

An acid-catalyzed phenolic adhesive for radiofrequency laminating of hardwood composite framing

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Abstract

An acid-catalyzed phenolic resin, which is used in the foundry industry to bond sand into shell moldings and cores for metal castings, developed strong and highly durable bonds between hardwood veneer and flakeboard core edges in composite framing lumber. The acid-phenolic is a lower-cost and viable alternative to other thermosetting adhesives commonly used for radio-frequency laminating of wood products. Wood species, moisture content (MC), resin molecular weight, adhesive spread rate, and closed assembly time all strongly interacted and significantly impacted adhesive bond integrity. Controlling the mobility of the phenolic adhesive to prevent overpenetration of the porous edges of the flakeboard core, while maintaining adequate penetration of the veneer surface, was of critical importance when using radio-frequency heating to produce bonds of high integrity. Of the 72 combinations of material and assembly factors tested, all but a few property values far exceeded the minimum performance requirements proposed for the new composite. From the standpoint of achieving high bond integrity, practicable operating conditions, and low costs, sweetgum or yellow-poplar dried to 4-1/2 percent MC could be effectively bonded with the high-molecular-weight resin at closed assembly times between 5 and 15 minutes, even at spread rates as low as 50 lb./Mft.²

For several years, the USDA Forest Service has been researching new ways to stretch the timber supply through more efficient utilization of existing wood resources. This effort has led to the development of a new building material called composite framing, which can be made from underutilized low-cost hardwoods. The composite is a sandwich construction, with strips of parallel-laminated veneer bonded to both edges of an oriented flakeboard core. It is manufactured to the same cross-sectional dimensions as conventional framing lumber but can be made to any length. Composite framing is an engineered product designed for structural applications such as wall studs, floor joists, and truss lum-

ber. The new building material was developed through the cooperative efforts of the Forest Service, the U.S. Department of Housing and Urban Development, and leading manufacturers of wood products.

One of the important tasks in the research program was to investigate new and existing adhesives and bonding techniques for laminating the veneer strips to the edges of flakeboard cores in the composite framing. These adhesives needed to be strong, rigid, and durable enough so the composite could support structural loads of long duration in occasionally severe service conditions. Other requirements were that the adhesive had to be curable with radio-frequency (RF) generated heat and be lower in cost than the commercial adhesives normally used for RF laminating. An acid-catalyzed phenolic (APF) molding resin, which had not been used as an adhesive for wood products, had potential for meeting all of these requirements.

An acid catalyst is used to accelerate the cure of the phenolic resin. It is well known that strong acids readily hydrolyze cellulose and cause the wood to lose strength. The rate at which hydrolysis occurs depends on the nature of the hydrolyzing acid and its concentration, the temperature of reaction, and the amount of moisture available for the reaction. Earlier accelerated-aging tests of APF adhesive bonds to wood have confirmed these operatives, but tests have also indicated that wood species vary considerably in their susceptibility to acid hydrolysis (5). Generally, important requisites for resistance of wood to acid attack are high α -cellulose, high apparent lignin, and low pentosan contents (3). Accelerated moist-heat aging tests have indicated that the APF adhesive develops highly durable bonds equivalent to phenol-resorcinol-formaldehyde (PRF) on southern pines and Douglas-fir. Red oak was much more susceptible to

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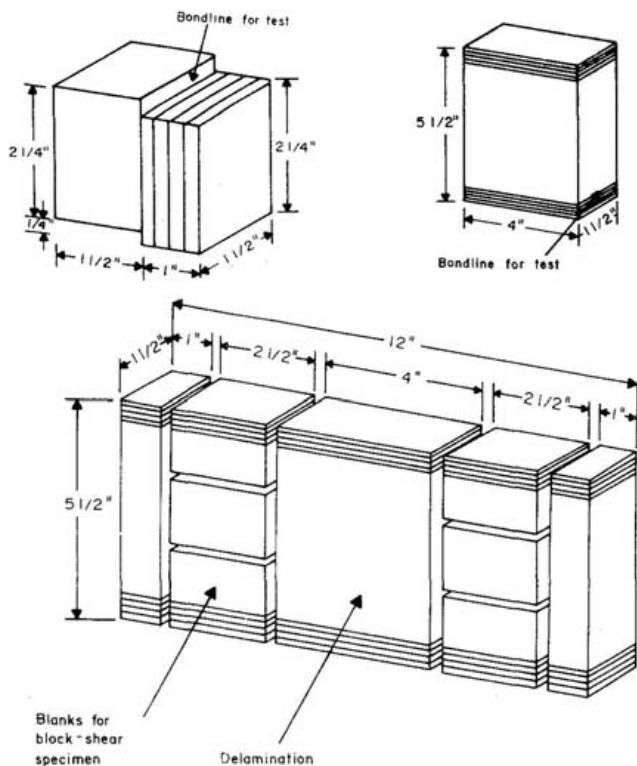


