Glueline bonding performance of decommissioned CCA-treated wood. Part I: Without retreatment

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Abstract

Recently, public awareness of health risks associated with heavy metals in the environment has increased. Consequently, there has been increased concern regarding traditional methods of disposal of chromated copper arsenate (CCA) treated wood, such as landfilling and incineration. Reuse and recycling of decommissioned treated wood could be an environmental and potentially economical solution to the critical problem of disposal of treated wood. This study investigated the gluability of CCA-treated utility pole wood plies cut from decommissioned southern pine (*Pinus* spp.) utility poles. Two surface treatment methods (priming and incising) were evaluated for their efficacy in improving the bonding performance of decommissioned utility pole wood and untreated virgin wood. Effects of CCA retention and distribution on glueline shear strength and delamination were investigated. Results showed that CCA reduced glueline shear strength. Incising had a marginally positive effect on glueline shear strength and delamination. Unevenly distributed CCA in decommissioned utility pole wood may present a recycling challenge for laminated members. Some decommissioned CCA-treated poles might not be suitable for the production of laminated members due to potentially high delamination which could hinder performance in exterior applications.

Wood in a humid environment is susceptible to biological attack and degradation, primarily by insects and fungi. Therefore, most wood products intended for exterior applications must be treated with a chemical preservative. Preservative treatment may prolong the useful life of wood products in extreme environments by as much as 20 to 40 times that of untreated wood, thereby markedly reducing the need to harvest the forest (Morrell 2004).

Recently, public awareness of health risks and environmental degradation due to environmental arsenic has increased. Consequently, there has been increased concern regarding traditional methods of disposal of chromated copper arsenate (CCA) treated wood, such as landfilling and incineration. Each year in the United States, about 5 million metric tones (11 billion pounds) of spent preservative-treated wood are deposited in landfills (Falk 1997). In 2005, 65 percent of decommissioned treated wood was landfilled (WRAP 2005). Not only can rainwater leach preservatives from landfills (Jambeck et al. 2004), but the availability of landfill sites is diminishing. Burning of treated wood includes combustion and incineration. About 25 percent of decommissioned treated wood is combusted in the United States (WRAP 2005). Burning of preservative-treated wood produces smoke and ash that contains high concentrations of preservative chemicals. Only certified burners are permitted to incinerate treated wood. In 2004, the U.S. Environmental Protection Agency (EPA) phased out the use of CCA in residential applications. More rigorous regulations regarding the disposal of decommissioned treated wood are likely in the near future, which could result in prohibitive disposal costs for treated wood. Since CCA will continue to be one of the most commonly used preservatives for industrial applications, disposal costs for treated wood products will increase in the future as these products reach the end of their service lives. A solution to the disposal problem must be found in the near future.

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Decommissioned treated wood has the potential to be economically and safely reengineered into value-added exterior structural products. But, there are obstacles that must be overcome. For example, preservatives in the wood may interfere with the bonding of synthetic resins. Structural laminated composites are commonly consolidated using synthetic resins such as resorcinol phenol-formaldehyde (RPF). Waterborne preservatives (mainly CCA) reduce the shear strength of plywood (Thompson 1962, Choong and Attarzedah 1970, Hutchinson et al. 1977), adversely affect bending and internal bond properties of waferboard (Boggio and Gertjejansen 1982), negatively impact thickness swelling and mechanical properties of particleboard and flakeboard (Davis 1993, Vick et al. 1996, Munson and Kamdem 1998, Mengeloglu and Gardner 2000, Li et al. 2004, Clausen et al. 2006), adversely affect mechanical properties of wood-cement particle composites (Gong et al. 2004), and affect the delamination of laminated beams (Vick 1995, Tascioglu et al. 2003).

