressing should be short, preferably 48 hours or less.[2] It was not possible to maintain such a tight schedule in this test. The veneer cut in Fordyce was peeled on June 8, 1964, and that at Madison during the week of June 15, 1964. Hot pressing was begun on July 27 and was concluded on Aug. 1, 1964. Therefore the longest elapsed time between lathe and hot press was 55 days.

Gluemixing and Spreading

The 6 gluemixes, described in Table 1, comprised two levels of a phenol-formaldehyde resin, one primary extender, and three types of secondary extension—none, wheat flour only, and wheat flour and blood.

The resin formulation (Reichhold 22–398 Plyophen) contained 40 grams of solids out of a weight of 100 grams.[4] Therefore, in every 1,000 grams of mixed adhesive, 525 grams of resin, as supplied by the manufacturer, were required to achieve 21-percent resin solids in the final mix. For the 26-percent mix, 650 grams were included.

Veneer from trees 12, 25, K4-4, and 17 were glued first. Then separate mixes were made for the replication, that is, trees 13, 10, K12-2, and 4.

Glue was applied at spreads of 65 and 75 pounds per 1,000 square feet of core, equally divided on the two sides of the core. These spreads are equal to 29.5 and 34.1 grams per core (Figure 5). Each core was weighed before and after spreading, and those with more than a 1-gram variation were rejected. Glue batches were used within 3 hours of mixing, and every ½ hour the spreader was washed down and fresh adhesive placed in the reservoirs.

[4] Any trade names mentioned in this article are necessary to a factual report of data; their use implies no approval to the exclusion of other products that may also be suitable.

Assembly

The veneers were assembled into three-ply panels immediately after the cores were spread. The grain of the core was arranged to run at a 90° angle to that of the face and back. Ambient temperature averaged 76° F. All of the panels were prepressed

Table 1.—INGREDIENTS OF THE SIX GLUE MIXES[1]

Ingredient	26 percent resin solids			21 percent resin solids		
		Wheat flour	No secondary extender	Blood and wheat flour	Wheat flour	No secondary extender
(1)	(2)		(4)			(7)
	Percent			Percent		Percent
Water (90°-100° F.)	19.7			27.4		27.4
Furafil primary extender	9.0			11.6		13.7
Soluble blood secondary extender	1.9			1.6		.0
Wheat flour secondary extender	.7			.5		.0
50 percent caustic soda solution	2.8			4.6		4.6
Soda ash	1.1			1.7		1.7
22-398 Plyophen[2]	64.8			52.6		52.6
Total	100.0			100.0		100.0

[1]Percentage by weight of completed wet mix.
[2]A phenol-formaldehyde formulation containing 40 percent resinsolids (Reichhold Chemicals, Inc.).

Figure 5.—Twenty-six-inch spreader used to double-spread exterior adhesive mix on 12- by 12-inch cores. Cores were weighed before and after application to insure correct spread.

at 150 p.s.i. for 5 minutes in a cold press (Figure 6), but with varying assembly times before and after prepressing. Total assembly time (including prepress) between spreading and hot pressing was controlled to 13 minutes, 24 minutes, or 32 minutes. In the following notation, the first figure is the closed assembly time prior to prepressing, the second figure is the prepress time, and the last is assembly time after prepressing but before admission to the hot press. All times are in minutes:

$$5 + 5 + 3 = 13$$
$$16 + 5 + 3 = 24$$
$$14 + 5 + 13 = 32$$

All panels were pressed for 6½ minutes in a two-opening hot press, two panels to the opening (Figure 7); temperature was 285° F., and specific pressure was 175 p.s.i. The numbered side of each panel was in contact with a platen. As the panels were removed, they were immediately placed in a hot box where they remained overnight.

Panel Cut-up for Specimens

Figure 8 diagrams the method by which each panel was cut to yield test specimens.

