Minimizing and Predicting Delamination Of Southern Plywood in Exterior Exposure

By

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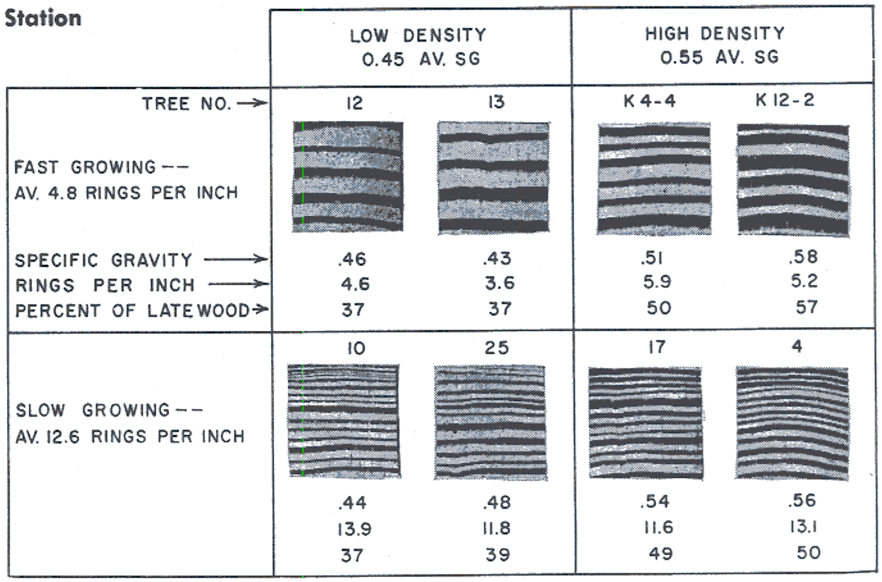

Figure 1. — Representative 1-inch-square cross sections from the eight loblolly pines. Trees in each box — for example, 12 and 13, K4-4 and K12-2 — are considered replications of each other.

SOUTHERN PINE PLYWOOD is substantially all being manufactured with phenolic glue for exterior use. Because panels must not delaminate in service, a reliable predictor of glueline durability is required. Drawing on the experience of the Douglas-fir plywood industry, southern manufacturers have adopted as a predictor the percentage of wood failure (% WF) observed in randomly selected and thoroughly wetted shear specimens. A high % WF is accepted in the industry as evidence that the bond will be durable (7, 6).

This paper examines the interrelationships of seven variables (eight including time exposed) affecting glue-bond durability and the merit of % WF and several other parameters as predictors of durability. Background data will be found in four previous papers (1, 2, 3, 4).

Procedure

Portions of eight loblolly pine trees (Figure 1) were converted into three-ply panels 12 inches square and 3/8-inch thick. Half the panels were made from veneer peeled cold and loose (10 lathe checks per inch averaging 0.09 inch deep) with a roller nosebar; the other half, from veneer peeled hot and tight (14 lathe checks per inch averaging 0.05 inch deep) with a fixed nosebar. In all, 576 panels were manufactured—72 from each tree.

The seven variables included:

1) Specific gravity, ovendry weight and green volume: either under 0.5 or over 0.5.

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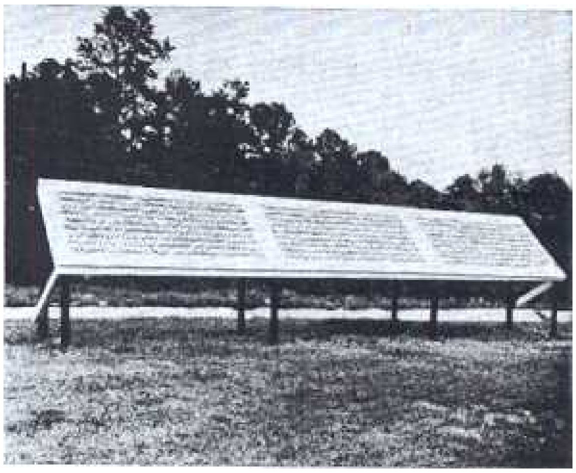

Figure 2. — South-facing, 45-degree exposure deck. Specimens (1,152 of them) are supported 3/4-inch from white deck on 1/8-inch, centered, brass machine screws. Location is Alexandria, Louisiana.

