Laminated Crossarms Made from Decommissioned Chromated Copper Arsenate–Treated Utility Pole Wood. Part II: Preservative Retention, Glue-Line Shear, and Delamination

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Abstract

Laminated utility pole crossarms constitute one of the potential industrial products that can be produced from decommissioned wood utility poles. A previous report evaluated the mechanical properties of laminated utility pole crossarms made from decommissioned chromated copper arsenate (CCA)–treated southern pine (*Pinus* spp.) utility pole wood, untreated virgin wood, and a mixture of virgin wood and decommissioned utility pole wood. In particular, the bending strength, stiffness, and acoustic properties were assessed after pentachlorophenol (penta) retreatment. This study evaluated CCA and penta retention, glue-line shear, and glue-line delamination of the laminated crossarms. The results of this study show that, after penta retreatment, penta retention increased in correlation to the presence of increasing numbers of treated wood plies in the beams. All the laminated crossarms met the minimum shear strength requirement of 8.60 MPa, which is specified in American Society for Testing and Materials (ASTM) Standard D2559. Most of the laminated crossarms (22 of 24) showed a delamination average of less than 5 percent. However, none of the beams met the individual glue-line delamination requirement (1%) of ASTM Standard D2559. More glue-line delamination was found between two utility pole wood plies and between a utility pole wood ply and a virgin wood ply than between two virgin wood plies. Delamination could be a concern for utility pole wood laminated crossarms to be used in an adverse environment. A better gluing system is needed to improve the delamination performance of utility pole wood laminated beams for exterior applications.

In recent years, a rising concern for the disposal of preservative-treated wood has generated interest in the reuse and recycling of decommissioned treated wood. Reusing decommissioned preservative-treated wood extends the service life of the wood and is the most favorable environmental option. A large portion of decommissioned wood utility poles remain 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). Laminated utility pole crossarms are one of the potential industrial products that can be made from decommissioned utility pole wood.

Glue-line bonding strength and delamination properties determine the integrity and durability of laminated beams in adverse environments. Previous reports showed that large delamination (particularly more than 1% in individual glue

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lines) often failed the beams after accelerated exposure (Piao et al. 2009a, 2009b). This large delamination occurred in beams made of untreated virgin wood as well as in beams constructed from decommissioned chromated copper arsenate (CCA)–treated wood. Thus, a further characterization of crossarm glue-line delamination and shear will increase the understanding of the delamination mechanisms of laminated crossarms. Moreover, recycled decommissioned preservative-treated wood often requires retreatment with the same or different preservatives in the wood, depending on the applications of the new products. In particular, pentachlorophenol-treated crossarms usually are more dimensionally stable and have fewer checks than CCA-treated crossarms. Therefore, laminated crossarms made from decommissioned CCA-treated utility pole wood, for example, may be retreated with pentachlorophenol (penta or PCP). A previous study showed that the gain in CCA retention as a result of CCA retreatment for beams made of decommissioned CCA-treated utility pole wood was comparable to the gain in CCA retention for the beams made of untreated virgin wood (Piao et al. 2009a). It is necessary to investigate penta absorption of decommissioned CCA-treated wood after penta retreatment. Therefore, the aims of this study were (1) to determine the delamination properties of laminated crossarms made entirely from virgin wood, entirely from decommissioned CCA-treated wood, and from a mixture of decommissioned CCA-treated wood and virgin wood, and (2) to determine the penta retention as affected by the CCA in the wood.

This study was one of our ongoing studies focusing on the reuse and recycling of decommissioned preservative-treated utility pole wood. The research results on the reuse of decommissioned penta-treated utility pole wood will be reported in the future.

Materials and Methods

Forty-five solid-sawn and 60 laminated crossarms were constructed for this study. The procedures for the fabrication of laminated crossarms made of decommissioned utility pole wood were described in detail in a previous report (Piao and Monlezun 2010). They are briefly summarized here.

Of the 45 solid-sawn crossarms, 22 were made of virgin southern pine and 23 were made of decommissioned CCA-treated utility poles. The 22 solid-sawn virgin southern pine crossarms were obtained from a commercial crossarm producer. The 23 solid-sawn utility pole wood crossarms were cut from either the bottom or the middle section (not from the top) of decommissioned wood utility poles.

Of the 60 laminated crossarms, each was composed of six plies that measured 102 mm wide by 19 mm thick by 2.44 m long. Each ply was cut from either virgin pine or decommissioned CCA-treated utility pole wood according to one of four possible composition schemes (Fig. 1):

Composition B: All six plies were made of virgin wood.

Composition C: The two middle or core plies were made of decommissioned CCA-treated utility pole wood, and the four outer plies (two top and two bottom) were made of virgin wood.

