Laminated Crossarms Made from Decommissioned Chromated Copper Arsenate–Treated Utility Pole Wood. Part I: Mechanical and Acoustic Properties

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Abstract

In recent years, rising concern over the disposal of preservative treated wood has generated interest in the reuse and recycling of this biomass resource. The primary objective of this study was to evaluate the bending strength and stiffness of laminated crossarms consisting entirely of virgin wood, entirely of decommissioned chromated copper arsenate (CCA)–treated utility pole wood, or a mixture of virgin wood and decommissioned CCA-treated utility pole wood after treatment with pentachlorophenol (penta). The secondary objective was to correlate acoustic properties of the laminated crossarms with their mechanical properties. Solid sawn virgin wood crossarms, solid sawn crossarms cut from decommissioned CCA-treated utility pole wood, and the laminated crossarms were evaluated for strength, stiffness, strain, and acoustic properties. The solid sawn virgin wood crossarms and all compositions of laminated crossarms met the American National Standards Institute minimum strength requirement. Only the solid sawn decommissioned CCA-treated utility pole crossarms failed to meet the minimum strength requirement. Both crossarm composition and surface preparation had no significant effect on the strength of laminated crossarms. Maximum strain decreased with an increase in the number of utility pole wood plies in the laminated crossarms. Cubic relationships were found between stress wave acoustic velocity and the number of utility pole plies contained in the laminated crossarms. Both before and after penta treatment, a linear relationship was found between bending modulus of elasticity and stress wave acoustic velocity of the laminated crossarms. Penta treatment significantly reduced stress wave acoustic velocity for all categories of crossarms, both laminated and solid sawn.

Most decommissioned preservative treated wood ends up in landfill or incineration. In recent years, rising concern for the disposal of treated wood has generated interest in the reuse and recycling of this biomass resource. Decommissioned wood utility poles, a resource in great abundance and good quality, have been the subject of much of this interest. Research has found that a large portion of decommissioned poles are still mechanically sound and reusable for other purposes (Huhnke et al. 1994, Cooper et al. 1996, Munson and Kamdem 1998, Falk et al. 2000, King and Lewis 2000, Mengeloglu and Gardner 2000, Morrell 2004, Leichti et al. 2005). Utility pole crossarms are among the possible products that can be constructed from decommissioned utility pole wood.

A crossarm is a beam attached to the upper portion of a utility pole that carries electric wires and telecommunication cables. In the United States and Canada, more than 50% of transmission line miles rely on wood structures and crossarms (Barras 2004). Wood crossarms in North America are made of timber having dense grain and few knots. Crossarms are typically made out of southern pine (*Pinus* spp.), Douglas-fir (*Pseudotsuga menziesii*), or slower-growing trees, the latter being known as ''old-growth'' timber (American National Standards Institute [ANSI] 1995). As suitable trees become more difficult to acquire,

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however, second- and third-growth timber has to be used to construct these crossarms. Second- and third-growth timber does not meet the strength requirements for wood crossarms because of the presence of juvenile wood (Liebel and Mueller 1994). Nevertheless, the past two decades have seen a tendency for crossarms to be cut from small-diameter timber having an abundance of juvenile wood (Barnes and Winandy 2001). The elevated price of dense grain crossarms and the increase in juvenile wood crossarms has led to the efforts by crossarm manufacturers to seek alternatives to solid sawn crossarms (Jokerst 1972, Youngquist et al. 1977, Liebel and Mueller 1994, Leichti et al. 1998).

Experimental laminated timber crossarms were first produced for Bell Telephone Laboratories (Jokerst 1972). These crossarms were made of southern pine and Douglas-fir and were treated with creosote and pentachlorophenol (penta) preservatives. The plies were bonded with room-setting resorcinol adhesive. The bonding quality of these crossarms was excellent, even after 16 to 23 years of exterior exposure. Since then, several studies have investigated the performance of laminated crossarms. Youngquist et al. (1977) found that commercial laminated Douglas-fir crossarms and laminated crossarms consisting of a mixture of the western species Douglas-fir, hemlock, and white fir were within 10 percent of the strength of Douglas-fir solid sawn crossarms. Similar results were found in Liebel and Mueller's (1994) study, which concluded that laminated crossarms of mixed species were comparable in strength to solid sawn crossarms (species information was not given in the paper). Finger joints were found to be the weak points of the laminated crossarms in the studies of Jokerst (1972) and Liebel and Mueller (1994). Jokerst also found finger joints to be susceptible to decay. Leichti et al. (1998) found, after 20 years of service exposure, that the bending stiffness and allowable load capacities of tapered/curved laminated crossarms were significantly lower than the original values.

Reusing decommissioned treated wood offers economic and ecological advantages, such as (1) less harvesting of the forest due to the extension of the service life of treated wood, (2) a reduction of toxic chemicals (such as chromated copper arsenate [CCA], pentachlorophenol [penta], and creosote) in the environment due to less treated wood being landfilled and/or incinerated, and (3) a reduction in the disposal costs of treated wood.

The major objective of this study was to determine the joint effects of crossarm composition and ply surface preparation on bending strength and stiffness. The secondary objective was to correlate acoustic properties of the crossarms with their mechanical properties. All utility pole wood was cut from decommissioned CCA-treated utility poles. Each ply in each laminated crossarm consisted of a single piece of lumber. No finger-jointed segments were glued together to form a ply.