Figure 1. - Configuration and dimensions of block-shear specimen (upper left), cross section for delamination test (upper right), and locations for cutting specimens from a composite assembly (lower).

acid attack (5). After 3 years of both direct and sheltered outdoor exposure and 800 cycles of an automatic boil-dry test, the APF performed as well as the PRF adhesive in Douglas-fir joints (6).

The purpose of this study was to determine the working properties, strength, and durability of the APF molding resin when it was used to bond yellow-poplar and sweetgum veneer laminates to the edges of hardwood flakeboard cores (a mixture of both species) using RF heat for curing. Factors studied that were expected to affect those properties included veneer species (SP), veneer and flakeboard moisture content (MC), resin molecular weight (MW), adhesive spread rate (SR), and closed assembly time (CAT).

Materials

Adhesive

The APF was a single-stage, phenolic molding resin, identified as PLENCO 10634 and manufactured by Plastics Engineering Company¹ of Sheboygan, Wis. It contained about 80 percent solids, 7 percent of which was urea resin solids. The resin cured on addition of an aqueous ammonium nitrate catalyst (PLENCO 12203) and heat. Two phenolic resins of differing MWs were tested. One had a weight-averaged MW of 3,967 and the other was 6,404, as determined by gel permeation chromatography.

¹ The use of trade or firm names in this publication is for reader information and does not imply endorsement by the USDA of any product or service.

Twenty parts per hundred (pph) of catalyst was added to 100 pph of resin. To the mixture containing the low MW resin, 20 pph of a 50:50 blend of 200-mesh birch wood flour and walnut shell flour was added. Only 18 pph of the filler blend was added to the high-MW resin, because less filler was needed to make the viscosities of both adhesive mixtures approximately equal.

Veneer laminates

Veneer laminates for sections of 2-by 6-inch composite framing were prepared with 1/4-inch-thick, rotary-cut, yellow-poplar and sweetgum veneers. Three plies of veneer, all of the same species, were parallel laminated so that open lathe checks in the veneer faced toward the core. A PRF adhesive was used to laminate the veneers. The laminates were cut 1-1/2 inches wide and 12 inches long. Laminates within each species were randomly divided into two equal-size groups. One group was conditioned to 2-1/2 percent MC and the other to 4-1/2 percent MC. Veneer laminate surfaces were not planed before bonding to core edges.

Flakeboard cores

Flakeboard cores were made from a homogeneous, electrostatically oriented flakeboard containing 6 percent phenolic binder. Flakeboard density averaged 42 lb./Mft.² and ranged from 37 to 46 lb./Mft.² The flakes were yellow-poplar and sweetgum mixed in equal proportions by weight. The drum-cut flakes were in sizes large enough to be retained on a 1/16-inch-mesh screen. It was necessary that cores be 1-1/2 inches thick, so two 3/4-inch-thick flakeboards were laminated together with a PRF adhesive. The laminates were cut into 4-inch-wide by 12-inch-long sections. These were randomly divided into two equal-size groups, which were dried to an average MC of either 2-1/2 or 4-1/2 percent.

Methods

Experimental design

This experiment was a completely randomized design with factorial arrangement of the 2 x 2 x 2 x 3 x 3 levels of experimental factors into 72 treatment combinations. Each observation of each of the five physical properties was replicated four times within a single treatment combination.

Experimental factors	Levels of factors
Veneer species	Sweet gum Yellow-poplar
Moisture content	2-1/2 percent 4-1/2 percent
Resin molecular weight	Low (3,967 MW) Hi h (6,404 MW)
Adhesive spread rate	50 lb./Mft. ² 65 lb./Mft. ² 80 lb./Mft. ²
Closed assembly time	5 minutes 10 minutes 15 minutes

The effects of treatment combinations were determined from measurements of shear strength and wood failure in the dry and water-saturated conditions, and resistance to delamination after two cycles of vacuum-pressure soaking in water and drying (VPSD). Analyses of variance (ANOVA) were conducted for each of the five properties to determine which experimental factors and

TABLE 1. - Results of ANOVA showing levels of significance of experimental factors and their interactions on strength and durability of bonds.