Composition D: The four middle plies were made of decommissioned CCA-treated utility pole wood, and the two outer plies (one top and one bottom) were made of virgin wood.

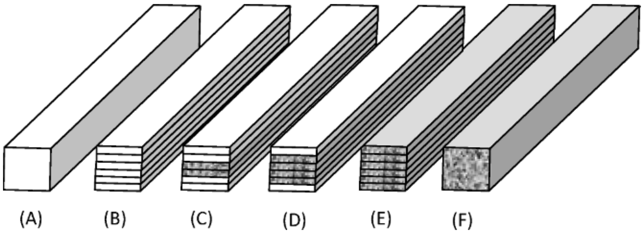

Figure 1.—A schematic diagram of the crossarms made for this study: (A) a solid-sawn crossarm fabricated from untreated virgin wood, (B) a laminated crossarm fabricated entirely from untreated virgin wood, (C) a laminated crossarm fabricated from four untreated virgin wood face plies and two utility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

Composition E: All six plies were made of decommissioned CCA-treated utility pole wood.

Fifteen laminated crossarms were fabricated for each of the four composition schemes.

One hundred eighty virgin pine plies and 180 decommissioned CCA-treated utility pole wood plies were prepared. Prior to the binding process, the surfaces of the plies used to construct the laminated crossarms were treated by one of two surface preparation methods (priming or incising) or were left untreated. Of the 15 laminated crossarms that were fabricated for each composition scheme, five were composed of primed plies, five were composed of incised plies, and five were composed of untreated plies. Therefore, of the 60 laminated crossarms that were fabricated, 20 were made of primed plies, 20 were made of incised plies, and 20 were made of untreated plies. The primer (commercial name MO-654) used in this study was obtained from Hexion Co. (Highpoint, North Carolina). MO-654 is a clear, colorless, odorless liquid chemical. According to the manufacturer, MO-654 is a surface-treating agent used to improve the strength of the bond between individual layers of CCA-treated lumber.

Resorcinol phenol formaldehyde (RPF; LT-5210 with 8% [wt/wt] powder hardener FM6210S) resin was uniformly applied to the binding surface of each primed or untreated ply at 463 g/m^2 regardless of whether the ply was made of CCA-treated utility pole wood or virgin wood. For incised plies, 506 g/m^2 of resin was applied. The beams were kept under pressure (0.86 MPa) at room temperature for 24 hours to cure the resin. After being conditioned in a non–air-conditioned building for 3 weeks, all crossarms were treated or retreated with pentachlorophenol (penta) in a wood preservative treatment mill. The RPF was obtained from Hexion Co. (Springfield, Oregon).

Each crossarm was then tested in bending according to the standard two-point loading flexural testing procedure specified in ASTM Standard D198-02, Section Flexure (ASTM International 2002). Two-point loading was applied symmetrically with 56 cm between load points on a 2.2-m span. Load was applied from the top of the beam through two bearing blocks. The testing speed was about 8 mm/min. Each beam was loaded to failure in 6 to 10 minutes. The peak load, modulus of rupture, and modulus of elasticity of each crossarm were measured. Photos were taken during the test of each beam for failure mode assessment. Figure 2 shows the setup for the bending test. Each beam was

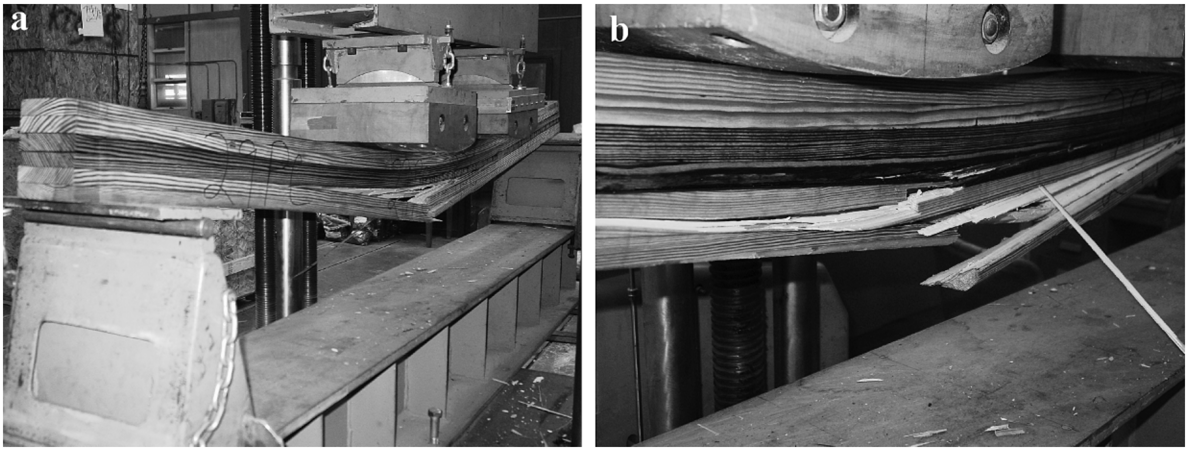

Figure 2.—Bending tests of laminated crossarms made of decommissioned chromated copper arsenate–treated utility pole wood: (a) a laminated beam (Composition C) was tested in two-point loading and (b) failure detail of a laminated crossarm after the bending test.

supported by two metal bearing plates that were supported by fixed knife-edge reactions.