Materials and Methods

One hundred five crossarms were constructed for this study: 45 were solid sawn and 60 were laminated. Of the 45 solid sawn crossarms, 22 were made of virgin southern pine (Fig. 1, Composition A), and 23 were made of decommissioned CCA-treated utility poles (Fig. 1, Composition F). The 22 solid sawn virgin pine crossarms were drawn randomly from surfaced products in the mill of a commercial crossarm producer. Most of the 23 solid sawn utility pole crossarms were cut from poles left from a previous study (Piao et al. 2009a, 2009b, 2009c); each came from the bottom or middle sections (not the top) of the pole from which it was cut. Rings per centimeter were measured for each solid sawn crossarm. Each laminated crossarm consisted of six plies. Each ply was made of either virgin pine or decommissioned CCA-treated utility pole wood according to one of the four possible composition schemes for the crossarm: (1) all six plies made of virgin wood (Fig. 1, Composition B), (2) the two middle or core plies made of decommissioned CCA-treated utility pole wood and the four outer plies (two top and two bottom) made of virgin wood (Fig. 1, Composition C), (3) the four middle or core plies made of decommissioned CCA-treated utility pole wood and the two outer plies (one top and one bottom) made of virgin wood (Fig. 1, Composition D), and (4) all six plies made of decommissioned CCA-treated utility pole wood (Fig. 1, Composition E). A total of 60 laminated crossarms were fabricated (15 crossarms $\times$ 4 compositions).

Utility pole plies for the laminated crossarms were obtained as follows. Each log segment was first cut into boards. Boards were then surfaced with a planer and cut into one or two 102-mm-wide by 19-mm-thick by 2.44-m-long plies, depending on the width of the board. Each ply was measured for width, thickness, length, weight, moisture content, and acoustic properties. The acoustic properties were measured using a handheld acoustic meter and a hammer (Carter et al. 2005). When measured, each ply was held at one end by a rubber stopper on a table, and then the acoustic meter receiver was pushed against the other (free) end of the ply. The sound wave produced by the hammer on the free end traveled through the ply, reflected by the stopper end of the ply, and finally, received by the meter. Traveling velocity of the sound wave through the ply was calculated and shown on the meter's LCD screen. Stress wave acoustic velocity was measured five times across the free end of each ply. The measured stress wave acoustic velocity was used not only to determine the location of the plies within a crossarm (surface ply or core ply) but also to estimate the mechanical properties of the crossarms made from the plies. The locations of the plies within the crossarms were determined as follows. Plies with greater stress wave acoustic velocity were believed to be stronger and were, therefore, used as surface plies. Plies with lower stress wave acoustic velocity were used as core plies. A total

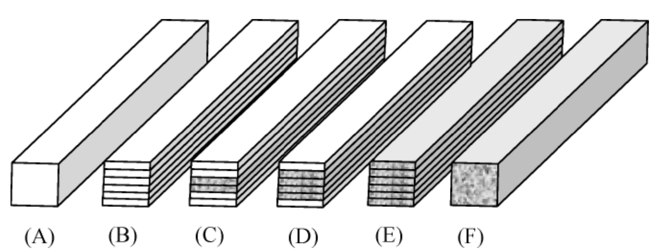

Figure 1.—A schematic diagram of the crossarms made for this study: (A) a solid sawn crossarm fabricated from untreated virgin wood, (B) a laminated crossarm fabricated entirely from untreated virgin wood, (C) a laminated crossarm fabricated from four untreated virgin wood face plies and two utility pole core plies, (D) a laminated crossarm fabricated from two untreated virgin wood face plies and four utility pole core plies, (E) a laminated crossarm fabricated entirely from utility pole plies, and (F) a solid sawn crossarm fabricated from utility pole wood.

of 180 treated wood plies were processed and used to fabricate the laminated crossarms of this study.

To construct virgin wood plies for the laminated crossarms, 90 pieces of high-density, southern yellow pine virgin wood lumber and 90 pieces of low-density, southern yellow pine virgin wood lumber were obtained from a local lumber mill. The dimension of the lumber was 140 mm wide by 38 mm thick by 2.44 m long. Each piece of lumber was first surfaced with a planer and then cut into a 102-mm-wide by 19-mm-thick by 2.44-m-long ply. Each ply was measured for width, thickness, length, weight, moisture content, and acoustic properties in a manner similar to that of the treated wood plies. A total of 180 virgin wood plies (90 high density and 90 low density) were fabricated for use in this study.

The two outer plies (one top and one bottom) of each of the 15 laminated crossarms made entirely of virgin southern yellow pine (Composition B) were made of high-density wood, while the four core plies were made of low-density wood. Each of the 15 laminated crossarms of Composition C had outermost top and bottom plies made of high-density virgin southern pine and two core plies made of low acoustic velocity decommissioned CCA-treated utility pole wood. The two plies between the core and outermost plies were made of low-density virgin southern pine. Each of the 15 laminated crossarms of Composition D had high-density virgin southern pine outer plies (one top and one bottom) and four low acoustic velocity decommissioned CCA-treated utility pole wood core plies. The two outermost plies (one top and one bottom) of each of the 15 laminated crossarms made entirely of decommissioned CCA-treated utility pole wood (Composition E) were made of high acoustic velocity utility pole wood, while the four core plies were made of low acoustic speed utility pole wood.

Prior to the binding process, the binding surfaces of the six plies that were to make up a laminated crossarm were treated in one of three ways: primed, incised, or control (i.e., the binding surfaces were left untreated). Of the 15 laminated crossarms that were constructed for each composition scheme (i.e., Compositions B, C, D, and E), 5 were composed of plies that had been primed only, 5 were composed of plies that had been incised only, and 5 were composed of plies that were untreated (i.e., had been neither incised nor primed). Of the 60 laminated crossarms that were constructed, 20 were made of plies that had been primed, 20 were made of plies that had been incised, and 20 were made of plies that been left untreated.