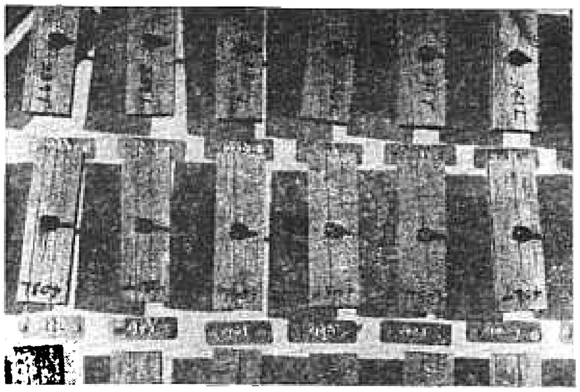

Figure 3. — Detail of 3/8- by 1- by 3-1/4-inch 3-ply specimens after 12 months of exposure. Most developed severe face checks.

2) Rings per inch: either less than 6 or more than 6.
3) Peel: either cut cold and loose or cut hot and tight.
4) Resin level: percent of resin solids in wet mixed adhesives, 26 or 21.
5) Secondary extension: wheat flour plus blood, wheat flour only, or no secondary extender.
6) Gluespread in pounds per 1,000 square feet of core (half on each side of core): 65 or 75.
7) Assembly time before hot pressing, minutes (before prepress, prepress, after prepress):

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

Fixed experimental conditions were:

Veneer thickness	0.130 inch
Veneer drying	19 minutes 24 seconds at approximately 300°F.
Moisture content of veneer before glue was spread	3 percent
Specific prepress pressure	150 p.s.i.
Panels per hot press opening	2
Time in hot press	6.5 minutes
Press temperature	285°F.
Specific pressure in hot press	175 p.s.i.

Procedures for tree selection, veneer manufacturing, panel assembly, glue mixing, glue spreading, assembly, and pressing are all described in the article cited (1).

Specimen Preparation

Two specimens, each measuring 1 inch wide by 3¼ inches long (parallel to the grain of face and back plys), were sawn from the central portion of each of the 576 panels and given exterior exposure (Figures 2 and 3). One of each pair of specimens was mounted with loose-to-loose glueline uppermost and the other with loose-to-tight line uppermost.

Time Factor

The exposure deck was put in place April 1, 1965. The first delamination evaluation was made 6 months later, and the final evaluation 1 year later. In effect, then, time was an eighth factor.

Evaluation of Delamination

On each specimen, delamination in both gluelines was measured after each time interval by sliding a ⅛-inch-wide, 0.006-inch-thick, rounded-end blade into the deteriorating glueline at sufficient points around the periphery to map the extent of the delamination on 1/10-inch grid paper. Areas were then summed and delamination was expressed as a percentage of each total glueline area. Actual probing of the 1,152 specimens required 3 weeks. This time was centered around each anniversary date.

Moisture Content

Just prior to glue spreading, the veneer averaged 3 percent moisture content. Moisture content of specimens at time of exposure was approximately 9 percent. During the year of exposure, selected specimens were weighed daily at noon. Figure 4 is a plot of moisture fluctuation over the year.

Results

Time

Rate of delamination appears to be linear with time (Figure 5). All conditions considered (576 panels, that is, 1,152 exposure specimens), delamination averaged 1.72 percent at 6 months and 3.30 percent at 12 months. Factor effects and interactions were so closely comparable for 6 and 12 months of exposure that there is little to be gained by considering them separately. Therefore, this discussion is largely on the 12-months' results.

Gluelines nearest the sun did not delaminate significantly more than those on the shady side; all specimens considered:

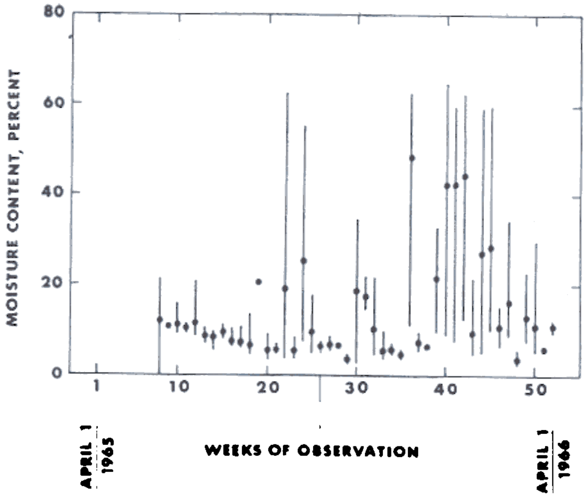

Figure 4. — Noontime moisture content of exposure specimens, plotted by week. Range during each 5-day work week is indicated by the vertical line and weekly average by the point.