Sources of variation	Degrees of freedom	Dry shear strength	Dry wood failure	Wet shear strength	Wet wood failure	Delamination
Species (SP)	1	--	*	--	*	**
Moisture content (MC)	1	*	--	*	--	--
Molecular weight (MW)	1	--	--	***	***	***
Spread rate (SR)	2	--	--	***	***	***
Closed assembly time (CAT)	2	**	*	--	***	***
SP × MC	1	**	--	--	--	--
SP × MW	1	--	--	--	--	--
SP × SR	2	--	--	*	--	--
SP × CAT	2	--	--	***	--	--
MC × MW	1	***	--	--	**	**
MC × SR	2	--	--	--	--	--
MC × CAT	2	--	*	--	--	--
MW × SR	2	--	--	**	***	***
MW × CAT	2	--	--	--	***	***
SR × CAT	4	--	--	*	***	***
SP × MC × MW	1	*	--	--	--	--
SP × MC × SR	2	--	--	--	--	--
SP × MC × CAT	2	--	--	--	--	--
SP × MW × SR	2	--	--	**	--	--
SP × MW × CAT	2	*	--	--	--	--
SP × SR × CAT	4	--	--	--	--	--
MC × MW × SR	2	*	--	**	--	*
MC × MW × CAT	2	--	--	--	--	--
MC × SR × CAT	4	--	--	***	--	--
MW × SR × CAT	4	--	--	--	--	--
SP × MC × MW × SR	2	--	--	--	--	*
SP × MC × MW × CAT	2	--	--	--	--	--
SP × MC × SR × CAT	4	--	--	--	--	--
MC × MW × SR × CAT	4	*	--	*	--	**
SP × MC × MW × SR × CAT	4	--	--	--	--	--
Error	216					
Total	287					

** indicates significance at the 0.05 level of probability; ** indicates significance at the 0.01 level of probability; *** indicates significance at the 0.001 level of probability.

interactions were significant. Any significant factor was further analyzed by Duncan's new multiple-range test to determine which levels of treatment were different from each other within that factor. Significant interactions were subanalyzed.

Specimens

Block-shear specimens (Fig. 1) were used to test bond shear strength and wood failure in both dry and water-soaked conditions. Resistance to delamination after two cycles of VPSD treatment was tested on cross sections of composite framing (Fig. 1). Two block-shear specimens and one delamination specimen were cut from each test bondline.

Specimen preparation

Test joint assemblies were prepared by bonding one 3-ply veneer laminate of yellow-poplar and one 3-ply laminate of sweetgum (each 1-1/2 in. wide by 12 in. long) to each edge of a 1-1/2-inch-thick flakeboard core (also 12 in. long). Adhesive was spread only on the veneer surface. It was applied with a roller at prescribed spread rates for each treatment combination. The accuracy of the spread was controlled by automatically weighing the adhesive as it was spread on the bonding surface. Adhesive-spread veneer laminates and cores were assembled and held together without pressure for prescribed closed assembly times.

The adhesive was cured with a Mann-Russell, Model 200, 13kVA RF generator operating at 27.12 MHz. Test joint assemblies were placed between the two electrodes so that the electric current of the RF field flowed parallel to the plane of the bondline (called parallel heating).

Pressure at 175 psi was applied to the joints while curing. A plate current of 1.0 A with 4.5-kW RF output was applied for 1 minute. The resin boiled immediately on application of power and stopped about 20 to 25 seconds later. Further study will be needed to determine the most efficient time, temperature, and power density requirements for curing the adhesive.

After bonding, test assemblies were cut into specimens as shown in Figure 1. Before testing for dry shear strength, specimens laminated at 2-112 and 4-112 percent MC were conditioned to approximately 6 percent MC.

Specimen testing

Tests for strength and wood failure in dry and water-soaked conditions were conducted according to the glue-line shear test in ASTM D 1037-78(2), except that the dimensions of the specimen were changed as shown in Figure 1 and the rate of loading was increased from 0.024 to 0.10 inch per minute.

