GLUABILITY OF OUT-OF-SERVICE UTILITY POLES

HAN ROLIADI†
CHUNG Y. HSE†
ELVIN T. CHOONG†
TODD F. SHUPE†

ABSTRACT

This investigation determined the gluability of weathered, out-of-service southern yellow pine (SYP) (*Pinus* spp.) utility poles. Three types of adhesives were used: resorcinol-phenol formaldehyde (RPF), polyvinyl acetate (PVA), and casein. The poles consisted of two service duration groups: 5 and 25 years. Longer weathering caused greater reduction in creosote content, especially in the outer and upper portions, but resulted in better gluability. Gluability of 25-year service life poles was the best and most comparable to untreated SYP. Five-year in-service poles and freshly treated poles showed less favorable gluability. Superior gluability was obtained using RPF followed consecutively by PVA and casein. In reutilization of out-of-service poles into engineered wood products, pieces that have retained sufficient creosote to be effective against decay should be placed into ground contact. Similarly, pieces of poles with lower creosote content, and consequently better gluability, would be better utilized in non-ground contact areas of engineered wood products. Latewood percentage and angle of growth ring to the glueline also affected gluability. Latewood correlated positively with shear strength and negatively with wood failure. The lower the angle of the growth ring, the higher the shear and the greater the wood failure.

Disposal of weathered, out-of-service utility poles is a serious problem. Nearly 5 million metric tons of preservative-treated wood are disposed of annually into landfills (3). Moreover, about 2 million m^3 per year of weathered utility poles treated with creosote are available for recycling (4). Of the approximately 150 million wood poles in service carrying electrical transmission and distribution lines, 1 to 2 million poles are replaced each year. Approximately 75 percent of the annual consumption of the poles consists of southern yellow pine (SYP) (*Pinus* spp.) (7). Creosote was used in 17 percent of U.S. pole production (11 million $ft.^3$) in 1993 and part of this volume was exported (2). Popular waste disposal options, such as combustion and land-filling, are becoming more and more limited due to environmental regulations (8).

Reutilization of waste poles by conversion to useful products, such as wood composite poles, can be regarded as one way to solve disposal problems. However, the remaining creosote content in the poles can affect the gluability of the sawn wood. In freshly treated poles, the creosote interferes with bonding due to poor contact between adhesive and wood substrate (9). As a result, fiber-to-glue bond strength in treated wood is lower than that in untreated wood. After several years in service, the creosote in poles, due to weathering, can undergo changes in its content and composition, which may affect gluability.

Therefore, before out-of-service poles can be properly utilized for engineered wood products such as composite poles, their gluing properties must be known. Contact angle and gluability are related when considering non-porous adherends and thermoplastic adhesives. However, for porous surfaces, such as wood,

The authors are, respectively, Former Graduate Research Assistant, School of Forestry, Wildlife, and Fisheries, Louisiana State Univ. Agri. Center, Baton Rouge, LA 70803-6202; Principal Wood Scientist, Southern Res. Sta., USDA Forest Serv., Pineville, LA 71360; and Professor and Assistant Professor, School of Forestry, Wildlife, and Fisheries, Louisiana State Univ. Agri. Center. This paper No. 99-22- 0653 is published with the approval of the Director of the Louisiana Agri. Expt. Sta. This paper was received for publication in November 1999. Reprint No. 9062.
† Forest Products Society Member.

Forest Prod. J. 50(10):76-81.

combined with thermosetting glues, the relationship is not as clear because with sufficient pressure an adhesive can be forced into a porous substrate, even if wetting thermodynamics are unfavorable. The objective of this study was to determine the effect of residual creosote on gluability.

Materials and Methods

The SYP poles selected for the study came from three service groups: freshly treated, 5 years in service, and 25 years in service. Five poles were randomly selected for each service group. These same poles were used in a previous study that investigated decay resistance (8). Samples from the poles were obtained as shown in **Figure 1**. The samples were glued with three types of adhesives: resorcinol-phenol formaldehyde (RPF), polyvinyl acetate (PVA), and casein glue.