Exposure	*Time on fence*	
	6 months	*12 months*
	Percent	Percent
Sunny	2.00	3.62
Shady	1.45	2.99

It may be recalled from the article cited (1) that 78 percent of the failures in wet shear specimens occurred in the loose-to-loose interface, as compared to 22 percent at the loose-to-tight interface. Surprisingly, loose-to-loose gluelines on these 1,152 exposure specimens (matched to the early experiment) did not delaminate significantly more than the loose-to-tight gluelines:

Glueline	*Time on fence*	
	6 months	*12 months*
	Percent	Percent
Loose-to-loose	1.82	3.32
Loose-to-tight	1.62	3.28

By analysis of variance, the percentage of delamination differed significantly with changes in the level of each primary variable except growth rate and type of peel (Table 1). Five of the seven variables (the exceptions were again growth rate and peel) proved significant at the 0.005 level in one or more first-order interactions (Table 2); interactions of higher order were not significant at this level.

Specific Gravity

In variance analysis, wood with specific gravity above 0.5 showed greater delamination (5.12 percent) than did less dense wood (1.48 percent). A linear regression relation (positive) of delamination to specific gravity provided a more sensitive evaluation than variance analysis and, although only accounting for 7 percent of the variation, proved significant at the 0.05 level (Figure 6). When these data are separated according to peel (Figure 7), it can be observed that dense wood will delaminate more rapidly if peeled loose than if peeled tight.

The interaction between specific gravity and assembly time (Table 2) revealed that a short assembly time is necessary with wood of high specific gravity if delamination is to be minimized in this most-difficult-to-glue wood.

The significant (***)[2] interaction between specific gravity and gluespread indicated the necessity of a 75-pound spread (compared to 65-pound) for dense wood.

These data support and expand Northcott's observations (5) that dense wood degrades bonds in service faster than does wood of low density.

Rings per Inch

By analysis of variance, growth rate as measured by rings per inch was not related to delamination, nor did it interact with any other primary factor (Table 1). Regression analysis also failed to find a significant (*) relationship.

Peel

By analysis of variance, type of peel was not related to wood failure, nor did peel interact with any other primary factor (Table 1). Figure 8 reveals a very weak, but significant (*), positive regression relationship between delamination and depth of lathe checks in the core. Since the relationship accounts for only 1 percent of the variation in delamination, it is of questionable practical importance. Check frequency showed no regression relationship to delamination. From these data, it cannot be concluded that rate of delamination was significantly affected by peel. Figure 7 does, however, suggest that for a given high specific gravity, tight-peeled wood will delaminate at a slower rate than loose peeled.

Resin Solids in Wet Mix

The effect of the percentage of resin solids was revealed in the interaction with type of secondary extender (Table 2). Thus gluelines with

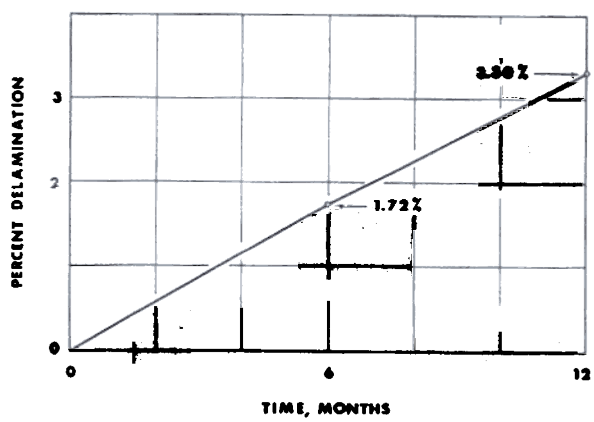

Figure 5. — Near-linear relationship between percent of delamination and time during first year of exposure. Each of the 3 points plotted is an average of 2,304 gluelines; that is, all factors were ignored except time.

[2]Note: *indicates significance at the 0.05 level, ** at the 0.01 level, and *** at the 0.005 level.