After flexural testing, two of the five failed laminated crossarms from each composition scheme (i.e., Compositions B to E) and surface preparation method (i.e., primed, incised, or untreated) and two solid-sawn crossarms made of virgin southern pine (i.e., Composition A) and utility pole wood (i.e., Composition F) crossarms were randomly selected. A total of 24 laminated crossarms (3 surface preparation methods × 4 composition schemes × 2 duplicates) and 4 solid-sawn crossarms (2 materials × 2 duplicates) were selected and then tested for preservative retention, glue-line shear, and glue-line delamination in accordance with the standard procedure specified in American Wood Protection Association (AWPA) Standard A9-01 (AWPA 2006a) and ASTM Standard D2559-04 (ASTM International 2004a).

Prior to the cutting, shear and delamination samples were marked off along each selected beam. Care was exercised to situate the shear and delamination samples away from the failure spot in the middle of each beam. When a failure surface went through a shear or delamination sample, the sample was reglued at the failure surface immediately after it was removed from the beam. The shear or delamination data collected at the reglued glue lines were discarded. Results show that, of all the shear and delamination samples removed from the beams, only a few were reglued. Figure 3 illustrates the shear stair and delamination samples that were cut from a laminated beam.

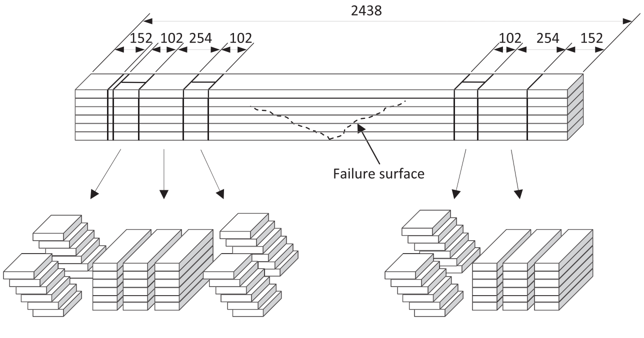

Figure 3.—Diagram illustrating the locations (mm) of the stair shear samples and delamination samples cut from a laminated beam after a destructive bending test.

The sampling procedure for retention, shear, and delamination measurement is as follows. A 152-mm section was removed from each end of the failed laminated and solid-sawn crossarms and discarded. A 25-mm contiguous crossarm section was then removed from one end of each remaining crossarm and used for the CCA and penta retention evaluation. Each laminated crossarm section was separated into ply segments by cutting along each of the five glue lines, and each solid-sawn crossarm section was cut in a similar way. Each of the six resulting samples was cut into 13-mm blocks for CCA and penta retention measurement. Each block sample was then dried in an oven at 60°C for 48 hours prior to testing. After drying, block samples were chopped and ground into powder passing a US standard 30-mesh sieve. An X-ray spectrometer was used to measure the CCA and penta retention rates for each block according to AWPA standard A9-01 (AWPA 2006a).

Glue-line shear strength was measured on six stair samples taken from each of the two laminated crossarms. Two stair samples were taken at each of three locations along the length of each beam. Two of the three locations were situated at one side of the failure spot of the failed beam, and one was situated at the other side of the failure spot. The crossarm block at each location produced two stair samples whose grain direction in the wood was parallel to the direction of loading during test. A total of 144 shear stair samples (3 surface preparation methods × 4 composition schemes × 2 crossarms × 6 duplicates) were tested for glue-line shear strength according to ASTM Standard D2559-04 (ASTM International 2004a). Each stair sample was tested for shear strength using a shearing tool recommended by ASTM Standard D905-04 (ASTM International 2004b). The loading speed of the moving head was 12 mm/min. Each glue line was tested at a uniform loading rate to failure. The shear strength of each glue line was calculated on the basis of the bonded area between two laminations.

In addition to the stair samples that were cut from each of the 24 laminated beams, six delamination samples also were cut from each beam according to the ASTM Standard D2559-04 (ASTM International 2004a). These delamination samples each measured 76 mm long by 127 mm wide by

114 mm high. Three samples were removed from one side of the failure spot, and three were removed from the other side of the failure spot. A total of 144 delamination samples (3 surface preparation methods × 4 composition schemes × 2 crossarms × 6 duplicates) were obtained and tested for glue-line delamination. The three-cycle accelerated delamination test was conducted as follows (ASTM International 2004a).