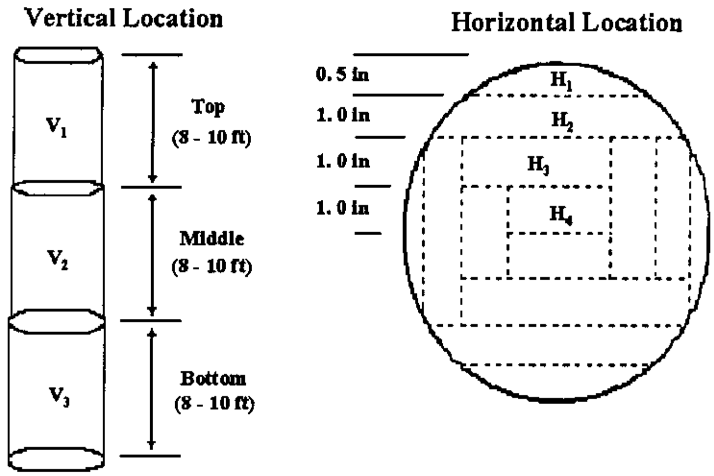

Figure 1. — Pattern of sawing procedures in treated poles.

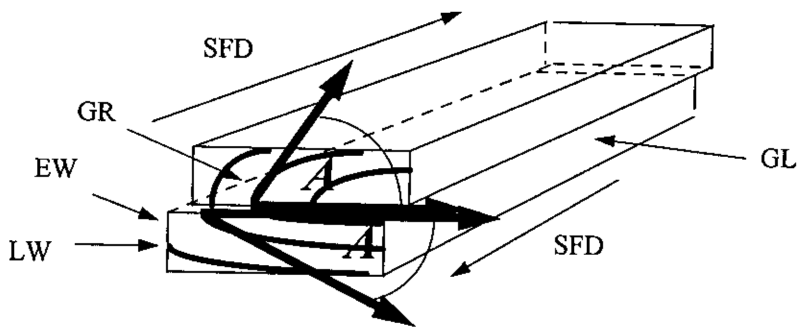

Figure 2. — Schematic of method of determination of angle (A) between growth rings and glueline on a shear block test sample (EW = earlywood, LW = latewood, GR = growth ring, GL = glueline, and SFD = shear force direction). The earlywood/latewood effect is maximum on flat grain surfaces, which have an angle = 0 degrees, because the surface could be totally comprised of either earlywood or latewood. The earlywood/latewood effect is minimal on edge-grain surfaces, which have an angle = 90 degrees, because of the comparatively narrow latewood and wide earlywood band. The effect of pole taper on earlywood/latewood patterns was not considered.

The RPF adhesive was made by reacting a mixture of Cascophen LT-5210 resorcinol-phenol resin with FM-6210S paraformaldehyde hardener, both of which were obtained from the Borden Chemical Company in Springfield, Oreg. The proportion of mixture by weight was resorcinol-phenol : paraformaldehyde : water = 2.500 : 0.333 : 0.667. The paraformaldehyde was first dissolved in water solvent, then the solution was mixed with resorcinol-phenol formaldehyde in a mixer until a homogenous solution was obtained.

Cross-linked PVA was prepared at room temperature by reacting CL-4379 PVA resin emulsion with a catalyst of K-4 trivalent salt ($AICI_3$), using a weight ratio of 100 : 5, respectively, both of which were obtained from the National Casein Company in Tyler, Tex. Casein was also obtained from the same company in the form of dry powder. The powder contains non-casein matters such as calcium hydroxide (20%) and sodium fluoride (5%). Casein glue was made by dissolving the powder in water with a weight ratio of 1:2 and then thoroughly agitating in a mixer at room temperature.

Gluing was carried out at room temperature by bonding together 2- by 1.75- by 0.75-inch samples of these creosote-treated samples at 75 pounds per 1,000 $ft.^2$ of joint area with a hydraulic pressure of 175 psi for 7 hours. For comparison purposes, gluing was also done on 20 pieces of untreated SYP. After gluing, all samples were conditioned in an environmental chamber at a temperature of 68°F and a relative humidity of 65 percent for 24 hours. The gluability of test samples was determined on the basis of glueline shear strength and percent wood failure in accordance with ASTM D-905-86 (1).