Several hypotheses have been offered to explain the adverse effects of waterborne preservatives on wood–adhesive bonding. For example, preservatives may reduce adhesive viscosity, decrease wood wettability, and reduce the number of hydroxyl groups available for hydrogen bonding (Thompson 1962, Bryant 1968, Hutchinson et al. 1977, Boggio and Gertjejansen 1982). Chow et al. (1973) showed that the surfaces of each microfibril in the secondary wall of wood treated with CCA are coated by a layer of metallic deposits about 1.5 to 2.0 nm thick. Similar results were found by Vick and Kuster (1992), who also reported that the surfaces of cell lumens of CCA-treated wood are covered with preservative deposits. These metallic deposits appear to prevent the bonding of wood to adhesive. Metal particles, however, are too small to block perforations in tracheids and vessel members in the xylem of wood. Therefore, more penetrative resins and/or thin wood substrates can achieve high-quality bonds between layers of treated wood (Vick and Kuster 1992, Prasad et al. 1994). The bonding of decommissioned preservative-treated wood with synthetic resins for structural laminated composites has not been adequately studied. Investigating the effects of retention rates of preservatives (waterborne and oilborne) on the bonding of treated wood will be crucial to the reengineering of decommissioned preservative-treated wood. The objectives of this study were to determine the joint effects of two cross-sectional locations (sapwood and heartwood) and three different surface preparation methods (i.e., chemical priming, physical incising, and control) on resin bonding strength and on delamination.

Materials and methods

Six decommissioned CCA-treated southern pine (*Pinus* spp.) utility poles were obtained from local power companies. These poles were decommissioned in 2007 and had service spans ranging from 7 to 13 years. Summary data obtained from the marks on the poles are listed in **Table 1**. Poles 3, 4, and 6 were complete poles when they were collected and had the original length as marked on the poles. Poles 1, 2, and 5 were not complete poles, and sections were missing from either the top and/or bottom.

Bonding members from these poles were obtained as follows. First, all of the metal attachments, such as wires and nails, were removed. The poles were air-dried under a shed for 2 months. After air-drying, consecutive 1.1-m (42-in.) sections were marked off along the entire length of each pole. Three of these 1.1-m sections were randomly selected for removal from each pole. After removal, each 1.1-m section was cut into boards and planed to a final thickness of 19.1 mm (3/4 in.). Six contiguous pieces of 19.1-mm-thick planed lumber, each greater than 177.8 mm (7 in.) in width, were taken from each 1.1-m section and stacked in their original order within the 1.1-m section. They were kept in this order within the stack for the remainder of the experiment. The 108 pieces of lumber (six pieces per 1.1-m section × three 1.1-m sections per pole × six poles) in the 18 stacks will, henceforth, be referred to as Sample A.

Table 1. — Summary data of the CCA-treated decommissioned utility poles. Poles 1, 3, and 5 were used in this study.

Pole #	Class	Original length	Actual length	Missing sections	Year marked	Service period ended
		----- (m) -----				
1	3	13.7	11.4	bottom	1995	2007
2	3	13.7	7.6	top	1995	2007
3	3	15.2	15.2	–	2000	2007
4	5	9.1	9.1	–	2000	2007
5	5	13.7	6.6	top and bottom[a]	1999	2007
6	5	10.7	10.7	–	1999	2007

[a] 3.7 m (12 ft) from the top and 2.1 m (7 ft) from the bottom were missing.

One inch (25.4 mm) was cut off of the end of each Sample A piece. These 1-inch pieces constitute Sample B. Each Sample B piece was then cut into 25.4 mm (1 in.) long by 25.4 mm (1 in.) wide by 19.1 mm (3/4 in.) thick blocks that were used to measure CCA retention rates from the outside to the center of the Sample A piece from which the blocks were cut. The blocks were dried in an oven at 103° ± 2°C (217° ± 4°F) for 24 hours and then ground into powder with a Wiley mill. An x-ray spectrometer was used to analyze the CCA retention rate for each block according to American Wood Protection Association (AWPA) standard A9-01 (AWPA 2006).