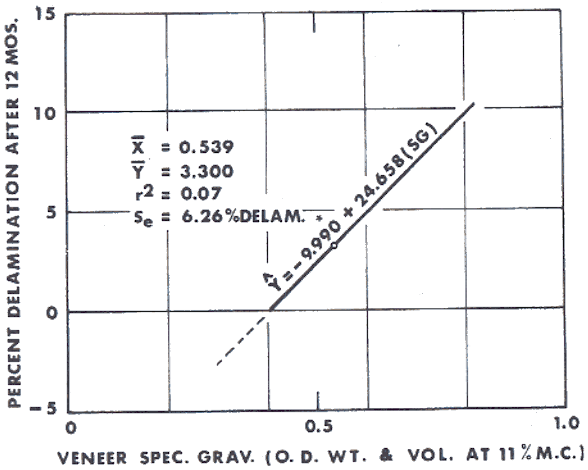

Figure 6. — Specific gravity (average of the three 1/8-inch-thick plys — no glue) relative to delamination. The tabulated $\bar{x}$ of 0.54, based on 1,152 specimens, compares to the average 0.50-specific-gravity value for the wood prior to peeling (green volume and ovendry weight). Curve defined by 2,304 gluelines.

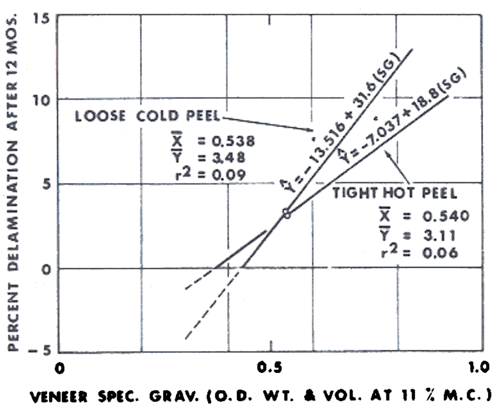

Figure 7. — Effect of peel on specific gravity (average of the three plys—no glue) relative to delamination. Each curve is defined by 1,152 gluelines.

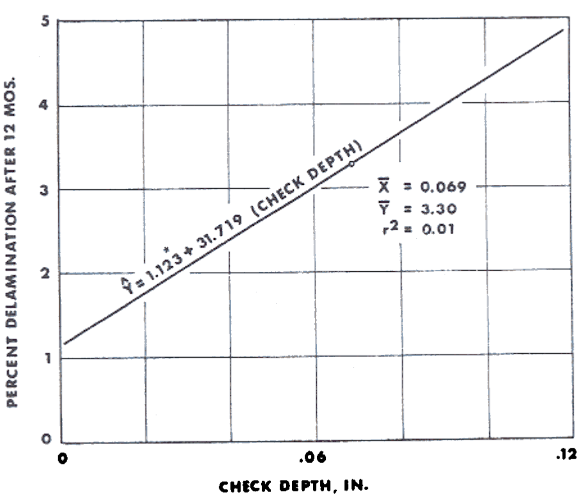

Figure 8. — Significant (*) but weak relation ($r^2 = 0.01$) of lathe check depth in core to delamination. Curve defined by 2,304 gluelines.

the optimum secondary extender (wheat flour only) suffered significantly less delamination with 26 percent resin solids (1.75 percent) than with 21 percent (3.15 percent). For reasons not understood, the poorest secondary extender (wheat flour plus blood) performed better with 21 percent resin solids than with 26 percent.

Secondary Extension

There was a significant (***) difference between secondary extenders (Table 1). Wheat flour only was best (2.45-percent delamination); no secondary extender, next best (2.85 percent), and wheat flour plus blood poorest (4.60 percent).

Gluespreads

As Table 1 indicates, a gluespread of 75 pounds was significantly (***) better (1.89 percent delamination) than 65 pounds (4.71 percent). The interaction between spread and assembly time (Table 2) indicates that a short assembly time is desirable at both spread levels, but is particularly important with a 65-pound spread. The interaction between specific gravity and spread (Table 2) has been previously discussed, namely, dense wood particularly requires the heavier spread.

Assembly Time

As shown in Table 1, the 13-minute time was best (1.14 percent delamination); 24 minutes, next best (3.34 percent); and 32 minutes, poorest (5.42 percent). The interaction (Table 2) indicates that a low gluespread requires the shortest assembly time.