A resorcinol phenol formaldehyde resin was uniformly applied to the binding surfaces of each ply that was assigned to the primed or untreated categories of surface preparation at the rate of 463 g/m^2 (43 g/ft^2), regardless of whether the ply was made of CCA-treated utility pole wood or virgin wood. For incised plies, 506 g/m^2 (47 g/ft^2) of resin was applied to both CCA-treated wood and virgin wood plies. Beams were kept under pressure (0.86 MPa, or 125 psi) at room temperature for 24 hours to cure the resin.

All crossarms were sawn and surfaced to 89 mm wide by 114 mm thick by 2.44 m long with a planer. Both solid sawn and laminated crossarms then were air dried for 4 weeks. After air drying, all crossarms were treated with penta in a wood preservative treatment mill. The treatment procedure followed a Lowery empty-cell process. Prior to the penta treatment, each crossarm was measured for width, depth, length, weight, and acoustic properties. After treatment, each crossarm was measured again for weight and acoustic properties. Five acoustic measurements were made for each crossarm before and after the penta treatment.

All crossarms were subjected to bending tests according to ASTM Standard D198–02 (American Society for Testing and Materials [ASTM] 2003) and ANSI Standard 05.3–95 (ANSI 1995). Two-point loading was applied symmetrically with 56 cm between load points on a 2.2-m span. Each crossarm was continuously loaded to failure in 5 to 10 minutes. The peak load, modulus of rupture (MOR), and the modulus of elasticity (MOE) of each crossarm were measured using a destructive two point bending test. Prior to the bending test, two of the five replicate crossarms of each combination of composition scheme and surface preparation were fitted with strain gages to measure axial strain of the crossarms. Axial strain variations were measured during the bending tests of each of the crossarms. The gauges (SGD-30/120-LY40) were 30-mm grid, 120-ohm, extra-long grid pattern strain gauges for inhomogeneous materials.

Crossarm samples were tested to failure after penta treatment. Flexural MOR and MOE were measured on each crossarm after penta treatment. However, the nondestructive stress wave modulus of elasticity, $\mathrm{MOE_{sw}}$ (unit of measurement Pa), was estimated for all crossarms, both before and after penta treatment, using the following formula (Kaiserlik and Pellerin 1977, Ross et al. 2005):

$$\mathrm{MOE_{sw}} = C^2\rho \qquad (1)$$

where C is stress wave acoustic velocity through the crossarm and ρ is bulk density of the crossarm (g/cm^3). Acoustic properties were correlated with the strength and stiffness of the crossarms.

For the 60 crossarms containing at least some utility pole wood, both CCA and penta were present in the crossarms. Therefore, after the bending test, penta and CCA retentions in these crossarms were evaluated. Only penta retention was measured for the 37 crossarms made of virgin southern pine only. Glueline shear strength of the laminated crossarms after penta treatment was measured according to ASTM Standard D2559 (ASTM 2004). The results of these studies are presented in our next report.

Results and Discussion

Physical properties

The physical and mechanical properties of all fabricated crossarms are summarized in Table 1. For each crossarm, initial and final bulk density was determined both before and after pentachlorophenol (penta) treatment. Before penta treatment, mean density values of the laminated crossarms ranged from 0.57 to 0.70 g/cm^3, with an increase from Compositions B to E due to the increasing number of recycled CCA-treated wood plies in the crossarms. Also, before penta treatment, mean density for the solid sawn virgin wood crossarms (0.66 g/cm^3 for Composition A) was much higher than those of either the solid sawn treated wood crossarms (0.57 g/cm^3 for Composition F) or the laminated crossarms made entirely from virgin wood plies (0.59, 0.57, and 0.57 g/cm^3 for Composition B, series no. 1 to 3, respectively, in Table 1). Density values of all crossarms increased after the penta treatment because the crossarms absorbed penta during the treatment process. After the penta treatment, mean density values of the

Table 1.—Physical and bending properties of all crossarms fabricated for this study.

Series no.	Composition[a]	Ply surface preparation	No. of crossarms	Avg density (g/cm^3) Before penta treatment	Avg density (g/cm^3) After penta treatment	Avg moisture content at test (%)	Avg (SE) MOR after penta treatment (MPa)	Avg (SE) MOE after penta treatment (GPa)
1	B (0/6)	Priming	5	0.59	0.70	12.6	69.6 (2.17)	11.1 (0.66)
2	B (0/6)	Incising	5	0.57	0.68	12.4	64.0 (3.72)	11.3 (0.73)
3	B (0/6)	Control	5	0.57	0.66	12.2	74.7 (3.57)	11.6 (0.35)
4	C (2/6)	Priming	5	0.60	0.68	12.7	69.7 (4.12)	11.3 (0.58)
5	C (2/6)	Incising	5	0.60	0.72	12.1	64.7 (5.30)	11.3 (0.92)
6	C (2/6)	Control	5	0.63	0.73	12.9	69.8 (4.91)	12.1 (0.72)
7	D (4/6)	Priming	5	0.63	0.70	13.1	66.0 (3.00)	11.3 (0.45)
8	D (4/6)	Incising	5	0.63	0.68	13.1	62.4 (5.86)	10.9 (0.39)
9	D (4/6)	Control	5	0.60	0.68	12.9	63.9 (2.62)	10.6 (0.69)
10	E (6/6)	Priming	5	0.68	0.78	13.0	65.8 (4.97)	13.9 (0.53)
11	E (6/6)	Incising	5	0.70	0.78	12.2	66.9 (4.44)	14.0 (0.62)
12	E (6/6)	Control	5	0.68	0.80	14.0	65.9 (4.92)	13.9 (0.49)
13	F[b]	—	15	0.57	0.66	13.2	50.7 (3.54)	11.2 (0.38)
14	A[c]	—	15	0.66	0.76	14.2	69.8 (1.93)	13.0 (0.20)