1. The test samples were first submerged underwater using a screen and weight in a pressure vessel at room temperature. A vacuum of 635 mm Hg was drawn to the vessel and held for 5 minutes. Immediately after the vacuum was released, a pressure of 5.27 kg/cm^2 was applied for 1 hour. The vacuum–pressure cycle was then repeated. The soaked samples were dried in an oven at 65.5°C for 21 hours.
2. After drying in Step 1, the samples were returned to the pressure vessel. Steam at 100°C was introduced into the vessel and flew over the samples for 1½ hours. The drain was kept open during the entire 1½-hour steam treatment. Tap water was then admitted to the vessel, and a pressure of 5.27 kg/cm^2 was applied for 40 minutes. The samples were then placed in an oven and dried at 65.5°C for 21 hours.
3. The first cycle was repeated once, making the duration of the complete period 3 days.

After the three-cycle treatment, the total length of open joints (i.e., delamination) on the end-grain surfaces of each sample was measured.

Factorial analyses of variance were used to analyze preservative retention, glue-line shear, and glue-line delamination data for the direct test of laminated and/or solid-sawn beams made of decommissioned CCA-treated utility pole wood and untreated virgin wood.

Results and Discussion

Penta retention after retreatment

After fabrication, each laminated crossarm was either treated or retreated with penta. Therefore, the laminated crossarms made of virgin wood plies (Compositions A and B) contained penta only, while the laminated crossarms made of mixed virgin wood and treated wood plies (Compositions C and D), the laminated crossarms made of treated wood plies only (Compositions E and F), and the solid-sawn crossarms (Composition F) directly cut from decommissioned utility poles contained both penta and CCA.

The penta and CCA retention averages of the laminated and solid-sawn crossarms appear in Tables 1 to 3. The penta retention averages of the laminated crossarms were 4.1, 4.7, 4.8, and 5.2 kg/m^3 for Compositions B, C, D, and E, respectively. The penta retention averages of solid-sawn crossarms, on the other hand, were 3.6 and 7.0 kg/m^3 for Compositions A and F, respectively. The penta retention specified for crossarms in AWPA standard Use Category UC3B is greater than 6.4 kg/m^3 (AWPA 2006b). Compared with this standard value, all the laminated crossarms (Compositions B to E) and solid-sawn virgin wood crossarms (Composition A) failed to meet the standard requirement.

Analysis of variance revealed that the composition scheme's main effect was significant ($P < 0.0001$). Pairwise comparisons of these sample averages revealed that the penta retention average for Composition B (all virgin wood plies) was significantly lower than the penta retention averages for Compositions C, D, and E ($P \leq 0.0018$). Because the number of utility pole wood plies in the crossarms was the only variable among the six composition schemes, penta retention was likely different because of the presence of utility pole wood plies in the crossarms.

The surface preparation's main effect on penta retention was found to be significant ($P = 0.0018$). It was expected that incision would prove more favorable for penta penetration into the wood and therefore that incised beams would contain more penta. The test results showed, however, that the penta retention averages for the untreated, primed, and incised crossarms were 4.9, 4.5, and 4.5 kg/m^3, respectively. The penta retention average for the untreated crossarms was significantly higher than the penta retention average of the primed ($P = 0.0019$) or incised ($P = 0.0026$) crossarms.

A further examination of the data in Table 1 reveals that the penta retention averages of the control crossarms in Composition C and E groups registered higher than the averages of all the other beams in Composition B and D groups. Table 1 also shows that the CCA retention for Compositions C and E registered the highest among the averages for all the other beams (primed, incised, and control) in Compositions B and D. As mentioned earlier, the significant effect of surface preparation also was likely due to the greater CCA retention in the control crossarms. It was not understood that the presence of CCA in wood favored penta absorption. One possible reason for the increased penta absorption in high-CCA-retention beams could be that transient pass ways and microcapillaries in wood cell walls may have been opened up while the wood was pressure treated with CCA. These pass ways and cavities may have remained open by the CCA particles after treatment and thus led to increased penta absorption (higher retention) when utility pole wood was retreated with penta. Incising has long been used to increase the transverse flow of preservatives in wood (Morrell et al. 1998). Therefore, the weak, positive incising effects on penta absorption likely were masked by the strong effects of CCA in the wood. The results suggest that the penetration of penta was more effective in recycled CCA-treated utility pole wood than in untreated virgin wood.