Block-shear specimens were saturated by submerging them in tap water in a pressure vessel. A vacuum of 25 inches of mercury was drawn and held for 30 minutes. Afterward, a pressure of 75 ± 2 psi was applied for 2 hours. Specimens were tested immediately after the vacuum-pressure soaking (VPS) procedure.

Delamination specimens were subjected to the AITC Test T-110, Cyclic Delamination Test (1). This procedure was extremely severe and essentially consisted of repeating two cycles of VPS, as described in the previous paragraph, with each cycle followed by 10 to 15 hours of air-drying at 160°F. Delamination was measured in the test bondline across the 1-1/2-inch width at both ends of the

TABLE 2. - Effect of experimental factors on strength and durability of bonds.

Experimental factors	Dry shear strength	Dry wood failure	Wet shear strength	Wet wood failure	Delamination
	(psi)	(%)	(psi)	(%)	(%)
Species					
Sweetgum	1,289 A ^a	98 A	684 A	96 A	2.1 A
Yellow-poplar	1,324 A	96 B	701 A	95 B	3.4 B
Moisture content					
2-1/2%	1,327 A	97 A	681 A	96 A	2.9 A
4-1/2%	1,286 B	98 A	705 B	95 A	2.5 A
Molecular weight					
High	1,289 A	98 A	711 A	98 A	1.4 A
Low	1,324 A	97 A	675 B	93 B	4.0 B
Spread rate					
50 lb./Mft. ²	1,242 A	97 A	630 A	93 A	4.7 A
65 lb./Mft. ²	1,304 B	97 A	697 A	95 B	2.1 B
80 lb./Mft. ²	1,374 C	98 A	752 C	98 C	1.3 B
Closed assembly time					
5 min.	1,307 AB	96 A	690 A	91 A	4.7 A
10 min.	1,343 A	99 B	697 A	97 B	2.2 B
15 min.	1,270 B	97 AB	691 A	98 B	1.2 B

^a In comparisons of treatment means within a given property, means followed by the same capital letter are not significantly different at the 0.05 level of probability. Only means of levels of each experimental factor within each property are statistically compared. Statistical comparisons of treatment means are confirmed by the arc sine transformation in percentages of dry and wet wood failure, and by the square root transformation in percentage of delamination.

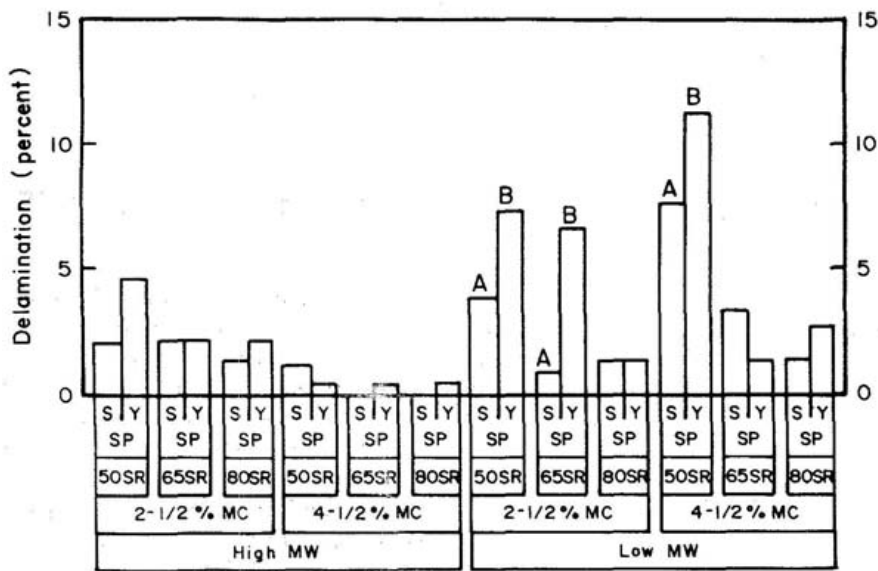


Figure 2. - Interaction of species (SP) (S = sweetgum; Y = yellow-poplar) with spread rate (SR), moisture content (MC), and molecular weight (MW), as it affects delamination. (Pairs of species means with different capital letters are significantly different at the 0.05 level of probability.)

composite section. The total length of delaminations on both ends, divided by the total length of endjoints (about 3 in.), constituted the measure of delamination.