Sixteen standard shear specimens were cut from each panel in such a manner that half could be pulled "open" and half "closed" (Figure 9). The identity of each group of eight specimens was maintained. The Quality Control Department of the American Plywood Association performed and evaluated the wet shear tests. Specimens were first thoroughly wetted by means of a vacuum pressure soak system devised by the APA. The rate of travel on the head of the testing machine (Figure 10) was adjusted to 6.6 inches per minute under no load; but speed control was approximate at best.

A portion of each panel (segment 2, in Figure 8) was used to determine the rings per inch and the depth and frequency of lathe checks in the core. The end of each test section was stained with an alcohol-soluble black dye and then sanded to a bevel of 45°. This procedure[5] made the checks visible (Figure 11). Measurements were made with a microscope. At the same time, it was recorded whether the glueline at the interface of the core and numbered side of the panel was loose-to-loose or loose-to-tight.

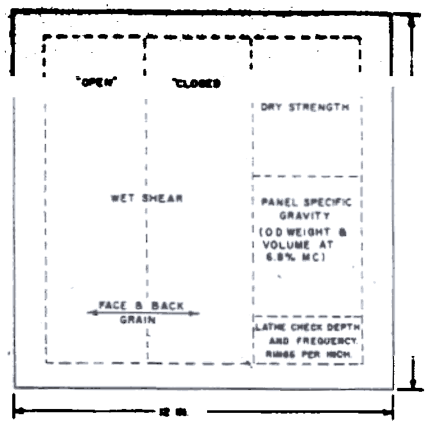

Figure 8.—Diagram of panel cut-up.

Portion 3 of each panel (Figure 8) was brought to an EMC of 6.8 percent. Then each portion was weighed, measured for volume, and ovendried and weighed again to permit determination of moisture content and specific gravity of each panel.

Results

Location of Failures in Wet Shear Specimens

Slightly more failures occurred in the cool glueline most distant from the hot platen (54 percent) than in the glueline adjacent to the hot platen (46 percent).

In the three-ply construction tested (Figure 9), 78 percent of the failures occurred at the loose-to-loose interface, as compared to 22 percent at the loose-to-tight interface. Plywood from slow-grown trees displayed significantly(*)[6] more failures at the loose-to-loose glueline (82 percent) than did wood from fast-grown trees (75 percent). Veneer peeled cold and loose displayed significantly(*) more failures in the loose-to-loose line (81 percent) than did veneer peeled hot and tight (75 percent).

Lathe Check Frequency

Veneer peeled cold and loose with a roller nosebar had fewer (*) lathe checks per inch (10) than veneer peeled hot and tight with a fixed nosebar (14).

Veneer peeled from fast-growing tres had more (*) checks per inch (12) than veneer peeled from slow-growers (11). Specific gravity did not affect check frequency.

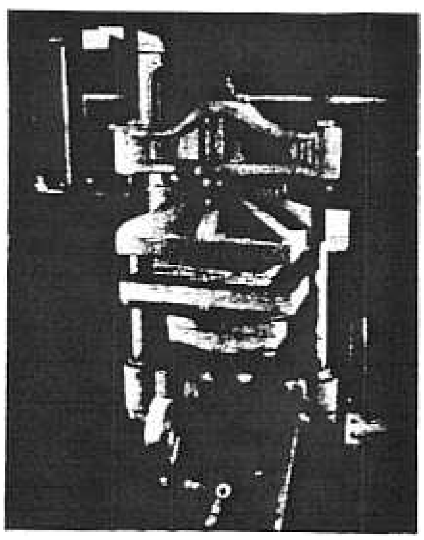

Figure 6.—All panels (12 three-ply panels per charge) were prepressed cold for 5 minutes.