Table 2 contains penta and CCA retention averages in each of the six plies (laminated) or layers (solid-sawn) of

Table 1.—Pentachlorophenol (penta) and chromated copper arsenate (CCA) retention (kg/m^3) of laminated crossarms prepared by three surface preparation methods.

	Composition[a]			
Surface preparation	B (0/6)	C (2/6)	D (4/6)	E (6/6)
Penta				
Priming	4.0	4.3	4.6	4.9
Incising	4.2	4.9	5.2	4.2
Control	4.1	5.0	4.5	6.5
CCA				
Priming	0	2.3	5.1	6.7
Incising	0	2.5	3.6	7.1
Control	0	2.7	4.4	7.5

[a] Crossarm composition scheme with the number of recycled utility pole wood plies/total number of plies given for laminated crossarms.

Table 2.—Pentachlorophenol (penta) and chromated copper arsenate (CCA) retention averages (kg/m^3) of plies of laminated and solid-sawn crossarms made of virgin and decommissioned CCA-treated utility pole wood.

	Composition[a]					Composition		
Plies	B (0/6)	C (2/6)	D (4/6)	E (6/6)	Average	F[b]	A[c]	Main effect
Penta								
1	5.5	4.7	5.5	5.9	5.4	7.7	4.3	6.0
2	3.6	3.4	4.3	5.3	4.2	7.2	3.4	5.3
3	3.5	5.8	4.3	6.5	5.0	6.0	3.2	4.6
4	3.6	6.3	4.5	4.2	4.6	6.0	3.9	5.0
5	3.5	3.4	4.7	5.2	4.2	7.4	3.2	5.3
6	5.1	4.9	5.5	4.3	5.0	7.7	3.3	5.5
CCA								
1	0	0	0	6.9	—	6.1	0	—
2	0	0	6.9	7.2	—	5.0	0	—
3	0	5.5	6.0	7.1	—	5.1	0	—
4	0	7.3	5.5	7.7	—	7.8	0	—
5	0	0	6.7	7.7	—	6.0	0	—
6	0	0	0	6.1	—	6.9	0	—

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

Table 3.—Pentachlorophenol retention (kg/m^3) of samples across plies or layers of laminated and solid-sawn crossarms made of virgin and decommissioned chromated copper arsenate–treated utility pole wood.

Sample location	Composition[a]					Composition		
	B (0/6)	C (2/6)	D (4/6)	E (6/6)	Average	A[b]	F[c]	Main effect
1	4.8	5.1	5.4	5.5	5.2	4.1	6.6	5.3
2	3.9	4.7	4.6	5.0	4.6	3.6	6.6	5.1
3	3.7	4.4	4.5	4.9	4.4	3.4	6.8	5.1
4	3.7	4.6	4.5	5.0	4.4	3.3	6.5	4.9
5	3.7	4.7	4.7	5.0	4.5	3.3	6.2	4.7
6	4.1	5.3	4.8	5.2	4.9	3.4	7.4	5.4
7	4.8	4.5	5.1	5.9	5.1	3.7	9.1	6.4

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

laminated and solid-sawn crossarms tested in the study; Table 3 contains the penta retention averages in each of the seven samples across all six plies (laminated) or layers (solid-sawn) of laminated and solid-sawn crossarms. Penta retention averages of each ply or layer for all the composition schemes are presented in Table 2. In addition, penta retention averages of each sample for all the composite schemes are presented Table 3. As expected, the top and bottom plies of the laminated crossarms (Compositions B to E) and the top and bottom layers of the solid-sawn crossarms (Compositions A and F) absorbed more penta than the center plies or layers (Table 2). Similarly, penta retention of samples located in the outer edge areas of each ply was greater than the penta retention of samples located in the central regions (Table 3).

The penta retention averages of the solid-sawn virgin wood (Composition A) and the utility pole wood (Composition F) crossarms were 3.5 and 7.0 kg/m^3, respectively, which were the lowest and the highest among all the composition schemes. The utility pole wood crossarms were cut from decommissioned distribution poles wood, which had a lower average density and higher CCA retention than the commercial solid-sawn crossarms. Therefore, the low density and the presence of CCA in the solid-sawn utility pole wood crossarms were among the factors that contributed to their high penta absorption after retreatment. Therefore, decommissioned CCA-treated utility pole wood is expected to absorb more penta in retreatment.

Glue-line shear

Table 4 summarizes the shear strength and corresponding wood failure for the 24 crossarms after the bending tests. Each value in the table represents an average of the shear strength values of 12 stair samples. All the laminated crossarms made entirely from virgin wood plies (Composition B), from a mixture of virgin wood and decommissioned treated wood plies (Compositions C and D), and entirely from decommissioned treated wood plies (Composition E) met the minimum shear strength requirement (8.60 MPa) by ASTM Standard D2559-04 (ASTM International 2004a).