Results and discussion

The APF adhesive developed excellent bonds between veneer laminates and the edges of flakeboard cores. With a few exceptions, which will be discussed later, average property values for all combinations of assembly factors far exceeded the proposed minimum performance requirements (4). The results of ANOVA are shown in Table 1 where the levels of significance of experimental factors (assembly conditions) and their interactions are indicated for each of the five physical properties. Average overall property values at each level of experimental factors are shown and compared statistically in Table 2, primarily to give the reader an appreciation of the property values that could be achieved with the APF adhesive.

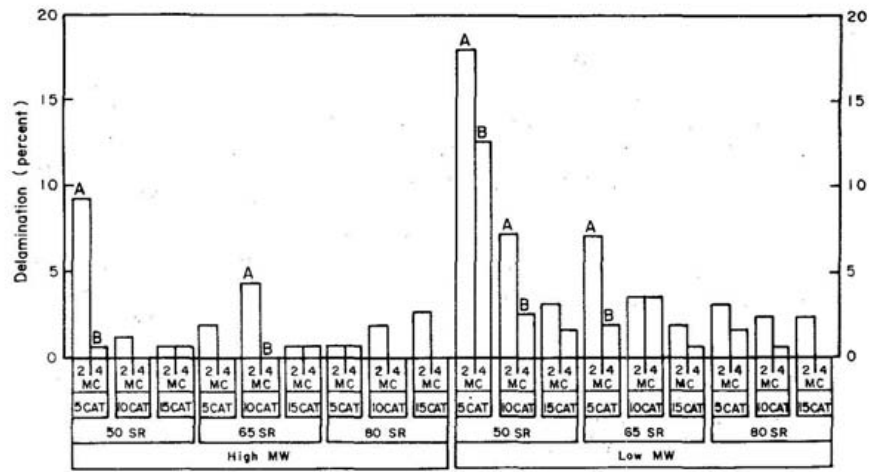
Most experimental factors proved to be significant main effects, but all were involved in significant four-

factor and lower-order interactions. Interacting experimental factors must be understood in terms of their interdependence before conclusions can be drawn about their contributions to individual property values.

Species

Species was a significant main factor affecting resistance to delamination, and it was involved in the significant four-factor interaction SP x MC x MW x SR (Tables 1 and 2). A sharp decrease in resistance to delamination occurred at certain combinations of these factors. Delamination was the only property significantly impacted, but because it is critical to evaluating the long-term durability of the product, its discussion is important. The four-factor interaction is graphed in Figure 2. Yellow-poplar had significantly higher delamination than sweetgum at the 50 lb./Mft.² SR with MC at 2-112 and 4-112 percent when MW was low. Delamination of yellow-poplar was also significantly higher at 65 lb./Mft.² with MC at 2-112 percent when MW was low. Note that delamination greater than 5 percent did not occur with

Figure 3. - Interaction of moisture content (MC) with closed assembly time (CAT), spread rate (SR), and molecular weight (MW), as it affects delamination. (Pairs of MC means with different capital letters are significantly different at the 0.05 level of probability.)



the high-MW resin. Delamination must be less than 10 percent in composite framing (4). According to these results, delamination well below 5 percent was possible on both yellow-poplar and sweetgum at the lowest cost 50 lb./Mft.² SR as long as the high-MW resin was applied to wood at 4-1/2 percent MC.

Species was not a significant main effect on wet shear strength, but it was involved in the three-factor interaction SP x MW x SR and two two-factor interactions with SR and CAT (Table 1). On further study of these interactions, it was evident that the two species were producing significant differences, but the differences between species were too inconsistent from one treatment level to the next to establish any important trend for either species: Furthermore, the interactions were not corroborated by any of the other five tests, and strength reductions were not of sufficient magnitude to warrant further consideration.

Species was a significant main effect on wet and dry wood failure; however, species was not involved in significant interactions. Table 2 shows average wet wood failure of sweetgum was 96 percent, which was significantly higher than the 95 percent of yellow-poplar. Dry wood failure of sweetgum was 98 percent, which was significantly higher than the 96 percent of yellow-poplar. While these differences between species are statistically significant, differences are so small and the averages themselves are so very high, no practical significance can be given to these species differences.