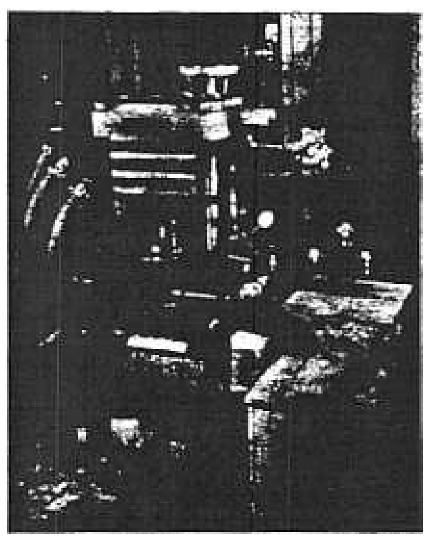

Figure 7.—Panels were hot pressed two to the opening for 6½ minutes and then stored overnight in the hot boxes illustrated in the foreground.

[5] Batey, T. E., Jr. 1955. Technique for rendering lathe checks clearly visible. Douglas-Fir Plywood Association Lab. Bul. 55-C.

[6] *indicates significance at the 0.05 level, ** at the 0.01 level, and *** at the 0.005 level.

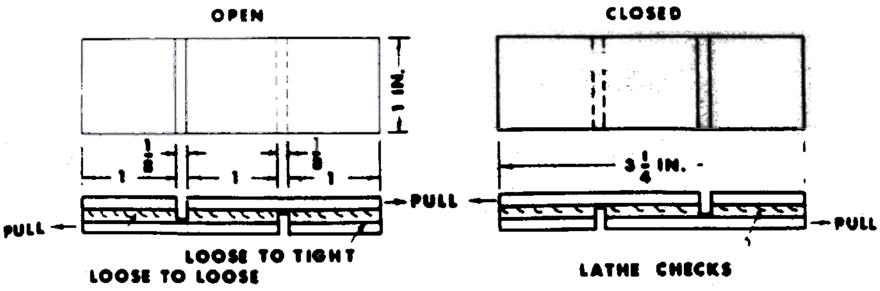

Figure 9.—Standard shear specimens illustrating alternative methods of kerfing to cause lathe checks to be pulled "open" or "closed." Tight side of face and back plies was outermost. Therefore, the interface between core and face (or back) was either "loose to loose" or "loose to tight," dpending on core placement.

Lathe Check Depth

Veneer peeled cold and loose had deeper (*) checks (0.09 inch) than did veneer peeled hot and tight (0.05 inch).

Veneer peeled from trees of low specific gravity had shallower (*) checks (0.06 inch) than did veneer peeled from trees of high specific gravity (0.07 inch). Rate of tree growth did not affect check depth.

Lathe check depth showed a strong negative association (***) with check frequency. The straight-line function that best fitted the data was:

$$D = 0.121 - 0.00452F$$

where D is check depth in inches and F is check frequency per inch. A curvilinear trend was indicated but not tested.

Wood Failure

By analysis of variance, wood failure differed significantly with changes in the level of each primary variable except tree specific gravity and growth rate (Table 2). All seven variables proved significant at the 0.005 level in one or more first-order interactions (Table 3); interactions of higher order were not significant at this level. A straight-line regression relation of wood failure to specific gravity of individual panels provided a more sensitive evaluation than variance analysis and proved significant at the 0.005 level.

As shown in Table 2, Column 2, veneer from trees of low specific gravity yielded higher wood failure (85 percent) than did veneers from trees of high specific gravity (67 percent). Panel specific gravity was negatively related to wood failure. The straight-line regression explained 20 percent of the variation, and indications were a curvilinear form would have better. On the average, panels from fast and from slow-growing did not differ (*) in percent of failure.

Veneer cut cold and loose, as in Table 2, Column 2, yielded more (*) wood failure (80 percent) than veneer cut hot and tight (72 percent). Lathe-check frequency showed a significant (*) but extremely weak negative relationship to wood failure (explained 1 percent of the variation), that is, the more checks per inch the lower the percent of wood failure. Check depth did not relate (*) to wood failure. When pulled "open," wet shear specimens yielded 11 percent more wood failure than when pulled "closed."

As shown in Table 2, the 26-percent level of resin solids yielded higher (***) wood failure (80 percent) than did the resin level of 21 percent (72 percent). Resin level interacted with the type of secondary extender, peel, and assembly time, as shown in Table 3.