[a] Crossarm composition scheme with number of recycled utility pole wood plies/total number of plies given for laminated crossarms presented in parentheses.
[b] Solid sawn utility pole wood crossarms.
[c] Solid sawn virgin wood crossarms.

laminated crossarms ranged from 0.66 to 0.80 g/cm^3. The increase in mean density after penta treatment for the laminated crossarms ranged from 0.05 g/cm^3 (series no. 6) to 0.12 g/cm^3 (series no. 5 and 12). Therefore, laminated crossarms of all composition groups and surface preparations absorbed, on average, anywhere from 50 kg/m^3 (3.1 pcf) to 120 kg/m^3 (7.5 pcf) of penta during the treatment process. Solid sawn utility pole crossarms and solid sawn virgin wood crossarms absorbed, on average, 90 kg/m^3 (5.6 pcf) and 100 kg/m^3 (6.2 pcf) of penta, respectively, during the treatment process. Penta retention and its effect on glue line shear of laminated crossarms will be discussed in more detail in our next report.

Flexural MOR and MOE

Average MOR, bending MOE, and moisture content at test appear in Table 1 for each combination of composition scheme (i.e., Compositions B to E) and surface preparation method for the plies (i.e., primed, incised, or control) of the laminated crossarms and each composition scheme (i.e., Composition A or F) for the solid sawn crossarms. The MOR averages of the laminated crossarms ranged from 62.4 to 74.7 MPa. The average of the MOR values for the 60 laminated crossarms was 67 MPa. The minimum fiber stress required for communication and power crossarms designated by the ANSI standard is 54 MPa (7,800 psi; ANSI 1995). The average strengths of the laminated crossarms were from 116 to 138 percent greater than that required by the ANSI standard. Figure 2 offers a visual summary of the MOR values averaged over the 15 crossarms fabricated for each composition scheme. The dashed line in the figure is at the ANSI minimum strength value. The only composition scheme average that failed to meet the ANSI standard strength requirement was that of the solid sawn crossarms cut from decommissioned CCA-treated utility poles.

A two-factor factorial analysis of variance revealed that crossarm composition scheme and surface preparation method of the plies had little effect on the MOR of laminated crossarms. The crossarm composition scheme main effect was not significant ($P = 0.4570$), meaning that the averages of the 15 (MOR) strength values for each the four composition schemes (namely, 69.4 MPa for Composition B, 68.0 MPa for Composition C, 64.1 MPa for Composition D, and 66.2 MPa for Composition E) were due to sample variation only and not to actual differences between the corresponding averages of the population means. The surface preparation method main effect was also not significant ($P = 0.3744$), meaning that the averages of the 20 (MOR) strength values for each of the three surface preparation methods (namely, 67.8 MPa for primed, 64.5 MPa for incised, and 68.6 MPa for control) were due to sample variation only. In addition, the MOR crossarm composition scheme by surface preparation method interaction was not significant ($P = 0.8731$).

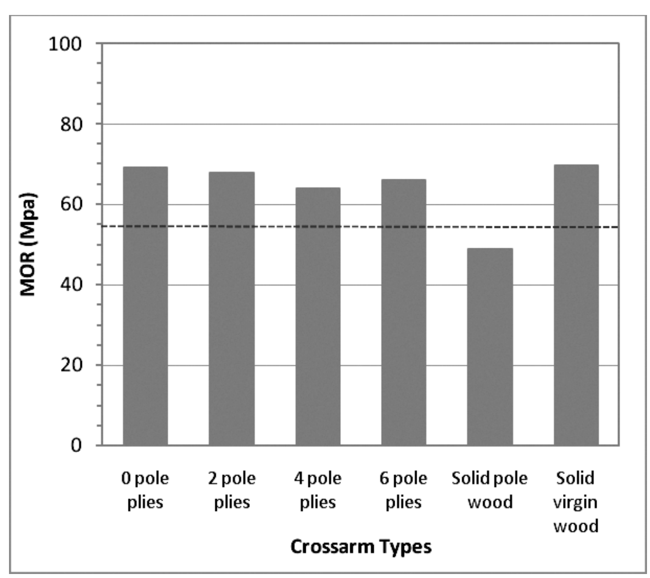

Figure 2.—MOR averaged over the 15 crossarms of each of the Compositions B, C, D, E, F, and A of Figure 1 (in the order given).

Because of the conclusions of no surface preparation by composition interaction and no surface preparation main effect in the MOR population means of the laminated crossarms, the MOR values of the 15 crossarms in each composition scheme were concluded to have the same population mean and were, therefore, pooled together and used to compare the six population average MOR values of the six composition schemes. The analysis of variance results showed that the averages of the 15 MOR values for each of the six composition schemes (namely, 69.8 MPa for Composition A, 69.4 MPa for Composition B, 68.0 MPa for Composition C, 64.1 MPa for Composition D, 66.2 MPa for Composition E, and 50.7 MPa for Composition F) were significantly different ($P < 0.0001$). The only pairwise comparisons of these six averages found to be significantly different from zero were those between Compositions F and the other five ($P \leq 0.0003$). The P values of all pairwise comparisons appear in Table 2. It is concluded, then, that the population average strengths of the four categories of laminated crossarms are equal to each other and, in fact, are equal to the population average strength of solid sawn virgin wood crossarms (P values ranging from 0.1079 to 0.9175). Barnes and Winandy (2001) reported an average MOR value of 63.3 MPa (9,175 psi) for commercial southern pine solid sawn crossarms. The average strength of the 75 crossarms fabricated for this study that were not made according to Composition F was 67.5 MPa, comparable to the average reported by Barnes and Winandy.