After Sample B removal, the remaining Sample A piece was trimmed to remove a margin from the entire length of the piece. The opposite side was cut so that the remaining Sample A piece was 127 mm (5 in.) in width. The resulting 1.0 m (41 in.) long by 127.0 mm (5 in.) wide by 19.1 mm (3/4 in.) thick Sample A pieces were used as plies for the beams in this study. Each ply was measured for volume, weight, and moisture content (MC) to estimate its specific gravity (SG). The plies were then glued together with an RPF resin (commercial name LT-5210) to form laminated beams, six plies per beam, three beams per decommissioned pole (a total of 18 beams: three beams per decommissioned pole × six decommissioned poles). Beams were trimmed so that each was 1.0 m (40 in.) long. Each beam was composed of six Sample A pieces from the same stack, maintaining the same order in the beam as in the stack. This kept the CCA retention about the same for the two surfaces of each glueline. Prior to gluing, both glue surfaces of each ply were treated in one of three different ways: not treated (i.e., control), incised, or primed with a surface primer used to improve the bonding of CCA-treated wood. Of the three beams made with wood from the same pole, one beam consisted of six pieces of lumber that had been primed only, one consisted of six pieces that had been incised only, while the six pieces that comprised the other were not treated. The three surface preparations were randomly assigned to the three Sample A stacks of lumber cut from the same pole prior to application. For incised beams, sample surfaces were incised at 10,000 incisions/m^2 (929 incisions/ft^2). In the priming treatment, sample surfaces were brushed with a chemical primer (commercial name MO-654) at 116 g/m^2 (0.024 lb/ft^2). MO-654 is a clear, colorless liquid chemical without odor. The SG of MO-654 was 1.01. According to the manufacturer, MO-654 is used as a surface treating agent to improve bonds in CCA-treated lumber. Both RPF resin and MO-654 were obtained from Hexion Co. (Springfield, Oregon).

Pieces of Grade C southern pine dimensional lumber 25.4 mm (1 in.) by 152.4 mm (6 in) by 6.1 m (20 ft) were obtained from a local store (the nominal dimension of 1 in. was actually 0.75 in.). Lumber plies 1.0 m (40 in.) long by 127.0 mm (5 in.) wide by 19.1 mm (0.75 in.) thick were cut from each piece. Each ply was measured for volume, weight, and MC to estimate its SG. The plies that were cut were formed into 18 groups, with each group containing six plies. The 18 groups were randomly divided into three clusters, six groups per cluster. The three surface preparations (control, incising, and priming) were randomly assigned to the three clusters, with all of the groups within the same cluster receiving the same surface preparation. These virgin wood plies were incised and primed on both sides at the same rates as were the utility pole plies. After administration of the surface preparation, the six plies in each group were glued together to form a beam. These 18 beams (six primed, six incised, six control) served as the untreated virgin wood control to the 18 beams made from decommissioned utility pole wood.

The RPF resin was uniformly applied to both surfaces of all of the plies of lumber assigned to the primed or untreated categories of surface preparation at the rate of 463 g/m^2 (0.095 lb/ft^2), whether the lumber was cut from CCA-treated decommissioned wood or virgin wood. For incised plies, 506 g/m^2 (0.104 lb/ft^2) of resin was applied to both CCA-treated utility pole wood and virgin wood plies. Beams were kept under pressure at room temperature for 24 hours to cure the resin. After gluing, beams were conditioned to an equilibrium moisture content (EMC) of 23° ± 2°C (73° ± 4°F) and 50 to 65 ± 5 percent relative humidity (RH).