At low resin level, the wheat-only secondary extender gave more wood failure (77 percent) than either wheat plus blood (72 percent) or no secondary extender (68 percent). Wheat plus blood at high resin level yielded no better results (77 percent) than wheat alone at low resin level (77 percent). At the high resin level, wheat alone was better (82 percent) than wheat plus blood (77 percent). These data are given in Table 3.

The poorer performance of the low resin level was magnified with a tight peel; that is, the plywood made veneer peeled hot and tight 78-percent wood failure at ... resin level but only 67-percent failure at the low resin level. By co... parison, values for veneer peeled co... and loose were 82 percent at the high resin level and 77 percent at the low. These data are given in Table 3.

Resin level interacts with assembly time, as shown in Table 3. At the low level, the 24-minute time was better (75-percent wood failure) than either the 13- or the 32-minute times, each of which averaged 70-percent wood failure. At high resin level, the 13-minute time was better (85-percent wood failure) than the 24-minute time (78 percent), or the 32-minute time (77 percent).

As shown in Table 2, wheat as a secondary extender yielded more (***) wood failure (80 percent) than either no extender (74 percent) or wheat plus blood (74 percent). Extenders interacted with both assembly time and rings per inch of the tree, as shown in Table 3. With wheat plus blood, the 13-minute assembly gave higher wood failure (80 percent) than did the 24-minute (73 percent) or 32-minute assembly (69 percent). With wheat alone, wood failure was not affected by assembly time, and the average was consistently higher than with either of the other extensions. With no extender, the 24-minute time was better (78 percent)

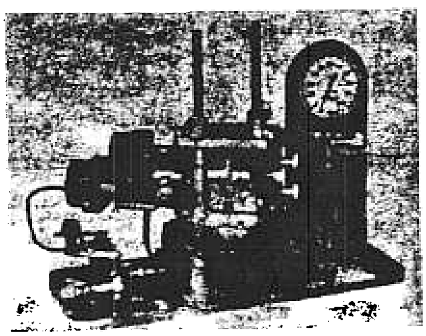

Figure 10.—Apparatus used to evaluate wet shear specimens for wood failure and wet shear strength. Head speed was approximately 6.6 inches per minute.

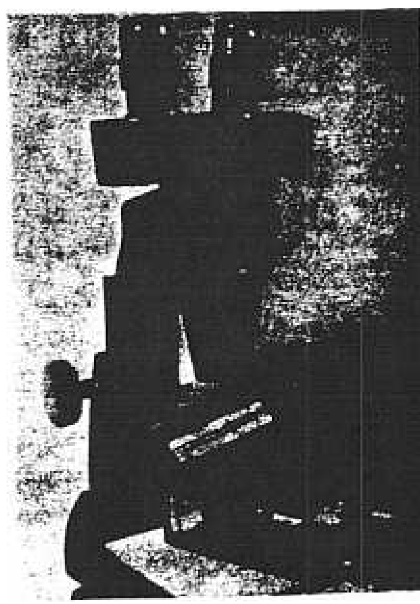

Figure 11.—Set-up for measuring rings per inch and depth and frequency of lathe checks in the core, and for locating the loose-to-loose bond. This particular core had a check depth of 0.095 inch and a check frequency of 7.9 per inch.

than the 13-minute time (72 percent).

Of the three extenders, only wheat interacted with rings per inch of the tree: wood failure averaged 83 percent for slow-grown wood and 77 percent for fast-grown (Table 3).

A gluespread of 75 pounds per 1,000 square feet of core yielded 80-percent wood failure, as compared to 72 percent for the 65-pound spread (***). Gluespread interacted with assembly time. With the low spread, 13 minutes was better (77 percent) than 24 minutes (72 percent), or 32 minutes (68 percent). With a 75-pound spread, assembly time made no difference.

As shown in Table 2, the 13- and 24-minute assembly yielded more (***) wood failure (78 and 77 percent, respectively) than did the 32-minute time (73 percent).