Moisture content

MC was not a significant main effect in the test of resistance to delamination, which was the most rigorous of the five tests, but it was strongly involved in the important four-factor interaction MC x MW x SR x CAT (Table 1). The graph of the interaction (Fig. 3) clearly shows that, in most instances, the 4-1/2 percent MC produced greater resistance to delamination than the 2-1/2 percent MC. Only one treatment combination at 4-1/2 percent MC showed delamination greater than the unacceptable 10 percent (4). That occurred with the low-MW resin at the 50 lb./Mft.² SR after 5 minutes CAT. However, at this same lowest cost SR, delamination can be held well below 5 percent by applying the high-MW resin to wood at 4-1/2 percent MC.

TABLE 3. - Interaction of molecular weight with spread rate as it affects wet shear strength, wet wood failure, and delamination.

Spread rate (lb./Mft. ²)	Molecular weight	Wet shear strength (psi)	Wet wood failure (%)	Delamination (%)
50	High	669 A ^a	97 A	2.0 A
	Low	591 B	88 B	7.5 B
65	High	714 A	99 A	1.2 A
	Low	680 B	92 B	3.0 B
80	High	750 A	99 A	0.9 A
	Low	754 A	98 A	1.7 A

^aIn comparisons of treatment means within a given property, means followed by the same capital letter are not significantly different at the 0.05 level of probability. Only means of the two molecular weights at each spread rate are statistically compared.

Control of MC level of the wood was of critical importance in controlling the mobility of the aqueous phenolic adhesive. The greater amount of water, though only slightly so, available from the higher 4-112 percent MC wood increased the wood's affinity (water-to-water attraction) for the aqueous resin system. As a result, wetting and penetration of the wood's surface, particularly the veneer surface, was more complete than with the 2-112 percent MC wood.

When the interaction in Figure 3 was replotted (not shown) to compare the effects of MC levels on wet shear strength, the results were less consistent but generally supported the findings from the tests of delamination. Of the seven comparisons where significant differences were found, five showed 4-1/2 percent MC produced significantly higher wet strength than 2-1/2 percent MC.

This same four-factor interaction was significant in the test of dry shear strength. When comparisons were made to show MC effects, the results were contradictory to the findings from the delamination and wet shear tests we just discussed; however, the wet-tested properties were by far the more reliable measures of bond integrity.

As can be seen from Table 1, MC was a factor in several other three- and two-factor interactions that affected several properties. In each interaction, from fourth-order on down, it was repetitively clear that most favorable results occurred when the wood MC was 4-1/2 percent rather than 2-112 percent, and resin MW was high.

Molecular weight

Table 1 shows that MW was a significant main effect and was involved in several four-, three-, and two-factor interactions that affected the three most important wet-tested properties. The high-MW resin produced significantly higher wet shear strength, wet wood failure, and greater resistance to delamination (Table 2). The graph of the interaction MC x MW x SR x CAT is shown in Figure 3. The favorable effect of high-MW resin can be seen by simply comparing the left half (high MW) with the right half (low MW) of the graph. It is generally evident over the entire experiment that the high-MW resin produced the least delamination. With the wood at 4-112 percent MC, delamination did not exceed 1.2 percent at any SR and CAT with the high-MW resin. These findings were confirmed in the lower-order interactions as well. Where the same interaction affect-

ed wet shear strength, the favorable effect of high MW was less generalized (not shown), though higher wet strength was still associated with higher MW. Molecular weight in the MC x MW x SR x CAT interaction had differing and inconsistent effects on dry strength compared to its effects on delamination and wet strength. At none of the combinations of assembly conditions did the level of MW cause important dry strength losses.

The favorable effects of high MW on wet wood failure were evident in the interaction with MC. At both MCs, the higher MW significantly increased wet wood failure (to 99% for 4-112% MC and to 98% for 2-1/2% MC).

In Table 3, where the interacting effects of MW and SR are shown on three significant wet-tested properties, the influence of MW in strengthening bonds is clear. At the 50 and 65 lb./Mft.² SRs, all three properties were significantly improved by the high-MW resin. At the 80