Latewood (LW) percentage was also determined by scanning the cross section area of one end of the glued shear strength specimens with a Desk Scan II 1.61 scanner. The LW percentage was calculated by a programmable computer equipped with Tif-Idressi software to study its possible effect on gluability. In addition, angle of growth rings to the glueline on the shear block sample was determined (**Fig. 2**). Contact angle determination, measured in degrees, was accomplished with a microscope equipped with a goniometer eyepiece. The microscope tube was arranged horizontally. Wood specimens were placed on a stage, and a 0.05-mL droplet of resin was applied with a pipette to the surface of each specimen. The contact angle was measured in the direction parallel to the grain and accomplished by rotating the goniometer eyepiece so that the hairline passed through the point of contact between droplet and wood and was tangent to the droplet at that point.

TABLE 1. — Analysis of variance of shear strength using three types of adhesives: RPF, PVA, and casein.

Source of variation	DF	F-values[a] RPF	PVA	Casein
Service duration (S)	2	14.01**	20.63**	18.21**
Error (a)	12			
Vertical location (V)	2	32.04**	34.19**	29.81**
Horizontal location (H)	2	19.74**	21.49**	22.42**
Interactions				
S × V	4	18.21**	16.85**	11.84**
S × H	4	15.47**	13.92**	16.98**
V × H	4	24.22**	18.74**	16.79**
S × V × H	8	9.17**	6.97**	8.24**
Angle of growth rings to the glueline (X3)	1	4.33*	4.06*	5.71*
Error (b)	95			

[a] ** and * denote significance at alpha = 0.01 and 0.05 levels, respectively.

TABLE 2. — Analysis of variance of wood failure using three types of adhesives: RPF, PVA, and casein.

Source of variation	DF	F-values[a] RPF	PVA	Casein
Service duration (S)	2	34.71**	29.13**	27.61**
Error (a)	12			
Vertical location (V)	2	24.97**	22.18**	25.72**
Horizontal location (H)	2	18.72**	20.48**	19.48**
Interactions				
S × V	4	16.93**	11.39**	12.28**
S × H	4	15.28**	13.28**	14.06**
V × H	4	9.47**	10.13**	8.79**
S × V × H	8	5.73**	6.78**	4.93**
Angle of growth rings to the glueline (X3)	1	5.49*	6.21*	
Error (b)	95			

[a] ** and * denote significance at alpha = 0.01 and 0.05 levels, respectively.

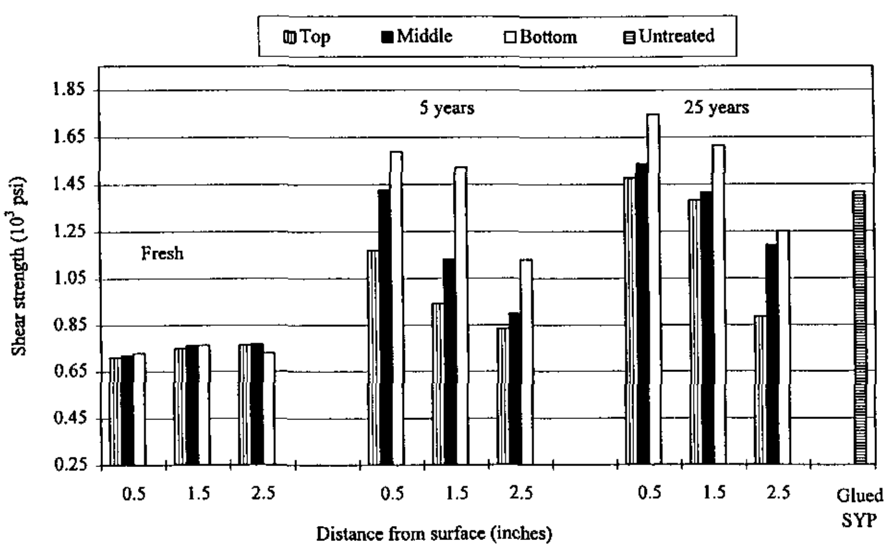

Figure 3. — Glueline shear strength of treated poles using resorcinol-phenol-formaldehyde resin.