As noted, the average MOR of solid sawn crossarms cut from spent utility poles failed to meet the ANSI minimum strength requirement and was significantly different (actually, lower) than the average strengths of the four categories of laminated crossarms as well as the average strength of the solid sawn virgin wood crossarms. In this study, all solid sawn utility pole crossarms were cut from low-density poles. The average density of these 15 crossarms was 0.57 g/cm^3 (Table 1). Although these crossarms were cut from low CCA-retention areas of the poles, some CCA was present in this wood. Therefore, the measured density of these crossarms included the CCA present in the wood. The average growth ring density of the solid sawn utility pole crossarms was 2.3 rings per cm. Both the density (0.66 g/cm^3) and the rings per centimeter (3.0) of the solid sawn virgin wood crossarms were higher than the respective values of the solid sawn utility pole crossarms. However, one of the solid sawn utility pole crossarms had an MOR value of 57.9 MPa; the density and rings per centimeter of this crossarm were 0.61 and 3.4 g/cm^3, respectively. The (MOR) strength of one high-density (0.75 g/cm^3) solid sawn virgin wood crossarm (2.5 rings per cm) was measured to be 64.3 MPa. It is, therefore, conjectured that solid sawn utility pole crossarms may meet the ANSI standard strength requirement after penta treatment if wood density is greater than 0.66 g/cm^3 (CCA inclusive) and/or rings per centimeter is greater than 3.0. However, utility poles or pole sections having density lower than 0.55 g/cm^3 (CCA inclusive) may not be suitable for crossarm production, regardless of the section of the pole (top, middle, or butt) from which the crossarm is to be cut. More research into the strength of solid sawn crossarms cut from spent wood utility poles is warranted.

A two-factor factorial analysis of variance of the laminated crossarms revealed no surface preparation by composition interaction and no surface preparation main effect in the MOE population values ($P = 0.9441$ and 0.9106, respectively). The MOE values of the 15 crossarms in each composition scheme were, therefore, pooled together and used to compare the six population MOE average values of the six composition schemes. The results from the analyses of variance showed that the averages of the 15 MOE values for each of the six composition schemes (namely, 13.0 GPa for Composition A, 11.3 GPa for Composition B, 11.6 GPa for Composition C, 10.9 GPa for Composition D, 13.9 GPa for Composition E, and 11.2 GPa for Composition F) were found to be significantly different ($P < 0.0001$). Pairwise comparisons revealed that population average MOE values for both solid sawn virgin wood crossarms (Composition A) and laminated crossarms made entirely of utility pole plies (Composition E) were significantly different (actually greater) than population average MOE values for the other four composition schemes ($P \leq 0.0026$). Table 1 reveals that average MOE values of the laminated crossarms ranged from 10.6 to 13.9 GPa. The overall average of the MOE values of the 60 laminated crossarms was 11.9 GPa (1,725,500 psi), which was lower than the MOE average of 13 GPa (1,885,000 psi) for the 15 commercial solid sawn virgin wood crossarms tested in this study and lower than the MOE value of 12.5 GPa (1,806,945 psi) for commercial southern pine crossarms reported by Barnes and Winandy (2001). However, the average MOE of the 15 laminated crossarms made entirely from utility pole plies (13.9 GPa, or 2,015,500 psi) was comparable to the average MOE of commercial solid sawn virgin wood crossarms tested in this study as well as the value reported by Barnes and Winandy.

Maximum axial strain

Axial strain gauges were attached to at least two of the five laminated crossarms fabricated for each combination of

Table 2.—Probability values of pairwise comparisons between MOR averages.

Composition[a]	B (0/6)	C (2/6)	D (4/6)	E (6/6)	F[b]	A[c]
B (0/6)	—	0.6902	0.1325	0.3606	**<0.0001**[d]	0.9157
C (2/6)	0.6902	—	0.2664	0.6050	**<0.0001**	0.6141
D (4/6)	0.1325	0.2664	—	0.5503	**0.0003**	0.1079
E (6/6)	0.3606	0.6050	0.5503	—	**<0.0001**	0.3081
F[b]	**<0.0001**	**<0.0001**	**0.0003**	**<0.0001**	—	**<0.0001**
A[c]	0.9157	0.6141	0.1079	0.3081	**<0.0001**	—

[a] Crossarm composition scheme with number of recycled utility pole wood plies/total number of plies given for laminated crossarms presented in parentheses.
[b] Solid sawn utility pole wood crossarms.
[c] Solid sawn virgin wood crossarms.
[d] Bold values were statistically significant at a 5% significance level.

Table 3.—Average maximum microstrain and deflection.

	Composition[a]					
	B (0/6)	C (2/6)	D (4/6)	E (6/6)	F[b]	A[c]
No. of crossarms	8	8	7	10	9	11
MOR (MPa)	71.1	57.7	61.1	69.5	48.1	69.6
Avg maximum microstrain	7,853	7,512	6,327	5,756	4,766	5,949
Avg deflection/beam depth[d]	0.58	0.53	0.53	0.44	0.42	0.56

[a] Crossarm composition scheme with number of recycled utility pole wood plies/total number of plies given for laminated crossarms presented in parentheses.
[b] Solid sawn utility pole wood crossarms.
[c] Solid sawn virgin wood crossarms.
[d] The average over the 15 crossarms in each beam composition group.

composition scheme and surface preparation, one gauge per crossarm. Therefore, at least six crossarms were measured for maximum axial strain for each of the four laminated crossarm composition schemes. Nine solid sawn utility pole wood crossarms and 11 solid sawn virgin wood crossarms were measured for maximum strain. The average maximum strain, deflection, and MOR values are given in Table 3 for those crossarms that were fitted with strain gauges. It can be seen from the table that there was a pronounced decrease in average maximum strain of the laminated crossarms as the number of utility pole plies in the crossarms increased, while average MOR of the four composition crossarm groups fluctuated mildly at about 65 MPa. The decrease in average maximum strain indicates that laminated crossarms became more brittle as the amount of utility pole wood in the crossarms increased.