Optimum Conditions to Minimize Delamination

Wood of low specific gravity delaminates less rapidly than wood of high specific gravity. In industry, wood of all specific gravities must be used. With the full range of density, delamination after 12 months was minimized (0.68 percent) when plywood was fabricated with the following: wheat flour only as a secondary extender, 26 percent resin solids in the wet mix, 13-minute assembly time, and 75 pounds of glue per 1,000 square feet of core.

Table 3 compares this set of conditions with the next best condition, which was identical except that no secondary extender was used. Wheat flour appeared to make the adhesive more effective on dense wood and, at the same time, gave the gluebond in dense wood more tolerance to long assembly time (at 32 minutes: 2.93 percent delamination as compared to 5.34 percent with no secondary extender). For reasons not clear, the 65-pound spread showed up surprisingly well in these 8-panel averages.

Predictors of Delamination in Service

The parameters listed below were analyzed by regression technique to evaluate them as indicators of delamination.

1) % WF

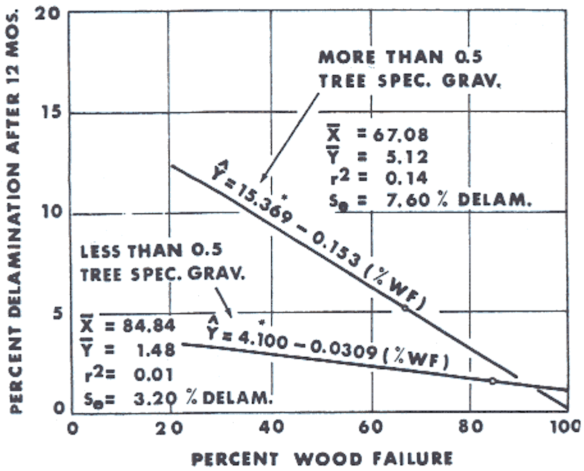

Figure 9. — Effect of specific gravity on percent of wood failure relative to delamination. Each curve is defined by 1,152 gluelines (576 specimens). The dense wood had a specific gravity (green volume and ovendry weight) prior to peeling of 0.55 and a veneer gravity (volume at 11-percent moisture content and ovendry weight) of 0.59. Comparable values for the less dense wood were 0.45 and 0.48. For pooled data, delamination averaged 3.30; % WF averaged 75.96 and accounted for 17 percent of the variation in delamination.

2) Specific gravity (volume of veneer at 11-percent moisture content and ovendry weight —no adhesive)
3) Lathe check depth, inch
4) Lathe check frequency, checks per inch
5) Wet rolling-shear strength, p.s.i.
6) Compressive strength of the face and back plies parallel to the grain, p.s.i.
7) Modulus of elasticity in compression parallel to grain of face and back plies, p.s.i.
8) Dry rolling-shear strength, p.s.i.

The 6-month and 12-month data were so similar that only the latter will be discussed. At the 0.05 level, 3 parameters were significant in 1-factor simple straight-line regressions:

% WF	$r = -.41$ (Figures 9 and 10)
Specific gravity	$r = +.27$ (Figures 6 and 7)
Check depth	$r = +.12$ (Figure 8)

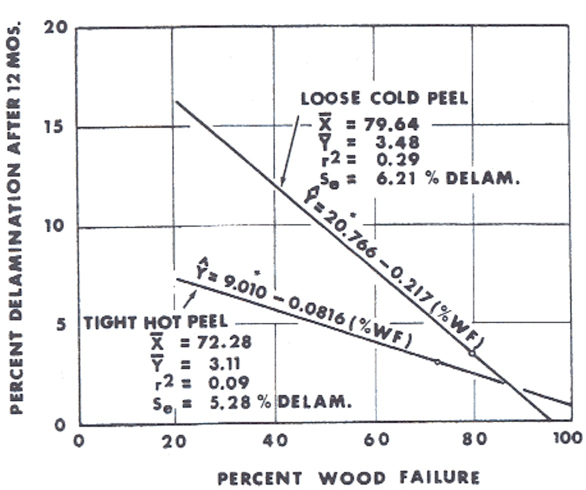

Figure 10. — Effect of peel on wood failure relative to delamination. Each curve is defined by 1,152 gluelines. For pooled data, delamination averaged 3.30; % WF averaged 75.96 and accounted for 17 percent of the variation.