A total of 36 beams were made. Each was 1.0 m (40 in.) long, 114.3 mm (4 1/2 in.) high, and 127.0 mm (5 in.) wide. After environmental conditioning, 18 of the 36 beams were directly tested for glueline shear strength and delamination according to the American Society for Testing and Materials (ASTM) Standard D2559 (ASTM 1996). Of these 18, nine were made of untreated virgin wood plies and nine were made of plies cut from CCA-treated decommissioned utility poles. The nine CCA-treated beams were obtained by randomly selecting one of the two poles with the same year of marking. The nine CCA-treated beams that were directly tested came from the plies that were cut from Poles 1, 3, and 5. The nine untreated virgin wood beams that were directly tested were obtained by randomly selecting three of the six virgin wood beams having the same surface preparation (i.e., incised, primed, or no surface preparation (control)). The 18 beams that were directly tested were the subject of this investigation. The remaining 18 beams (nine of decommissioned utility pole wood and nine of untreated virgin wood) were retreated with CCA and were tested according to the same ASTM standard. The results from that study will be presented in a future article.

In accordance with ASTM Standard D2559 (ASTM 1996), glueline shear strength were measured on six stair-samples taken from each of the 18 beams that were directly tested. Two stair-samples were taken at each of three locations along the length of each beam. Two of the three locations were toward the ends of the beam (one toward each end), and the other was at the center of the beam. Of the two stair-samples taken at each location along the length of each of the 18 CCA-treated utility pole beams, one consisted of lumber from the sapwood region of the pole from which it was cut, while the other came from the heartwood or sapwood/heartwood region, depending on the diameter of the pole.

In addition to the stair-samples that were cut from each of the 18 beams, six delamination samples, each 76.2 mm (3 in.) long by 127.0 mm (5 in.) wide by 114.3 mm (4.5 in.) high, were also cut from each beam according to ASTM Standard D2559 (ASTM 1996).

Statistical Models 1 and 2 described below were adopted to analyze glueline shear data and wood failure data for the direct test of beams made of lumber cut from decommissioned utility poles and beams made of virgin lumber, respectively.

$$\text{Model 1: } Y_{ijkl} = \mu_{jk} + \rho_i + \delta_{ij} + \varepsilon_{ijkl}$$

$$\text{Model 2: } Y_{ijk} = \mu_j + \delta_{ij} + \varepsilon_{ijk}$$

where:

Y = glueline shear/wood failure,
μ = fixed effect for the combination of surface preparation with CCA retention for Model 1, but surface preparation only for Model 2,
ρ = random pole effect,
δ = random beam effect, and
ε = random residual error.

The SAS procedures GLM and Mixed were used to process the glueline shear data and wood failure data (SAS 2008).

Results and discussion

SG, MC, and CCA retention

The decommissioned utility pole beams selected for direct testing were made from lumber cut from Poles 1, 3, and 5 (**Table 1**). Poles 1 and 3 had relatively wider growth rings and contained more springwood, while Pole 5 had narrower growth rings and contained more latewood. It was evident, then, that the SG of Pole 5 was likely greater than that of either Poles 1 or 3. The estimated SG that was measured on the plies cut from these poles ranged from 0.45 to 0.53 for Pole 1, 0.50 to 0.57 for Pole 3, and 0.62 to 0.66 for Pole 5. Estimated SG included both wood and preservatives, but not moisture. Estimated SG of the poles only (excluding CCA) would be lower than that measured, because CCA is heavier than wood. The estimated SG of the plies cut from untreated virgin wood ranged from 0.47 to 0.54. The MC of all of the shear stair-samples tested ranged from 12 to 15 percent.

CCA retention values obtained from the blocks cut from the Sample B pieces indicate that CCA retention in treated poles decreases the closer the wood is to the center (or pith) of the pole. The plot of CCA retention (for total CCA and three components) vs. assay zone (distance from the outer surface in mm) for Pole 3 of this study is given in **Figure 1**. The plot shows a decrease in CCA retention from the outside surface to the center of the pole. This is typical of all of the poles in this study, as well as others studied by Piao et al. (2008). **Table 2** shows average CCA retention in the sapwood and heartwood samples of each beam. Substantial differences were found between sapwood and heartwood regions for Poles 3 and 5. Thus, in the analysis that follows, heartwood samples may be interpreted as those that retained less (usually much less) of the CCA with which they were treated, while sapwood samples may be interpreted as those that retained most (or a large portion) of the CCA with which they were treated.