Table 3 also shows that laminated crossarms made entirely from virgin wood exhibited the highest strain and highest MOR, while the solid sawn utility pole crossarms had the lowest strain and lowest MOR. The average microstrain of the 33 laminated crossarms fitted with strain gauges was 6,862, higher than both the average microstrain of the 9 solid sawn utility pole crossarms (4,766) and the average microstrain of the 11 solid sawn virgin wood crossarms (5,949). To further evaluate deflective properties, the deflection in a unit beam depth (maximum deflection/beam depth) was calculated for all crossarms fabricated for this study. This parameter reflects the deflectability or brittleness of a beam. These values, which also appear in Table 3, reveal that maximum deflection per unit beam depth of the laminated crossarms decreased (not monotonically) with an increase in the amount of utility pole wood in the crossarms. It may, therefore, be concluded that the utility pole plies increased the brittleness of the crossarms. Wood embrittlement resulting from copper arsenate treatment was reported previously (Kaiserlik 1978). In addition, waterborne preservative treatment was found to reduce bending, shear, and impact strength (Winandy 1995, 1998; Morrell et al. 1998). Therefore, considerations must be given to the brittleness and strength aspects of structural products made from recycled preservative treated wood.

Acoustic properties

Stress wave acoustic velocity and MOE_{sw} averages appear in Table 4 for each combination of composition scheme and ply surface preparation method of the laminated crossarms and for each composition scheme of the solid sawn crossarms, both before and after penta treatment. For the laminated crossarms, acoustic velocity and MOE_{sw} were measured for the five crossarms fabricated for each

Table 4.—Crossarm stress wave properties.

Series no.	Composition[a]	Surface preparation	No. of crossarms tested	Acoustic velocity: Plies before penta (m/s)	Acoustic velocity: Arms before penta (m/s)	Acoustic velocity: Arms after penta (m/s)	Acoustic velocity: Decrease (%)	Avg (SE): MOE_{sw} before penta treatment (GPa)	Avg (SE): MOE_{sw} after penta treatment (GPa)
1	B (0/6)	Priming	5	4,794	4,777	4,412	7.6	13.4 (0.36)	12.8 (0.12)
2	B (0/6)	Incising	5	4,892	4,896	4,493	8.2	13.7 (0.31)	13.7 (0.71)
3	B (0/6)	Control	5	4,816	4,794	4,423	7.8	13.2 (0.46)	12.8 (0.79)
4	C (2/6)	Priming	5	4,926	4,951	4,570	7.7	14.7 (0.81)	14.0 (0.66)
5	C (2/6)	Incising	5	4,776	4,878	4,396	9.8	14.3 (0.61)	13.8 (0.58)
6	C (2/6)	Control	5	4,952	5,087	4,581	10.0	16.1 (0.75)	15.4 (0.16)
7	D (4/6)	Priming	5	4,746	4,834	4,477	7.4	14.7 (0.47)	14.0 (0.40)
8	D (4/6)	Incising	5	4,591	4,820	4,374	9.4	14.7 (0.53)	12.9 (0.81)
9	D (4/6)	Control	5	4,697	4,774	4,483	6.1	13.7 (0.71)	13.6 (0.64)
10	E (6/6)	Priming	5	5,030	5,223	4,787	8.4	18.5 (0.89)	18.1 (0.94)
11	E (6/6)	Incising	5	5,066	5,189	4,830	6.9	18.9 (0.74)	18.2 (0.73)
12	E (6/6)	Control	5	4,979	5,337	4,869	8.7	19.4 (0.62)	19.0 (0.75)
13	F[b]	—	8	—	4,794	4,442	7.3	13.1 (0.55)	13.1 (0.49)
14	A[c]	—	7	—	5,004	4,662	6.8	17.1 (0.73)	16.7 (0.58)

[a] Crossarm composition scheme with number of recycled utility pole wood plies/total number of plies given for laminated crossarms presented in parentheses.
[b] Eight of the 15 solid sawn utility pole crossarms.
[c] Seven of the 15 solid sawn virgin wood crossarms.

combination of composition and surface preparation. For the laminated crossarms, averages were calculated over the five crossarms that were fabricated for each combination of composition and surface preparation. However, for the solid sawn crossarms, only eight utility pole crossarms and seven virgin wood crossarms were measured for stress wave properties. These 8 utility pole crossarms plus the 15 summarized in Table 1 form the 23 total utility pole crossarms that were fabricated for this study; these 7 virgin wood crossarms plus the 15 summarized in Table 1 constitute the 22 virgin wood crossarms that were fabricated for this study. Stress wave acoustic velocity averages for Table 4 were calculated over these eight utility pole crossarms and seven virgin wood crossarms. Acoustic velocity was measured for individual plies prior to construction of the crossarms (hence, before penta treatment). Ply averages were calculated over all plies that made up the five crossarms at each combination of crossarm composition and surface preparation.