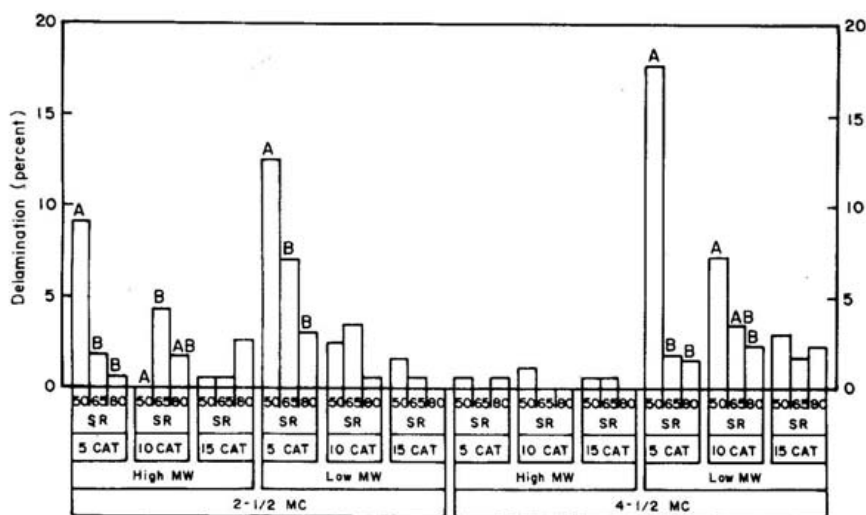


Figure 4. - Interaction of spread rate (SR) with closed assembly time (CAT), molecular weight (MW), and moisture content (MC), as it affects delamination. (In comparisons of three spread rates, means with different capital letters are significantly different at the 0.05 level of probability.)

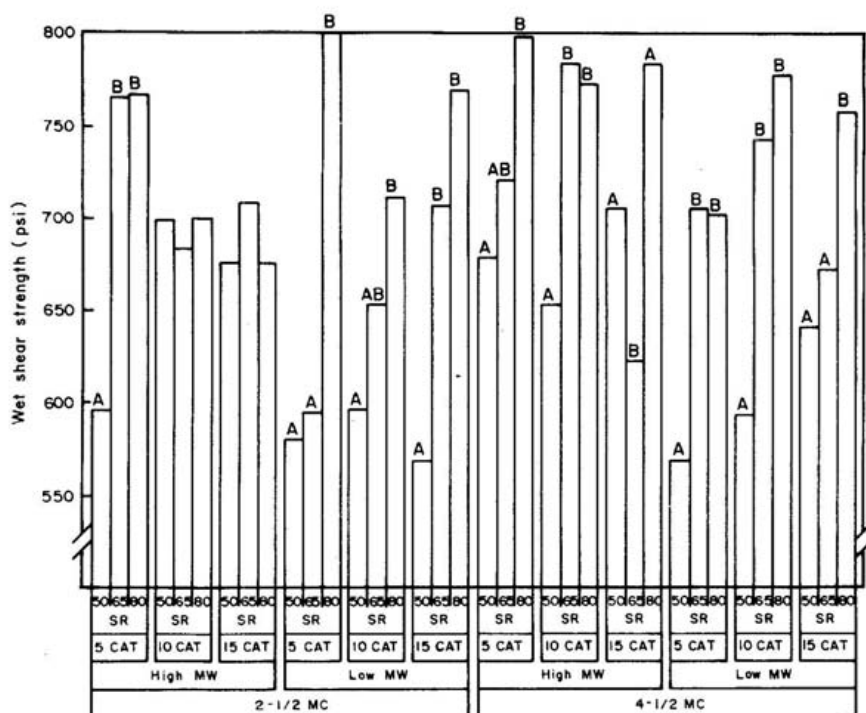


Figure 5. - Interaction of spread rate (SR) with closed assembly time (CAT), molecular weight (MW), and moisture content (MC), as it affects wet-shear strength. (In comparisons of three spread rates, means with different capital letters are significantly different at the 0.05 level of probability.)

lb./Mft.² SR, the higher MW resin did not improve strength properties any further, probably because the excess adhesive masked any effects of the higher MW resin.

The interaction of MW with CAT was significant in affecting wet wood failure and delamination. Both properties were significantly improved with the higher MW resin at both 5- and 10-minute CATs. MW was not a significant factor at the 15-minute CAT.

It seems clear from the foregoing that the higher MW resin had a decidedly favorable influence on the properties that required a high resistance to moisture. The higher MW contributed to lower adhesive mobility, hence less overpenetration of the highly porous flakeboard core edge.

Spread rate

Spread rate was a strong and significant main effect on four of the five properties tested (Tables 1 and 2). Each additional increment of higher SR produced a corresponding significant increase in resistance to delamination, wet wood failure, wet-shear strength, and dry-shear strength. Spread rate was also significantly involved in several four-, three-, and two-factor interactions.