Glueline shear

Table 3 summarizes shear strength and corresponding wood failure for the 18 beams in this study that were directly tested. Each value in the table is the average of the shear strength for the six stair-samples (both sapwood and heartwood samples) of each beam. For each stair-sample, five glueline shear strength values were measured. From these five, one overall shear strength value (i.e., the average of the five) was calculated for the stair-sample. In all cases, shear strength for a stair-sample refers to the overall shear strength. The overall shear strength values were those that were averaged in **Table 3**. All of the beams tested in this study met the minimum shear requirement of 9.04 MPa (1,310 psi) at 12 percent MC specified by ASTM Standard D2559 (ASTM 1996) except for the utility pole wood, control beam of Pole 5 and one of the virgin wood primed beams. Average sample wood failure for these two beams

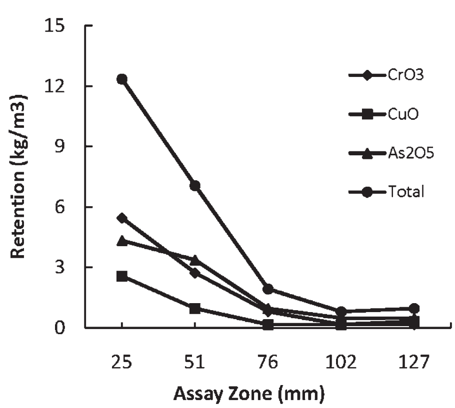

Figure 1. — CCA retention from the outer surface to the center across the top of decommissioned utility Pole 3. This 15.2-m- (50 ft) long Grade 3 pole was treated in 2000 and decommissioned in 2007.

Table 2. — Average CCA retention (kg/m^3) of beams made from three decommissioned CCA-treated utility poles.[a]

	Pole 1		Pole 3		Pole 5	
	Sap	Heart	Sap	Heart	Sap	Heart
Control	10.8	9.8	31.9	8.3	27.8	8.2
Primed	10.9	7.4	29.2	11.1	30.5	10.5
Incised	8.9	10.3	32.0	9.7	27.6	6.1

[a] Sap = sapwood region; heart = heartwood region.

was also the lowest in their respective groups, indicating that quality bonding between plies was not properly achieved in the two beams. Note that the corresponding shear strengths for Pole 5 were lower than those of the other two poles for each surface preparation, the only exception being that the Pole 5 incised sapwood stair-samples had a higher shear strength average than those of Pole 3 (**Table 3**).

It is likely that the high density of Pole 5 was a major cause for this reduced bonding performance. In addition, the greatest difference in shear strength averages between low CCA retention and high CCA retention stair-samples was observed for the control stair-samples of Pole 5. Both of these averages were less than the standard of 9.04 MPa. It may be the case that in high-density wood, high CCA retention caused a greater reduction in shear strength over low CCA retention for stair-samples that received no surface preparation. The average shear strength and wood failure of the nine beams made from decommissioned utility pole wood were 9.9 MPa (1,436 psi) and 70.3 percent, respectively, while the average shear strength and wood failure of the nine beams made from untreated virgin wood were 9.8 MPa and 58.6 percent, respectively. The high wood failure of decommissioned utility pole wood samples is likely because the decommissioned utility pole wood contained more juvenile wood and was aged in service. But, most beams made from decommissioned utility pole wood were comparable in glueline shear to the beams made from untreated virgin wood.