RESULTS AND DISCUSSION

Analysis of variance indicates that glueline shear strength (**Table 1**) and percent wood failure (**Table 2**) varied significantly with different service duration, vertical and horizontal locations, and angle of growth rings.

Average glueline shear strengths in treated poles and untreated SYP are summarized in **Figures 3**, **4**, and **5** for RPF, PVA, and casein glue, respectively. The corresponding average wood failures are shown in **Figures 6**, **7**, and **8**, respectively. On average, gluability increased with period of service duration. Values were highest for untreated SYP, followed in decreasing order by 25- and 5-years-old, and freshly treated poles. The effect of service duration was mainly related to the decrease in creosote content due to weathering (8).

The creosote, being oil-soluble, inhibits wetting and penetration of the adhesive, which results in inferior fiber-to-glue bond (9). This phenomenon is best illustrated with the contact angle data (**Table 3**), which shows that the average contact angle tended to decrease significantly in all three adhesives tested with the decrease in creosote content. The highest angle occurred in the freshly treated poles, and the lowest average contact angles were obtained from untreated SYP. The analysis of variance (**Table 4**) shows that the differences with respect to adhesives and wood substrates are significant. The decrease in contact angle indicates that adhesive wettability increased with reduction in creosote content.

Adhesive solution and wood substrate are polar, while creosote is non-polar; therefore, losing some of the creosote due to weathering could increase the polarity or reduce the hydrophobicity of the wood surface, enhancing wettability (5). Higher wettability also enables the adhesive to spread and penetrate into the wood structure (10).

The analysis also shows that location in the treated wood interacted with service duration to affect gluability. As shown in **Figures 3** through **8**, for poles of 5- and 25-year service lives, the shear strength increased and wood failure decreased from top to bottom in the vertical direction, while shear strength decreased and wood failure increased from the outer surface to the pith in the horizontal direction. This could be linked to the variation in LW percentage in all treated poles (**Fig. 9**). Also, a previous study found that creosote content decreased from the bottom to the top and from the outer to the inner portions of out-of-service poles (8). For freshly treated poles, the differences in both vertical and horizontal directions were not significant, partly because the creosote content inside fresh poles was relatively high in comparison with the creosote in aged poles.

Multiple-regression analysis indicates that shear strength increased proportionately with an increase in LW percentage, as shown by a significantly positive coefficient of partial correlation (R_p = 0.772 for RPF, 0.781 for PVA, and 0.812 for casein). Wood failure also increased proportionately with the decrease in LW percentage, as shown by significantly negative coefficient of partial correlation for all adhesives (R_p = -0.741 for RPF, -0.765 for PVA, and -0.789 for casein). This relationship is expected because of the relationship between LW percentage and wood permeability. In the green condition of most softwoods, the LW permeability is less than the earlywood (EW) permeability because the cell lumens in LW are smaller than in EW. However, after drying, most of the pits in the EW are aspirated. The pits in the LW are less likely to be aspirated because their margoes are thick and the pit membranes are rigid. Therefore, even though permeability is reduced after drying, the extent of reduction in the LW is considerably less than in the EW. In other words, the role of LW on permeability is greater than that of EW when wood is dry (13).

Because of the influence of LW percentage on wood strength, it was not surprising that for the 5- and 25-year service life poles, the decrease in LW percentage from bottom to top and from the outer portions to the pith of the poles (**Fig. 9**) corresponded with a reduction in shear strength (**Figs. 3-5**) and an increase in percent wood failure (**Figs. 6-8**).