A two-factor factorial analysis of the laminated crossarms revealed no ply surface preparation by composition interaction and no ply surface preparation main effect in the stress wave acoustic velocity population means either before or after penta treatment (before: $P = 0.4523$ for the interaction and 0.5727 for the surface preparation main effect; after: $P = 0.7547$ for the interaction and 0.5866 for the surface preparation main effect). The stress wave acoustic velocity values of the 15 crossarms in each composition scheme were, therefore, pooled together and used to compare the six population acoustic velocity means of the six composition schemes both before and after penta treatment. The acoustic velocity sample averages for Compositions A to F before penta treatment (5,004, 4,822, 4,972, 4,809, 5,249, and 4,794 m/s, respectively) were found to be significantly different ($P < 0.0001$). Pairwise comparisons of these sample averages found the average for the laminated crossarms made entirely of utility pole wood (i.e., 5,249 m/s) to be significantly different (actually higher) than the other five averages ($P \leq 0.0068$). Brashaw et al. (1996), however, found that CCA treatment had no effect on the longitudinal stress wave acoustic velocity across veneers made of either southern yellow pine or of Douglas-fir. The acoustic velocity sample averages for Compositions A to F after penta treatment (4,662, 4,442, 4,515, 4,444, 4,829, and 4,442 m/s, respectively) were also found to be significantly different ($P < 0.0001$). Pairwise comparisons of these sample averages found the average for the laminated crossarms made entirely of utility pole wood (i.e., 5,249 m/s) to be significantly different (actually higher) than the four averages for Compositions B, C, D, and F ($P < 0.0001$) but not significantly different from the Composition A (i.e., solid sawn virgin wood; $P = 0.0708$). The faster stress wave acoustic velocity across the laminated utility pole crossarms was likely due to the relatively higher densities of these crossarms (compared with the laminated crossarms of other composition schemes) both before and after penta treatment (Table 1). The stress wave acoustic velocity sample average for the laminated crossarm categories primed, incised, and control (in that order) were 4,946, 4,946, and 4,998 m/s before penta treatment and 4,561, 4,523, and 4,589 m/s after penta treatment.

In Figure 3, acoustic velocity values of the laminated crossarms are plotted versus the number of utility pole plies contained in the crossarms (regardless of surface preparation of the plies) both before and after penta treatment. In both cases, the relationship between acoustic velocity and number of utility pole plies was cubic.

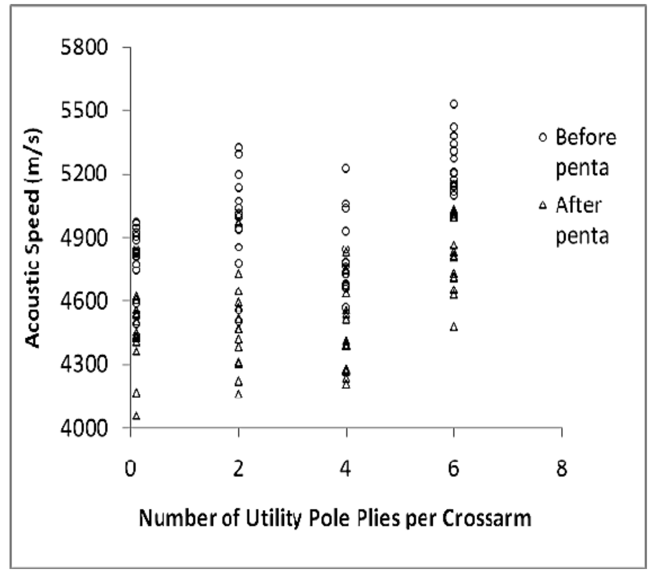

Figure 3.—Effect of pentachlorophonel treatment and composition scheme on the acoustic velocity of laminated crossarms.

A repeated-measures analysis on the laminated crossarm stress wave acoustic velocity population means (with fixed factors penta treatment, i.e., before and after, and composition scheme) revealed no penta treatment by composition scheme interaction ($P = 0.2317$) but highly significant main effects due to both penta treatment and composition scheme ($P < 0.0001$ for both). Overall, penta treatment reduced stress wave acoustic velocity by 8.1, 7.3, and 6.8 percent across laminated crossarms, solid sawn utility pole crossarms, and solid sawn virgin wood crossarms, respectively. Hoyle and Rutherford (1987) reported that the transverse stress wave acoustic velocity of Douglas-fir bridge beam timber completely penetrated with penta was approximately 65 percent of that of untreated wood. This indicates that penta in the wood can increase resistance to the propagation of stress waves. Bodig and Fyie (1986) found that full penetration by penta had no significant effect on strength and stiffness of solid sawn Douglas-fir lumber and laminated veneer lumber. Thus, the effect of penta on stress wave acoustic velocity should be taken into account when nondestructively accessing the mechanical properties of penta treated wood products.

Stress wave acoustic velocities of the plies were determined prior to gluing the plies into (laminated) crossarms. Stress wave acoustic velocities of the primed plies were determined prior to priming. Therefore, for the ply stress wave acoustic velocity analysis, surface preparation had but two levels, incised and untreated (or control). No surface preparation by composition scheme interaction and no surface preparation main effect were found in the stress wave acoustic velocity population means ($P = 0.0938$ for the interaction and 0.6180 for the surface preparation main effect); the composition scheme main effect was highly significant ($P < 0.0001$). Pairwise comparisons of the four composition scheme stress wave acoustic velocity averages (4,774 for B, 4,850 for C, 4,631 for D, and 5,139 for E) revealed that the average for Composition E was

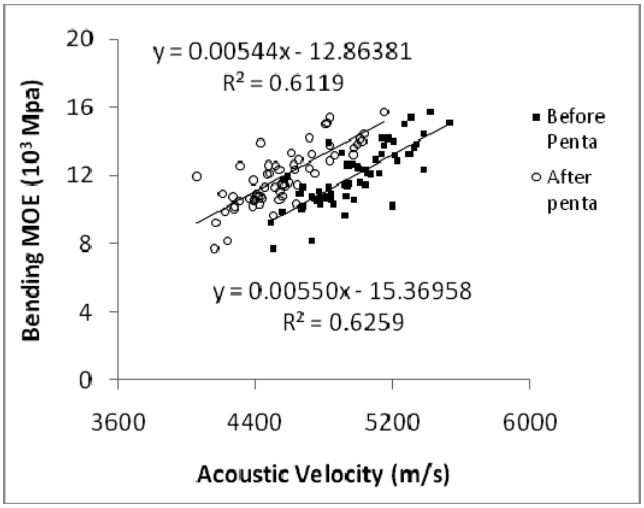

Figure 4.—The linear relationship between acoustic velocity and bending MOE for the 60 laminated crossarms before and after penta treatment.