Table 1. — EFFECT OF PRIMARY VARIABLES ON PERCENTAGE OF DELAMINATION IN EXTERIOR EXPOSURE.[1]

Factor	Duration of exposure 6 months	12 months
	Percent	Percent
Replication[2]		
Trees 12, 25, K4-4, 17	1.16	2.64
Trees 13, 10, K12-2, 4	2.29	3.96
Tree specific gravity[3, 4]	Signif. at 0.10 level	
Under 0.5 (12, 13, 10, 25)	0.52	1.48
Over 0.5 (K4-4, K12-2, 4, 17)	2.93	5.12
Rings per inch[3]	N.S.	N.S.
Less than 6 (12, 13, K4-4, K12-2)	2.27	4.19
More than 6 (10, 25, 17, 4)	1.18	2.41
Peel[3]	N.S.	N.S.
Cold-loose	2.03	3.48
Hot-tight	1.42	3.11
Resin solids in wet mix	(See T ble 2)	
26 percent	1.80	3.42
21 percent	1.65	3.18
Secondary extension	***	***
Wheat flour plus blood	2.51	4.60
Wheat flour only	1.17	2.45
None	1.49	2.85
Gluespread (pounds per 1,000 square feet of core)	***	***
65	2.58	4.71
75	0.87	1.89
Assembly time, minutes[5]	***	***
5 + 5 + 3 = 13	0.50	1.14
16 + 5 + 3 = 24	1.63	3.34
14 + 5 + 13 = 32	3.04	5.42
Significant interactions[6]		
(Gluespread) (Assembly time)		***
(Specific gravity) (Assembly time)		***
(Specific gravity) (Gluespread)		***
(Resin solids) (Secondary extension)		8
Average delamination	1.72	3.30

[1]Averages include data on all panels; the only segregation is by the factors in Column 1.

[2]Dummy factor.

[3]The design of the analysis of variance was such that the 0.10 level was accepted as a test for this factor. All other factors and interactions were tested at the 0.005 level (***).

[4]Specific gravity of peelable portion of each tree (oven-dry weight and green volume).

[5]First figure is assembly time after spreading and before prepress. A 5-minute prepress time was common to all. The third figure is assembly time after prepress and before hot press.

[6]Only these interactions proved significant at accepted levels. See Table 2 for cell averages.

[7]Calculated F value for this cell was 5.05, compared to a tabular value of 5.50 for significance at the 0.005 level.

[8]Calculated F value for this cell was 4.27, compared to a tabular value of 5.50 for significance at the 0.005 level.

Table 2. — PERCENTAGE OF DELAMINATION: SIGNIFICANT TWO-FACTOR INTERACTIONS[1].

Gluespread	Gluespread x Assembly Time: 13 minutes	24 minutes	32 minutes
65 pound	1.64	4.48	8.02
75 pound	0.65	2.19	2.81

Specific gravity	Specific Gravity x Assembly Time: 13 minutes	24 minutes	32 minutes
Less than 0.5	0.64	1.51	2.29
More than 0.5	1.65	5.17	8.55

Specific gravity	Specific Gravity x Gluespread: 65 pounds	75 pounds
Less than 0.5	2.12	0.84
More than 0.5	7.31	2.93

Resin solids	Resin Solids x Secondary Extension: Wheat plus blood	Wheat	None
26%	5.75	1.75	2.75
21%	3.44	3.15	2.94

[1]All interactions listed considered significant at 0.005 level by analysis of variance.

Although % WF was, indeed, the best available indicator of delamination in service, it can hardly be classed as a predictor inasmuch as it accounted for only 17 percent of the variation.

A study of the regression lines in figures 9 and 10 reveals that, if plywood is to be held to a given rate of delamination, dense veneer must be bonded to yield a higher % WF than veneer of low specific gravity; and loose-peeled veneer must be bonded to yield a higher % WF than tight-peeled. In practice, the first of these conditions is virtually impossible to achieve, while the second is usually attained as a matter of course (1).

In multiple-regression analysis, 4 parameters were significant (*) in stepwise combination and accounted for a total of 22 percent of the variation:

Parameter	*Stepwise and cumulative r^2*	
% WF	(−)	0.17
Wet rolling-shear strength	(−)	0.19
Specific gravity	(+)	0.21
Compression strength parallel to grain	(−)	0.22

Thus, % delamination (D):

$$D = 10.673 - 0.129\ (\%\ WF) - 0.0189\ (\text{wet shear strength}) + 18.920\ (\text{specific gravity}) - 0.000440\ (\text{compressive strength})$$

When only % WF, wet rolling-shear strength, and check depth were considered (two of these parameters are significant as single factors, all can be easily measured, and all are to some extent controllable), only the first two were significant by stepwise criteria. In combination they accounted for 19 percent of the variation to yield the following equation:

Table 3. — DELAMINATION UNDER OPTIMUM AND NEAR-OPTIMUM GLUING CONDITIONS[1,2] AFTER 12 MONTHS OF EXTERIOR EXPOSURE.