During gluing, the LW permitted more penetration of adhesive inside the dry wood than did the EW. When the adhesive cured, a stronger glue bond developed in the LW. The significant effect of LW on gluability has been reported in previous studies (6,14). Higher shear strength was accompanied by a decrease in wood failure.

Regression analysis further confirmed quantitatively the adverse effect on gluing by creosote content, as shown by negative partial correlation coefficients for both shear strength (R_p = -0.885 for RPF, -0.876 for PVA, and -0.892 for casein) and wood failure (R_p = -0.874 for RPF, -0.881 for PVA, and -0.843 for casein). In addition, angle of growth rings to the glueline affected gluing negatively, as shown by the negative values of partial correlation coefficients for both shear strength (R_p = -0.473 for RPF, -0.487 for PVA, and -0.671 for casein) and wood failure (R_p = -0.482 for RPF, -0.563 for PVA, and -0.682 for casein), respectively. The lower the angle, the more EW contacts with the adhesive. Since the EW has thin cell walls and large lumens, it is easily deformed and penetrated by adhesive (6,13). In the case of angle of growth rings, unlike the LW effect, higher wood failure, which was correlated significantly with lower angle of growth rings, was accompanied by an increase in glueline shear strength. A possible reason is that at a lower angle of growth rings, adhesive penetration into the wood structure is deeper and more extensive; therefore, a stronger an-

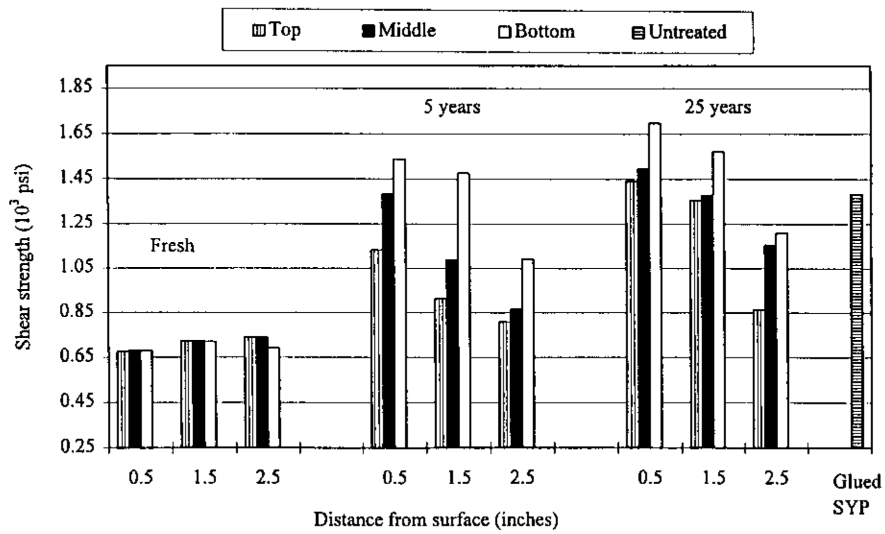

Figure 4. — Glueline shear strength of treated poles using polyvinyl-acetate resin.