The graph of the interaction MC x MW x SR x CAT (Fig. 4) clearly shows how SR interacted with other factors to strongly influence delamination. As one might expect, higher and sometimes unacceptable levels of delamination appeared as the lowest SR was approached. Higher delamination also occurred when low SR was combined with short CAT. At the low SR, the short CAT did not allow enough time for adequate penetration of the veneer. However, delamination was not a problem at these conditions with the high-MW resin and wood MC at 4-1/2 percent.

From the graph of the same interaction MC x MW x SR x CAT in Figure 5, it is quite evident in most statistical comparisons that the lowest SR produced significantly lower wet shear strengths than did the higher SRs. Note, however, that the high-MW resin on wood at 4-1/2 percent MC caused wet shear strengths at the lowest SR to be higher than strengths with the low-MW resin. During study of all interactions that involved SR and MW and their effects on the three wet-tested properties, the overriding influence of the higher MW resin was always present in maintaining high-property values, even at low SRs.

Closed assembly time

Closed assembly time was a significant determinant of strength and durability among most of the properties tested, particularly so among the more critical wet-tested properties (Tables 1 and 2). It was involved in several significant four-, three-, and two-factor interactions, most of which have already been discussed from standpoints of the other contributing factors.

The four-factor interaction MC x MW x SR x CAT, as it affected delamination, provides a good way of visualizing the interacting influence of CAT (Fig. 4). Here, the adverse effect on delamination of the 5-minute CAT in combination with the lowest 50 lb./Mft.² SR is

evident. The same relationship held for wet shear strength (Fig. 5). At the 50 lb./Mft.² SR, adequate adhesive was not available for penetration of the veneer during the short CAT. The longer assembly times improved the properties even at the low SR. Assembly time was not a limiting factor at higher SRs because enough adhesive was available for penetrating the veneer surface.

The short CAT also significantly and adversely affected wet wood failure when the low-MW resin was used. When the high-MW resin was used, no significant loss in properties occurred. The combined effect of low MW and short CAT points to overpenetration of the core and underpenetration of the veneer as the cause for poorer bond integrity.

It seems quite clear that a short CAT can produce inferior bonds at a low-adhesive SR (50 lb./Mft.²) with low-MW resin and at a low MC (2-1/2%). If short assembly time is to be used, then the high-MW resin may be spread at 50 lb./Mft.², but MC must be 4-1/2 percent.

Conclusions

The acid phenolic adhesive developed strong and highly durable bonds between hardwood veneer laminates and flakeboard core edges that far exceeded the minimum performance requirements proposed for composite framing.

Controlling the mobility of the phenolic adhesive between the two surfaces of markedly dissimilar porosity and roughness during RF curing was of critical importance to producing bonds of high integrity. As a result, each of the experimental factors studied, species, wood MC, resin molecular weight, adhesive spread rate, closed assembly time, and their complex interdependence, had an important impact on adhesive mobility, hence bond integrity. One set of experimental factors was consistently reiterated as best for highest bond integrity. The high-molecular-weight resin with wood at 4-1/2 percent MC produced excellent bonds on either sweetgum or yellow-poplar even at the lowest 50 lb./Mft.² spread rate with closed assembly times from 5 to 15 minutes.

Literature cited

1. American Institute of Timber Construction. 1983. Laminator's quality control system. *In*: Inspection Manual AITC 200-83, Vancouver, Wash. pp. 50-51.
2. American Society for Testing and Materials. 1982. Standard methods of evaluating the properties of woodbase and particle panel materials. ASTM D 1037-78. Part 22. Philadelphia, Pa. pp. 310-311.
3. Campbell, W.G. and K.F. Bamford. 1939. Factors affecting the relative resistance of certain woods to hydrolysis by dilute sulfuric acid. *J. Soc. Chem. Ind.* 58(5):180-185.
4. Koenigshof, G.A. 1985. Performance and quality-control standards for composite floor, wall, and truss framing. Gen. Tech. Rept. SE-33. USDA Forest Serv., Southeastern Forest Expt. Sta., Asheville, N.C. 20 pp.
5. Vick, C.B. 1984. Hydrolytic effects of an acid-phenolic molding resin on southern pine, red oak, and Douglas-fir. *Forest Prod. J.* 34(10):37-44.
6. _____ . 1987. Exterior and accelerated aging of an acid-phenolic molding resin in RF-cured Douglas-fir joints. *Forest Prod. J.* 37(10):43-48.