Regression analyses were made of the relation between wood failure and specific gravity of the individual panels, rings per inch in the core, and depth and frequency of lathe checks in the core. Results were:

1) With gluing variables ignored, specific gravity, rings per inch, check depth, and check frequency accounted for approximately one-fourth of the total variation.

2) As previously mentioned, a linear regression of specific gravity alone accounted for approximately 20 percent of the variation.

3) By stepwise criteria, the next best variable was check frequency, which in a two-variable equation with specific gravity accounted for 21 percent of the variation.

4) By stepwise criteria, the third best variable was tree growth rate (rings per inch), which in a three-factor equation with specific gravity and check frequency accounted for 23 percent of the variation.

5) Check depth made no significant (**) contribution after the foregoing variables were included (check depth and check frequency were negatively correlated).

Veneer from fast-grown trees of high specific gravity proved most difficult to glue; the following combinations of gluing conditions yielded wood failure of 85 percent or better in specimens from these difficult trees if veneer was peeled cold and loose:

Table 2.—EFFECT OF PRIMARY VARIABLES ON LOBLOLLY PINE PLYWOOD GLUEBONDS

Factor	Wood failure [1]	Ratio of wood failure open/closed [2]	Failures in glueline nearest to hot platen	Failures at loose-to-loose interface	Rings per inch	Lathe check frequency [3]	Lathe check depth [3]	Panel specific gravity [4]
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Percent		Percent	Percent		Checks per inch	Inch	
Replications [5]								
Trees 12, 25, K4-4, 17	81	1.09	47.9	80.0	10.3	11.6	0.07	0.56
Trees 13, 10, K12-2, 4	71	1.12	44.2	76.7	11.0	11.6	.07	.57
Tree specific gravity [6], [7]							*	*
Under 0.5 (12, 13, 10, 25)	85	1.06	47.9	79.6	9.8	11.8	.06	.51
Over 0.5 (K4-4, K12-2, 4, 17)	67	1.15	44.2	77.1	11.4	11.4	.07	.62
Rings per inch [6]				*	*	*		
Less than 6 (12, 13, K4-4, K12-2)	75	1.11	45.8	74.9	6.0	12.1	.07	.55
More than 6 (10, 25, 17, 4)	77	1.10	46.2	81.8	15.2	11.1	.07	.58
Peel [6]	*			*		*	*	
Cold loose	80	1.09	48.2	81.3	10.8	9.5	.09	.57
Hot tight	72	1.13	43.9	75.4	10.4	13.7	.05	.57
Resin solids in wet mix	***							
26 percent	80	1.08	45.5	79.0	10.3	11.6	.07	.57
21 percent	72	1.13	46.6	77.7	10.9	11.6	.07	.56
Secondary extension	***							
Wheat flour + blood	74	1.15	46.1	77.6	10.6	11.7	.07	.57
Wheat flour only	80	1.06	46.5	81.2	10.6	11.2	.07	.56
None	74	1.10	45.5	76.3	10.6	11.9	.07	.57
Gluespreads (lbs. per 1,000 sq. ft. of core)	***							
65	72	1.13	42.3	78.9	10.9	11.6	.07	.56
75	80	1.08	49.8	77.8	10.3	11.6	.07	.57
Assembly time, minutes [8]	***							
5+5+ 3=13	78	1.08	47.8	81.0	10.4	11.5	.07	.57
16+5+ 3=24	77	1.10	45.4	77.5	10.8	11.5	.07	.56
14+5+13=32	73	1.13	44.9	76.5	10.6	11.8	.07	.56
Average		1.11	46.0	78.4				

[1]Evaluated by American Plywood Association. Averages include data on all panels; the only segregation is by the factors in Column 1.
[2]See Figure 9.
[3]Core only (see Figure 11).
[4]Specific gravity of 3-ply plywood including adhesive (ovendry weight and volume at 6.8 percent moisture content).
[5]Dummy factor.
[6]The experimental design was such that the 0.05 level (*) was accepted as a test for this factor. All other factors were tested at the 0.005 level (***).
[7]Specific gravity of peelable portion of each tree (ovendry weight and green volume. See Figure 1).
[8]First figure is time after spreading and before prepress. A 5-minute prepress time was common to all. The third figure is time after prepress and before hot press.