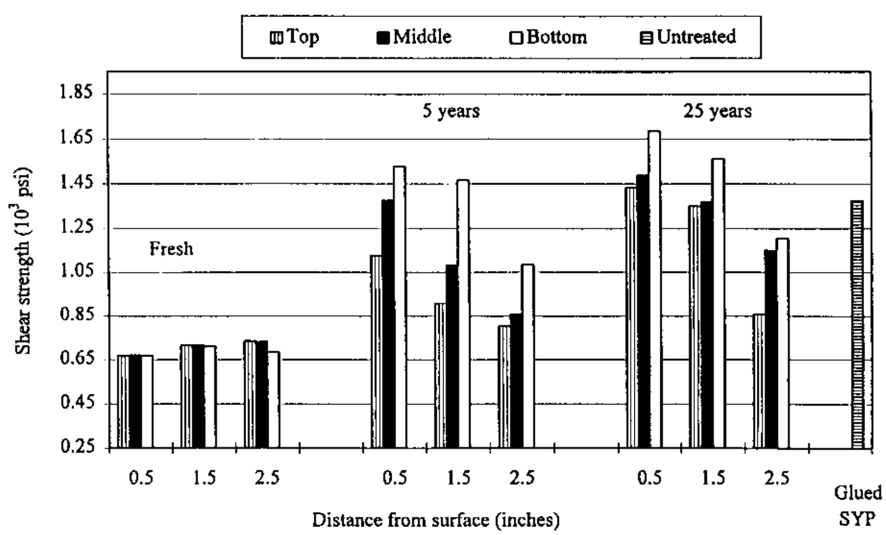

Figure 5. — Glueline shear strength of treated poles using casein resin.

TABLE 3. — Average contact angle of the three adhesives: RPF, PVA, and casein.

	Contact angle[a]			
	RPF	PVA	Casein	Mean
Treated poles				
Fresh	76.8	78.7	80.5	78.7
5 years	56.8	63.4	66.1	62.1
25 years	52.2	58.3	59.5	56.7
Untreated				
SYP	47.9	54.1	54.3	52.1
Mean	58.4	63.6	65.1	

[a] Average of 5 replications.

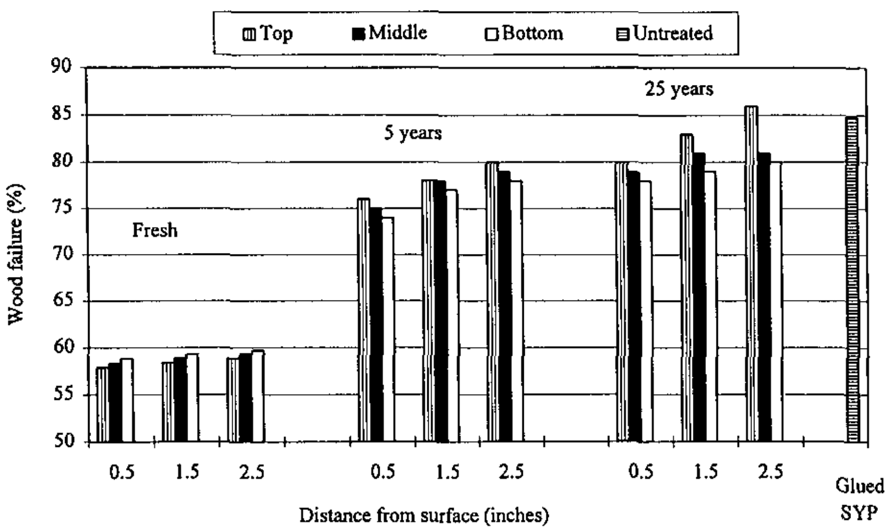

Figure 6. — Wood failure of treated poles using resorcinol-phenol-formaldehyde resin.

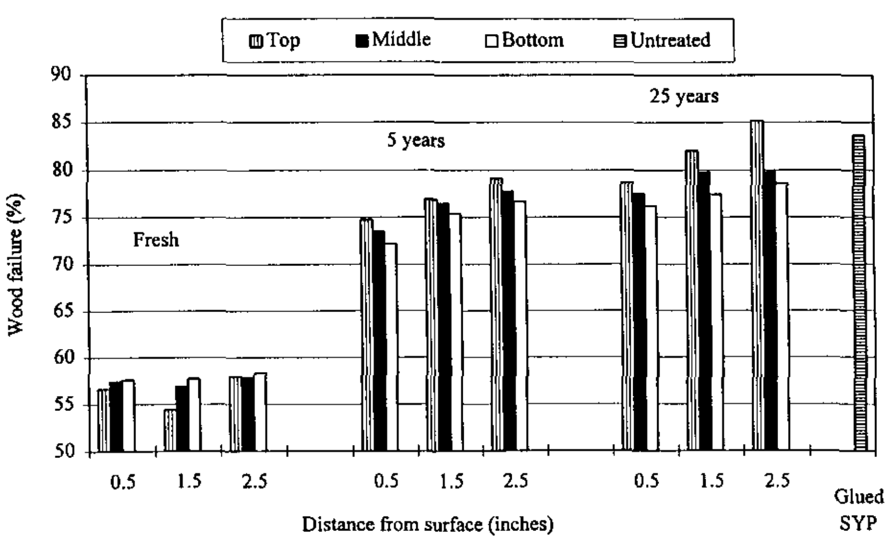

Figure 7. — Wood failure of treated poles using polyvinyl-acetate resin.

choring condition develops, which results in better gluability.