Table 4 contains the shear strength averages for each combination of surface preparation and cross-sectional region (heartwood and sapwood). Each is the average of nine glueline shear strength values, one for each of three stair-samples taken from each of three poles. Each of the three surface preparation main effects consists of the average of the two shear average values above it. Each of the two cross-sectional region main effects consists of the average of the three shear average values to the left of it. **Figure 2** displays the shear strength averages of **Table 4** in two different ways. In panel (a), shear averages were plotted vs. the levels of CCA retention for each surface preparation. In panel (b), shear averages were plotted vs. the three levels of surface preparation for each level of CCA retention. Using Model 1, it was concluded that there was no interaction between the population average shear values of surface preparation and cross-sectional region for beams made of lumber cut from the CCA-treated utility poles ($p = 0.7945$). Thus, the differences between the heartwood (low CCA retention) and sapwood (relatively high CCA retention) shear strength average values of **Table 4** for each of the three surface preparations were not statistically significant. The heartwood minus sapwood (low minus high CCA retention) mean shear differences 0.5 (10.5 to 10.0), 0.5 (10.9 to 10.4), and 0.9 (9.3 to 8.4) MPa for primed, incised, and control, respectively, were not equal because of sampling variation and not to actual differences between the corresponding population shear mean differences. This can be seen in panel (b) of **Figure 2**. The two "piecewise linear curves", one for each level of CCA retention, were not quite parallel. If the shear strength averages calculated from the data could be replaced with the shear strength population means, however, the two resulting "piecewise linear curves" would be parallel. Similarly, the three lines of panel (a) are not quite parallel. Nevertheless, if the shear strength averages calculated from the data could be

Table 3. — Shear strength averages and wood failure for beams made from decommissioned CCA-treated utility pole wood and beams made from untreated virgin wood.[a]

	Pole 1		Pole 3		Pole 5	
Treatment	Shear (MPa)	Wood failure (%)	Shear (MPa)	Wood failure (%)	Shear (MPa)	Wood failure (%)
Utility pole wood						
Control	9.3 (0.20)	79.5 (4.22)	10.0 (0.33)	74.1 (3.00)	7.1 (0.58)	57.4 (5.47)
Primed	10.7 (0.29)	80.7 (2.31)	10.5 (0.34)	61.3 (3.74)	9.5 (0.50)	68.8 (3.93)
Incised	11.2 (0.29)	65.8 (5.12)	10.3 (0.29)	84.1 (2.73)	10.5 (0.54)	59.8 (4.63)
Virgin wood						
Control	9.9 (0.37)	54.7 (4.50)	9.3 (0.30)	55.5 (4.11)	10.1 (0.23)	66.0 (3.76)
Primed	8.9 (0.24)	39.0 (3.92)	10.8 (0.21)	62.0 (4.42)	9.7 (0.24)	54.5 (3.25)
Incised	10.0 (0.28)	69.7 (3.72)	9.2 (0.25)	66.0 (3.39)	10.5 (0.23)	59.5 (5.23)

[a] Values in parentheses are standard errors.

Table 4. — Shear strength averages (MPa) for beams made from decommissioned CCA-treated utility pole wood classified by surface preparation and Cross-sectional region.

Cross-sectional region	Surface preparation			
	Primed	Incised	Control	Main effects
Sap	10.0	10.4	8.4	9.6
Heart	10.5	10.9	9.3	10.2
Main effects	10.2	10.7	8.8	

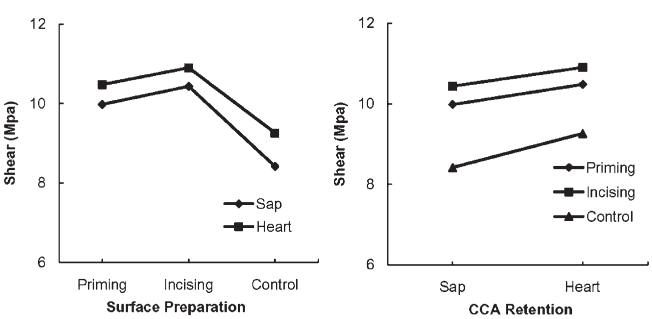

Figure 2. — Shear strength averages for utility pole beams displayed by cross-sectional region and surface preparation method (two different plots of the shear strength averages of ***Table 4****).*