Results of analysis of variance show that the composition scheme's main effect was not statistically significant ($P = 0.3416$). The average shear values for Compositions B, C, D, and E were 10.6, 10.6, 11.0, and 10.8 MPa, respectively. These shear averages may appear different because of

Table 4.—Glue-line shear and wood failure of laminated crossarms made of virgin wood and decommissioned chromated copper arsenate–treated utility pole wood.

Surface preparation	Composition[a] B (0/6)	C (2/6)	D (4/6)	E (6/6)	Main effect
Shear (MPa)					
Priming	10.9	10.9	11.6	11.5	11.2
Incising	10.5	10.7	10.4	11.1	10.7
Control	10.4	10.3	10.9	9.7	10.3
Wood failure (%)					
Priming	78	81	80	82	80
Incising	80	81	77	86	81
Control	80	79	82	76	80

[a] Crossarm composition scheme with number of recycled utility pole wood plies/total number of plies given for laminated crossarms.

sampling variability, not because of differences in the corresponding population's main effects.

The surface preparation's main effects were found to be significant ($P = 0.0010$). The shear averages for the primed, incised, and control beams were 11.2, 10.7, and 10.4 MPa, respectively. It was found that the shear average of the primed beams was significantly greater than the shear averages of the incised ($P = 0.0150$) and control ($P = 0.0003$) beams. The shear average of the incised crossarms was not significantly different from the shear average of the control crossarms ($P = 0.2738$). The effects of priming and incising on CCA-retreated utility pole wood beams were investigated in previous studies (Piao et al. 2009a, 2009b). Both priming and incising were found to have significant effects on the glue-line shear of CCA-treated utility pole wood beams before CCA retreatment. However, both surface preparation methods were found to have little effect on glue-line shear of the CCA-treated utility pole wood beams after CCA retreatment. Based on the results of this study and our two previous studies, it can be concluded that either priming the bonding surface with a primer or incising may have a minor positive effect on the glue-line shear strength of decommissioned CCA-treated utility pole wood.

For each laminated crossarm, five glue lines consolidated six wood plies into a beam. The two adherents of each glue line were either both virgin wood plies, one virgin wood ply and one utility pole wood ply, or both utility pole wood plies. The glue lines of each beam were numbered 1 to 5 from the top to the bottom of the beam. Table 5 contains the glue-line shear and wood failure of stair samples cut from laminated crossarms made of untreated virgin wood and decommissioned CCA-treated utility pole wood.

Table 6 contains the probability values of the pairwise comparisons among the shear averages of the five glue lines of the four composition schemes. It was found that the shear strength of Line 3 was significantly lower than the shear strengths of Line 1 ($P = 0.0149$) and Line 5 ($P < 0.0001$). In addition, the shear strength of Line 2 was significantly lower than the shear strengths of Line 1 ($P = 0.0080$) and Line 5 ($P < 0.0001$). Finally, the shear strength of Line 4 was significantly lower than the shear strength of Line 5 ($P = 0.0146$). Therefore, the central glue-line shear strength averages (Lines 2, 3, and/or 4) were significantly lower than the shear strength averages of the top and bottom glue lines (Lines 1 and 5).

For Compositions C to E, the two adherents of the central glue lines were primarily decommissioned CCA-treated wood plies. Therefore, the glue-line bonding was primarily between two decommissioned treated wood plies or between a virgin wood ply and a decommissioned treated wood ply. The lower shear strengths of the central glue lines were likely due to the interference of CCA in the decommissioned treated wood plies to the glue bonding between the two adherents. Previous studies have shown the interference

Table 5.—Glue-line shear and wood failure of stair samples cut from laminated crossarms made of untreated virgin wood and decommissioned chromated copper arsenate–treated utility pole wood.

Stair no.	Composition[a] B (0/6)	C (2/6)	D (4/6)	E (6/6)	Main effect
Shear (MPa)					
1	10.4	12.7	11.9	11.6	11.7
2	10.3	10.1	10.4	10.2	10.3
3	10.2	9.3	10.7	11.1	10.3
4	10.4	10.8	10.8	11.1	10.8
5	11.4	11.6	12.2	10.1	11.3
Wood failure (%)					
1	81	82	77	81	80
2	76	81	78	81	79
3	79	76	79	82	79
4	80	79	82	83	81
5	82	82	81	79	81

[a] Crossarm composition scheme with number of recycled utility pole wood plies/total number of plies given for laminated crossarms.

Table 6.—Probability values of pairwise comparisons between shears of five glue lines.