Departure from stated best and next best gluing conditions	Best conditions[3]: Density under 0.5	Best conditions: Density over 0.5	Best conditions: Average Density	Next best conditions[4]: Density under 0.5	Next best conditions: Density over 0.5	Next best conditions: Average density
(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Percent	Percent	Percent	Percent	Percent	Percent
Optimum—No departure	0.37	0.99	0.68	0.00	1.30	0.65
Resin level dropped from 26 to 21 percent solids in wet mix	.56	1.26	.91	.53	.91	.72
Gluespread lowered from 75 to 65 pounds per 1,000 square feet of core (other conditions optimum)	.12	.96	.54	1.01	.82	.92
Assembly time lengthened (other conditions optimum) from 13 minutes to 24 minutes	.37	2.61	1.49	.80	1.18	.99
32 minutes	1.29	2.93	2.11	1.01	5.34	3.18

[1]Each tabulated value in Columns 2, 3, 5, and 6 is an average for 8 panels (namely, 16 exposure specimens). Therefore, values in Columns 4 and 7 are averages for 16 panels (32 exposure specimens). Densities are for peelable portion of each tree (ovendry weight and green volume).

[2]For precise glue formulation see Table 1 of article cited (1).

[3]Wheat flour only as a secondary extender, 26-percent resin solids in wet mix, 13-minute assembly time, and 75 pounds of gluespread per 1,000 square feet of core.

[4]Same as conditions described in footnote 3, except no secondary extender used.

$$D = 19.024 - 0.149\ (\%\ WF) - 0.0195\ (\text{wet shear strength})$$

In a practical sense, this two-factor equation is not a great improvement over % WF alone (Figure 9).

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Abstract

This paper explores the interacting effects of wood specific gravity, rate of growth, tightness of peel, resin content of glue, type of secondary extender, gluespread, and assembly time on delamination of southern pine plywood. The plywood was made from eight loblolly pine trees selected to exhibit a range of specific gravity and growth rate.

Three-eights-inch 3-ply specimens (1 by 3-1/4 inches) were exposed outdoors for 1 year at Alexandria, Louisiana. For samples of all specific gravities combined, delamination was minimized at 0.68 percent in gluelines made by: (1) using wheat flour as the secondary extender (as contrasted with no secondary extender or with blood-plus-wheat flour extender); (2) increasing percent of phenolic resin solids in the wet glue mix to 26 percent (the lower level considered was 21 percent); (3) reducing assembly time to 13 minutes (other times considered were 24 and 32 minutes); and (4) increasing gluespread to 75 pounds per 1,000 square feet of core (as contrasted to 65 pounds).

Delamination occurred at a rate nearly linear with time, i.e., percent of delamination at 12 months was almost twice that at 6 months.

Plywood of high specific gravity delaminated 3 to 4 times more rapidly than samples of low density. The shortest assembly time (13 minutes), and heaviest gluespread (75 pounds) were necessary to minimize delamination in dense plywood. Among samples equal in percent of wood failure (as tested in thoroughly wetted shear specimens), high-density pieces delaminated faster than low-density pieces.

By regression analysis, dense wood appeared to delaminate less if peeled tight than if peeled loose; the less sensitive variance analysis did not support this conclusion. For wood of low or average density, peel had no effect on delamination. For all densities, loose-peeled veneer typically displayed higher percent of wood failure than wood peeled tight—and required this higher percent for equal durability.

Loose-to-loose bonds delaminated no faster than loose-to-tight bonds. The glueline nearest the sunny side of the specimens delaminated no faster than the line nearest the shady side.

While percent of wood failure proved to be the best single indicator of eight possible predictors analyzed, it accounted for only 17 percent of the variation in delamination, and hence could not be called good in this experiment. The best multiple regression accounted for only 22 percent of the variation. In order of importance the significant factors were: percent wood failure (−), wet rolling-shear strength (−), strength gravity (+), and compression strength parallel to grain (−).