Overall gluability results of RPF were superior to PVA and casein glue. The high shear strength and high wood failure accompanying the use of RPF may be enhanced by the contribution of paraformaldehyde, since it can react as a curing agent that results in the formation of primary (valence) bonds with the wood substance (11,12). On the other hand, PVA and casein bond wood by secondary forces such as Van der Waals and hydrogen bonding, in addition to providing adhesion by mechanical forces.

A previous investigation showed that sections of out-of-service poles with higher creosote content tended to have high decay resistance (8). Therefore, when out-of-service poles are reutilized for engineered wood products, one must consider the gain that is achieved from utilizing sections with high creosote and high decay resistance with potential losses in gluability.

Conclusions

Gluability depends on creosote content. The lower the creosote content, the better the gluability. Wood poles with lower creosote content have gluing properties comparable to those of untreated SYP. Glue bonds are also affected positively by LW percentage and negatively by the angle of growth ring to the glueline. This applies to all three adhesives tested. The best gluability results were obtained with RPF, which is the most water resistant, followed by PVA, and then casein glue.

Literature Cited

1. American Society for Testing and Materials. 1994. Strength and properties of adhesive bonds in shear by compression loading. ASTM D-905-86. ASTM, West Conshohocken, Pa.
2. American Wood Preservers' Institute. 1994. The 1994 wood preserving industry production statistical report. AWPI, Fairfax, Va.
3. Falk, B. 1997. Wood recycling: Opportunities for the woodwaste resource. Forest Prod. J. 47(6):17-22.
4. Felton, C.C. and R.C. De Groot. 1996. The recycling potential of preservative-treated wood. Forest Prod. J. 46(7/8):37-46.
5. Garrey, C.L. 1977. Physical properties in paper coating. TAPPI Press, Atlanta, Ga.
6. Koch, P. 1975. Utilization of the southern pines. Agri. Handb. No. 420. USDA Forest Serv., Southern Forest Expt. Sta., Pineville, La. pp. 1163-1167.
7. Micklewright, J.T. 1991. Wood preservation statistics. *In:* Proc. Am. Wood Preservers' Assoc. 87:258-272. AWPA, Granbury, Tex.

8. Roliadi, H., C.Y. Hse, E.T. Choong, and T.F. Shupe. 200_. Decay resistance of out-of-service utility poles as related to the distribution of residual creosote content. Forest Prod. J. (in press).
9. Selbo, M.L. 1958. Laminating preservative-treated Scotch pine. Forest Prod. J. 8(9): 25A-26A.
10. Stamm, A.J. 1964. Wood and Cellulose Science. The Ronald Press Co., New York.
11. Subramanian, R.V. 1983. The adhesive system. *In*: Adhesive Bonding of Wood and Other Structural Materials. R.F. Blomquist, A.W. Christiansen, R.H. Gillespie, and G.E. Myers, eds. 3rd Clark C. Heritage Memorial Workshop on Wood. USDA Forest Serv., Forest Prod. Lab., Univ. of Wisconsin Ext. Univ. Park, Pa. pp. 137-186.
12. Tsoumi, J.D. 1991. Science and Technology of Wood: Structures, Properties, and Utilization. Van Nostrand Reinhold, New York.
13. Walker, J.C.F., B.G. Butterfield, and J.M. Harris. 1993. Primary Wood Processing. Chapman and Hall, London, U.K.
14. Wellons, J.D. 1981. The adherends and their preparation for bonding. *In*: Adhesive Bonding of Wood and Other Structural Materials. R.F. Blomquist, A.W. Christiansen, R.H. Gillespie, and G.E. Myers, eds. 3rd Clark C. Heritage Memorial Workshop on Wood. Madison, Wis., August 1981. USDA Forest Serv., Forest Prod. Lab., Univ. of Wisconsin Ext., University Park, Pa. pp. 85-134.