Glue line	Glue line 1	2	3	4	5
1	—				
2	0.0080	—			
3	0.0149	0.8842	—		
4	0.3780	0.0768	0.1149	—	
5	0.1190	<0.0001	<0.0001	0.0146	—

[a] $P > |t|$ for H_0: least squares mean (i) = least squares mean (j).

of CCA on glue bonding of CCA-treated wood (Wang et al. 2001; Herzog et al. 2004; Lorenz and Frihart 2006; Piao et al. 2009a, 2009b). Since shear is maximal in the center glue line (Line 3) and minimal in the top and bottom glue lines (Lines 1 and 5) when a beam is subjected to bending, the low shear strength of the beam in the center glue line would result in shear failure. Therefore, in applications where shear failure is a major concern, one or both center plies can be replaced with virgin wood plies to improve the shear capacity of the beams.

It was found that the main effects of composition scheme, surface preparation method, and glue-line location on wood failure were not significant. The *P* values for the main effects of composition scheme, surface preparation, and glue-line location were 0.4236, 0.6526, and 0.1093, respectively. However, the *P* values for the pairwise comparisons of the glue line main effects ''Line 5 with Line 3'' and ''Line 1 with Line 3'' were 0.0239 and 0.0580, respectively. Of the five glue lines, the estimated wood failure percentage averages were 81.0, 79.2, 78.4, 81.0, and 81.5 percent for Lines 1 through 5, respectively. This indicates that the estimated glue-line wood failure percentage average of Line 3 (the center line) was likely lower than the estimated glue-line wood failure percentage average of Lines 1 and 5 (top lines). This result agreed with previous findings that glue-line shear strength of Line 3 was lower than the glue-line shear strength of the two top glue lines (Lines 1 and 5). As mentioned previously, the interference of CCA in the wood reduced the shear strength and wood failure of the glue lines containing utility pole wood plies.

Delamination

Delamination is a measure of an adhesive for bonding wood into structural laminated products for uses in adverse environments. It is measured in percentage by dividing the delamination length in a glue line by the total length of the measured glue line.

After a 3-day accelerated delamination exposure required by ASTM Standard D2559-04 (ASTM International 2004a), less swell, checks, and delamination were observed in the virgin wood beam delamination samples than in the decommissioned utility pole wood beam delamination samples. Previous results indicated that more swell, checks, and delamination occurred in virgin wood beam delamination samples before preservative CCA treatment than in virgin wood beam delamination samples after CCA treatment (Piao et al. 2009a, 2009b). The overall delamination averages of the virgin wood beams with and without CCA treatment were 3.55 and 6.42 percent, respectively. It was then concluded that metal deposits (CCA) reduced swelling, likely because the CCA blocked some of the hydroxyl groups of wood fibers. In the present study, penta treatment was found to have a similar dimensional stabilizing effect on laminated crossarms. The overall delamination average of virgin wood beams (Composition B) was 1.87 percent.

Table 7 contains the delamination averages of the laminated crossarms after accelerated delamination exposure. Each value in the table is a delamination percentage average of 12 block samples that were cut from two laminated beams with six delamination samples per beam. Except for the control crossarms in Composition E, all the delamination averages shown in Table 7 were less than 5 percent. Furthermore, of the 24 crossarms tested in this study, all the laminated crossarms except for two (one control crossarm and one primed crossarm in Composition E) delaminated less than 5 percent of their total glue line lengths.

ASTM Standard D2559-04 (2004a) places an individual requirement on each of the six delamination block samples measured in a particular beam. No more than 20 percent of the permissible 5 percent maximum delamination can occur in any single glue-line individually for each of the six block samples taken from a particular beam. It was found that none of the 24 crossarms in this study met this standard requirement.

Three-factor analyses of variance revealed that the composition scheme of the crossarms significantly affected delamination ($P < 0.0001$). The delamination averages for Compositions B, C, D, and E were 1.87, 2.34, 2.51, and 4.43 percent, respectively. The delamination average of Composition E registered significantly greater than the delamination averages of Compositions B, C, and D ($P < 0.0001$). This suggests that a higher content of decommissioned treated wood in Composition E likely leads to a greater delamination in the beam members. As mentioned previously, the presence of CCA in the decommissioned treated wood may have interfered with the bonding between two treated wood plies and between one treated wood ply and one virgin wood ply. The CCA interference to the bonding

Table 7.—Glue-line delamination (%) of laminated crossarms made of virgin wood and decommissioned chromated copper arsenate–treated utility pole wood.

	Composition[a]				
	B (0/6)	C (2/6)	D (4/6)	E (6/6)	Main effect
Prime	2.55	1.63	2.67	4.20	2.76
Incise	1.38	2.67	2.54	3.77	2.59
Control	1.68	2.71	2.32	5.31	3.01
Main effect	1.87	2.34	2.51	4.43	2.79

[a] Crossarm composition scheme with number of recycled utility pole wood plies/total number of plies given for laminated crossarms.

was more pronounced at the edges of each ply, where a higher CCA retention is expected.