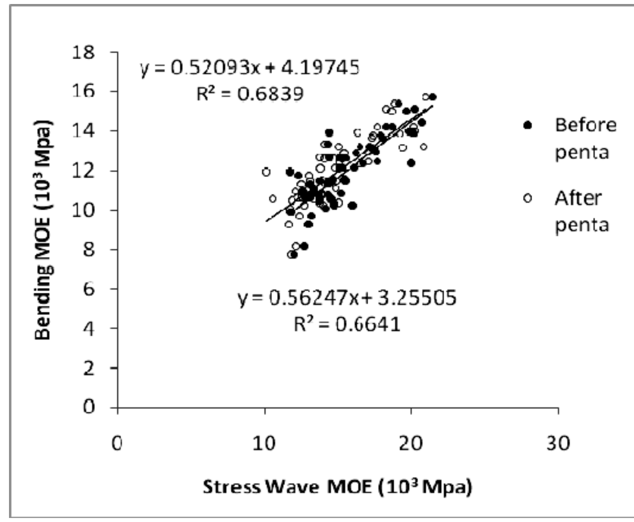

Figure 5.—The linear relationship between stress wave MOE and bending MOE for the 60 laminated crossarms before and after penta treatment.

highly significantly different from the averages of the other three compositions ($P < 0.0001$). These four stress wave acoustic velocity averages are comparable to the corresponding averages for the laminated crossarms, lower than the before-penta treatment crossarm averages (4,822 for B, 4,972 for C, 4,809 for D, and 5,249 for E) and higher than the after-penta treatment crossarm averages (4,442 for B, 4,515 for C, 4,444 for D, and 4,829 for E).

Simultaneous plots of bending MOE versus stress wave acoustic velocity before penta treatment and bending MOE versus stress wave acoustic velocity after penta treatment appear in Figure 4 for the laminated crossarms, together with the fitted regression lines. Penta treatment had little effect on the slopes of the fitted lines, both of which were highly significant ($P < 0.0001$ for both) and nearly parallel, with slopes 0.00550 and 0.00544 before and after treatment, respectively (0.00544 is a 1.1% decrease from 0.00550). Stress wave acoustic velocity can be used to predict bending MOE of the laminated crossarms with R^2 slightly greater than 60 percent both before and after penta treatment. The difference in intercepts for the two fitted lines is due to the decrease in acoustic velocity after penta treatment (see Table 4).

MOE_{sw} averages, both before and after penta treatment, appear in Table 4. These averages are larger than the actual bending MOE averages of Table 1 for each composition scheme of Figure 1. Simultaneous plots of bending MOE versus MOE_{sw} before penta treatment and bending MOE versus MOE_{sw} after penta treatment appear in Figure 5 for the laminated crossarms, together with the fitted regression lines, both of which were highly significant ($P < 0.0001$ for both). Penta treatment had more effect on the slopes of the lines in Figure 5 than in Figure 4. Although the fitted lines are not parallel, the slopes differ in the second decimal place only (0.56247 before penta treatment and 0.52093 after penta treatment; furthermore, 0.52093 is a decrease of only 7.4% from 0.56247). MOE_{sw} can be used to predict bending MOE of the laminated crossarms with R^2 slightly greater than 65 percent both before and after penta treatment.

As expected, no significant relationship was found between MOR and stress wave acoustic velocity values for laminated crossarm either before or after penta treatment.

Summary and Conclusions

Crossarms were fabricated according to six composition schemes and evaluated for strength, stiffness, strain, and acoustic properties. Of the six composition schemes, only the solid sawn utility pole crossarms failed to meet the minimum required strength of the ANSI standard. Furthermore, the strengths of the laminated crossarms of all four composition schemes were not significantly different from the strength of the commercial solid sawn virgin wood crossarms (Table 3). With the exception of the solid sawn utility pole crossarms, the strengths of all composition schemes were comparable to crossarm strengths appearing in the literature. Neither crossarm composition nor surface preparation had significant effect on the strength of laminated crossarms. Bending MOE averages for both solid sawn virgin wood crossarms and laminated crossarms made entirely of utility pole plies were significantly different (higher) than those for the other four composition schemes but not from each other. Maximum strain of the laminated crossarms was found to decrease as the number of utility pole plies increased. Significant linear relationships were found between stress wave acoustic velocity and bending MOE for the laminated crossarms. Penta treatment had little effect on the slopes of these two regression lines. Significant linear relationships were also found between MOE_{sw} and bending MOE for laminated crossarms, with penta treatment having more effect on the slopes of the regression lines in this case. MOE_{sw} after penta treatment was slightly lower than MOE_{sw} before penta treatment. Bending MOE was uniformly lower than MOE_{sw}, both before and after penta treatment. Penta treatment significantly reduced stress wave acoustic velocity for the laminated crossarms as well as for the solid sawn virgin wood crossarms and for the solid sawn utility pole crossarms. The stress wave acoustic velocity averages of the virgin wood plies were very close to the corresponding averages of the virgin wood crossarms made from these plies. However, as the number of utility pole plies in the laminated crossarms increased, ply averages and the corresponding crossarm averages tended to drift apart. For the laminated crossarms, ply surface preparation had no significant effect on either bending MOR or bending MOE or on stress wave acoustic velocity either before or after penta treatment.

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