TABLE 4. — Analysis of variance of contact angle.

Source of variation	DF	F-calculated[a]
Types of adhesives (A)	2	14.53**
Wood substrates (S)	3	11.73**
Interaction (A × S)	6	5.28**
Error	59	

[a] ** denotes significance at alpha = 0.01 level.

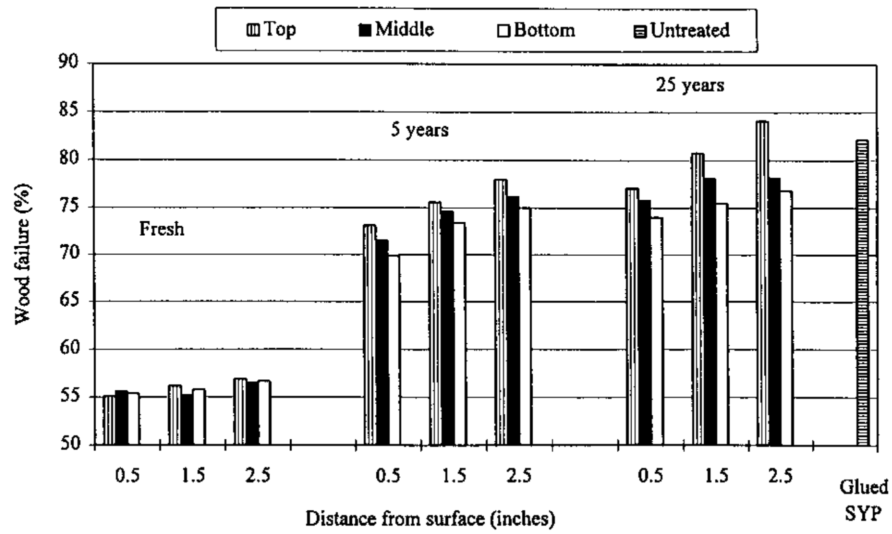

Figure 8. — Wood failure of treated poles using casein resin.

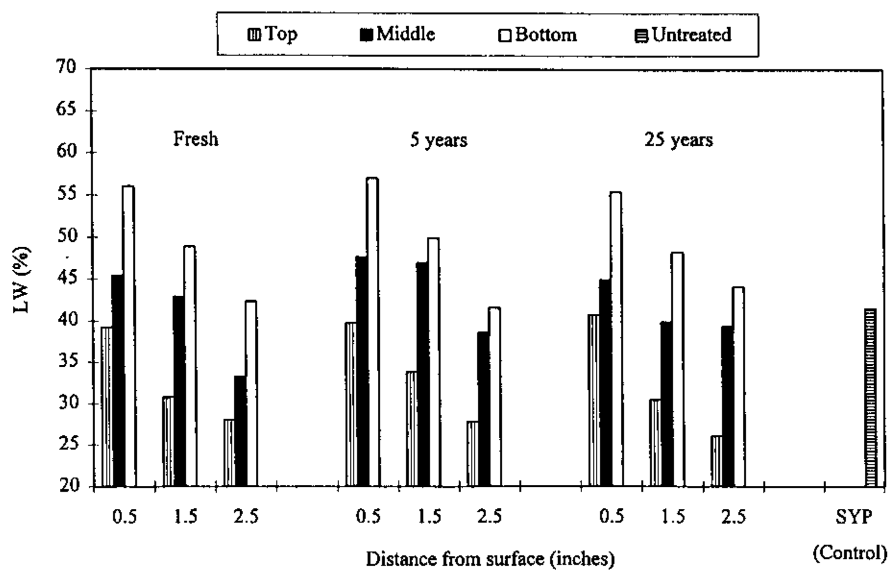

Figure 9. — Distribution of latewood in the treated poles.