Surface preparation methods were found to have little effect on beam delamination ($P = 0.6977$). The delamination averages for the beams that were primed, incised, and untreated were 2.76, 2.59, and 3.01 percent, respectively. The difference among the delamination averages was due to sampling variability only and was not due to the corresponding population means. A previous study found that incision reduced glue-line delamination for virgin wood beams (Piao et al. 2009b). In this study, the virgin wood beams (Composition B) that had been incised also exhibited lower delamination than the virgin wood beams that had been primed or untreated (control). The delamination averages of the virgin wood beams that had been primed, incised, and untreated were 2.55, 1.38, and 1.68 percent, respectively. The delamination average of the beams that had been incised was significantly lower than the delamination averages of the beams that had been primed ($P = 0.0146$) and untreated ($P = 0.0508$). Therefore, it was concluded that incision reduced the glue-line delamination of virgin wood laminated beams but had little effect on the delamination of the glue line between two treated wood plies.

Figure 4 displays the delamination averages of the five glue lines of each crossarm. It was found that the delamination averages of the five glue lines were significantly different ($P = 0.0032$). The delamination averages for the five glue lines were 2.18, 3.00, 3.28, 3.39, and 2.14 percent for Lines 1 through 5, respectively. Therefore, a higher delamination value would be expected for the glue lines between decommissioned treated wood plies and between virgin wood and treated wood plies.

Delamination could be a concern for utility pole wood laminated crossarms. A better gluing system may be needed to improve the delamination properties of decommissioned utility pole wood laminated beams for exterior applications. One such gluing system is isocyanate resin (Miyazaki and Nakano 2008). More research is warranted to improve the delamination properties of the laminated beams made of decommissioned CCA-treated utility pole wood and virgin wood as well.

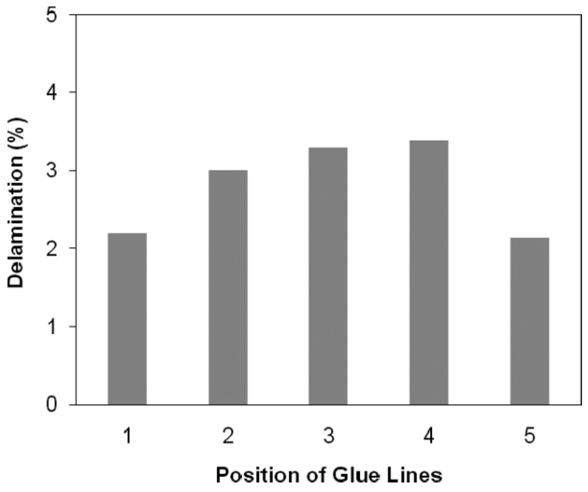

Figure 4.—Glue-line delamination averages of laminated crossarms made of decommissioned chromated copper arsenate–treated utility pole wood and untreated virgin wood.

Summary and Conclusions

In this study, laminated crossarms made of virgin wood and decommissioned utility pole wood were evaluated for CCA and penta retention, glue-line shear, and glue-line delamination. The results show that, after penta treatment, the penta retention averages of solid-sawn and laminated virgin wood beams registered significantly lower than the penta retention averages of solid-sawn and laminated utility pole wood beams. Penta retention averages increased with an increase of treated wood plies in the laminated beams. Penta penetrated more effectively into recycled utility pole wood plies than into virgin wood plies. Therefore, a beam made of mixed utility pole wood and virgin wood can be treated as a laminated crossarm made of virgin wood, whereas a beam consisted entirely of recycled utility pole wood plies can be treated at a lower pressure.

All the laminated crossarms met the minimum shear strength requirement by ASTM Standard D2559, whether the beams were made of virgin wood plies, decommissioned treated wood plies, or a mixture of virgin wood and decommissioned treated wood plies. For the five glue lines of each crossarm, the top and bottom glue lines (Lines 1 and 5) showed greater shear strength averages and lower delamination averages than the three central glue lines (Lines 2, 3, and 4). Surface preparation methods (priming and incising) had minor positive effects on the glue-line shear and delamination of decommissioned CCA-treated utility pole wood beams. The delamination averages of most of the laminated crossarms (22 of 24) were less than 5 percent. None of the beams, however, met the 1 percent individual glue-line delamination requirement specified in ASTM Standard D2559. Therefore, further research is warranted to examine other gluing systems of the same kind (RPF) or different adhesives (such as isocyanate resin) that may increase further the bonding strength and thus the delamination properties of the utility pole wood beams for exterior applications.

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