1) Wheat flour only as a secondary extender; 26-percent resin solids with a gluespread of 75 pounds per 1,000 square feet of core; assembly time of 13 minutes (91-percent wood failure).

2) Wheat plus blood as a secondary extender with other conditions the same as above (88-percent wood failure).

3) No secondary extender with other conditions the same as in item 1 above but with assembly times of either 13 or 24 minutes (86-percent wood failure).

Wood failure of 99 percent was achieved under the following optimum conditions: Veneer was peeled cold and loose from trees of less than 0.5 specific gravity, growing slower than 6 rings per inch; glue contained 26 percent resin solids, had wheat flour alone as a secondary extender, and was spread at 75 pounds per 1,000 square feet of core; panels were allowed an assembly time of 32 minutes.

Rate of tree growth made very little difference. If ring count was less than 6 per inch, all other conditions remaining optimum, the wood failure dropped only slightly to 98 percent.

The adhesive with wheat flour extender was not particularly sensitive to assembly time on veneer of low specific gravity. If all other conditions were optimum, a 24-minute assembly time reduced the wood failure to 98 percent, and a 13-minute assembly time to 93 percent.

If no secondary extender was used, and other conditions remained optimum, wood failure dropped to 96 percent.

If other conditions remained optimum, but blood and wheat flour were used as a secondary extender and assembly time was shortened to 13 minutes, wood failure dropped only slightly to 98 percent. If, however, assembly time was lengthened to 24 minutes, wood failure dropped to 86 percent.

If veneers were cut hot and tight, but all other conditions remained optimum, wood failure dropped to 94 percent.

If resin level in the glue was lowered to 21 percent solids, with other conditions optimum, wood failure dropped to 91 percent.

If less glue was spread, that is, 65 pounds per 1,000 square feet of core, all other conditions remaining optimum, failure dropped to 85 percent.

If veneer was taken from trees of high specific gravity and assembly time shortened to 13 minutes, with other conditions optimum, failure dropped to 91 percent. If, however, assembly time was left unchanged at 32 minutes, wood failure dropped sharply to 59 percent.

TABLE 3.—WOOD FAILURE: SIGNIFICANT TWO-FACTOR INTERACTIONS[1]

SPECIFIC GRAVITY x ASSEMBLY TIME

Specific gravity	13 minutes	24 minutes	32 minutes
Less than 0.5	82	87	85
More than 0.5	73	66	62

RING COUNT x GLUE EXTENSION

Rings per inch	Wheat plus blood	Wheat	None
Less than 6	75	77	74
More than 6	73	83	74

PEELING x RESIN LEVEL

Resin solids	Loose	Tight
26%	82	78
21%	77	67

RESIN LEVEL x EXTENSION

Resin solids	Wheat plus blood	Wheat	None
26%	77	82	81
21%	72	77	68

68 72 77 77 81 82

RESIN LEVEL x ASSEMBLY TIME

Resin solids	13 minutes	24 minutes	32 minutes
26%	85	78	77
21%	70	75	70

EXTENSION x ASSEMBLY TIME

Extender	13 minutes	24 minutes	32 minutes
Wheat plus blood	80	73	69
Wheat	81	79	78
None	72	78	73

69 72 73 73 78 78 79 80 81

SPREAD x ASSEMBLY TIME

Gluespread	13 minutes	24 minutes	32 minutes
65 pounds	77	72	68
75 pounds	79	81	79

[1]All interactions listed were significant at the 0.005 level. Comparisons within interactions were by Duncan's multiple range test: if the figures are encircled or underscored by the same line, they are not significantly (0.01 level) different; otherwise they are significantly different.