replaced with the shear strength population means, the three resulting lines would be parallel. The main effect of cross-sectional region (CCA retention level) on shear is statistically significant ($p = 0.0220$). Therefore, the difference 0.6 (10.2 to 9.6) MPa may be used to estimate the positive difference by which the average of the three population shear means for heartwood (low CCA retention) samples exceeds the corresponding average for sapwood (high CCA retention) samples. Incorporating the conclusion of no interaction reveals that this difference (namely, 0.6 MPa) may also be used to estimate the heartwood (low CCA retention) minus sapwood (high CCA retention) shear strength population mean difference for each of the three surface preparations individually (since these three differences were identical; again, envision the two distinct "piecewise linear curves" of **Fig. 2** (b) becoming parallel when shear strength averages calculated from the data are replaced by shear strength population means).

Finally, the main effect of surface preparation on the population shear values was not statistically significant ($p = 0.0990$). The average shear strengths were 10.2 MPa, 10.7 MPa, and 8.8 MPa for beams that were primed, incised, and untreated (i.e., control), respectively. But, the p-values for the pairwise comparisons of the surface preparation main effects "primed with control" and "incised with control" were 0.0984 and 0.0477, respectively. This indicates that both incising and priming likely had positive effects on glueline shear strength. Again using Model 1, expected utility pole wood failure percentages were found to be the same for both the three surface preparations ($p = 0.9818$) and the two cross-sectional locations ($p = 0.1087$). Model 1 also revealed no surface preparation by cross-sectional location interaction in the expected utility pole wood failure percentages ($p = 0.0815$). The relatively small p-values 0.1087 and 0.0815 were due to the relatively disparate wood failure percentage averages of 60.9 percent and 80.9 percent for the untreated (i.e., control) sapwood and heartwood beams, respectively.

It was found that priming with the modifier or incising had little effect on the shear strength of the untreated virgin wood beams. Using Model 2, surface preparation had no effect on the population shear means ($p = 0.9085$). The averages of the shear values obtained from the 18 stair-samples taken from the three virgin wood beams, six stair-samples per beam, that were primed, incised, and untreated (i.e., the control beams), respectively, were 9.8 MPa (1,421 psi), 9.9 MPa (1,436 psi), and 9.7 MPa (1,401 psi). Thus, the averages 9.8, 9.9, and 9.7 MPa were different due to sampling variability only, since the corresponding population mean shear values were found to be identical. It is likely that the two surface preparation methods (i.e., priming and incision) could not further increase the bonding strength of the virgin lumber because bonding groups were readily available on the cell walls of the lumber. Again using Model 2, expected wood failure of virgin wood beams was found to be the same for the three surface preparations ($p = 0.2206$).

Delamination

After 3-day, accelerated delamination exposure specified by ASTM Standard D2559, more swell, checks, and delamination were observed in virgin wood beam delamination samples than in decommissioned utility pole beam delamination samples. As expected, then, decommissioned CCA-treated utility pole wood beams were more dimensionally stable than untreated virgin wood beams. Furthermore, in each decommissioned utility pole beam delamination sample, more swell was observed in the heartwood region, which had a lighter shade of green due to less CCA retention (recall that plies in each utility pole beam retained the same orientation as in the pole). As previously mentioned, the metal deposits on cell wall surfaces and lumens likely blocked some of the hydroxyl groups of wood fibers, thereby reducing swelling. Therefore, dimensional stability is one of several potential recycling advantages that CCA may provide.

Table 5 contains the average delamination percentage of the six block samples for each of the 18 beams that were directly tested. Only the CCA-treated beams from Poles 1 and 3, the three virgin wood beams that were incised, and one of the three virgin beams that were primed met the requirement for these delamination averages of at most 5 percent set by ASTM Standard D2559 (ASTM 1996). D2559, however, also places an individual requirement on each of the six delamination block samples taken from a particular beam, namely, that no more than 20 percent of the permissible 5 percent delamination percentage (i.e., 1%) delamination can occur in any single glue-line individually for each of the six block samples taken from a particular beam. Only four of the 18 beams that were directly tested (delamination percentage averages for these four are highlighted in **Table 5**) met this individual standard for each of the six delamination block samples cut from the beam: the control and incised beams made from Pole 1, the incised beam made from Pole 3, and one of the incised virgin wood beams. Of the nine virgin wood beams, the three incised beams had the lowest delamination values. Of the nine CCA-treated beams, the three Pole 5 beams had the highest delamination values. Of the three Pole 3 beams, the incised beam had the lowest delamination value. The incised beam had the second lowest delamination value of the three Pole 1 beams.

Warp was observed in the virgin wood lumber obtained for this experiment. The stress in the virgin lumber plies was partially released by incising the lumber before it was pressed with other incised lumber plies into laminated beams, reducing warping of the lumber to some degree. The lowering of internal stress due to incising may partially account for the relatively small delamination values for the incised virgin wood beams in the accelerated weathering test. The incised beams of the decommissioned wood group had the highest shear averages (**Table 4**). For the decommissioned wood group, then, relatively low delamination values for the incised beams (except for Pole 5) is likely due to the fact that incising increased bonding strength more so than priming. It is also conceivable that the reduction in internal stress achieved by incising contributed to the relatively low delamination values for the incised decommissioned wood beams (except for Pole 5).

Table 5. — Delamination (%) of beams made from decommissioned CCA-treated utility pole wood and beams made from untreated virgin wood.[a]

	Pole 1	Pole 3	Pole 5
Utility pole wood			
Control	0.35 (0.17)	3.66 (0.78)	7.35 (1.74)
Primed	2.20 (1.00)	3.41 (1.25)	6.30 (1.45)
Incised	1.56 (0.97)	0.40 (0.25)	7.03 (1.04)
Virgin wood			
Control	9.10 (4.29)	9.03 (2.06)	5.64 (1.40)
Primed	13.03 (4.73)	4.44 (2.01)	9.14 (3.54)
Incised	2.37 (1.09)	3.21 (0.63)	1.86 (1.11)

[a] Values in parentheses are standard errors.

Summary and conclusions

Eighteen 6-ply laminated beams, nine consisting of plies made from decommissioned CCA-treated utility poles and nine consisting of virgin wood plies, were made, tested, and evaluated for glueline performance. It was found that with the exception of one beam made from decommissioned utility pole wood and one beam made from virgin wood, all of the utility pole wood and virgin wood beams of this study met the standard minimum strength requirement.

Density and CCA retention impacted bonding shear and delamination of treated wood. For beams made of utility pole plies, CCA retention significantly reduced shear strength, on average by the same amount, whether beams were made from plies that were incised, primed, or untreated. For the lone high-density pole of this study (i.e., Pole 5), it was found that stair-samples of one beam having plies that received no surface preparation prior to bonding failed to meet the minimum shear requirement of 9.04 MPa at 12 percent MC. Incising and priming may overcome the natural tendency of high-density untreated plies to produce beams that met the minimum shear requirement. From this study, it is unclear whether there would be a significant difference in shear strength, on average, between utility pole beams that were primed and those that were incised. On average, surface preparation was found to have no effect on the shear strength of beams made of virgin wood plies.

Laminated beams made from high-density (SG over 0.60, CCA inclusive) and high CCA retention (over 16.0 kg/m^3 or 1.0 pcf) poles or pole sections may not be suitable for exterior application, due to a tendency to delaminate. For beams made of untreated virgin wood, incision had a dramatic effect on delamination. All of the beams made from untreated virgin wood plies that were incised prior to bonding passed the standard 5 percent total delamination requirement, while none of the control virgin wood beams and two of the three virgin wood beams having plies that were primed prior to bonding failed to pass this requirement.

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