Glue-Line Bonding Performance of Decommissioned CCA-Treated Wood. Part II: Retreated with CCA

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Abstract

Disposal of decommissioned chromated copper arsenate (CCA)–treated wood as landfill has become an important environmental concern. Reusing and recycling decommissioned treated wood seems to be the most practical environmental solution to the problem. In a previous report, 6-ply laminated beams made from decommissioned CCA-treated southern pine (*Pinus* spp.) wood utility poles and 6-ply laminated beams made from untreated virgin wood were studied to evaluate the effects of surface preparation method and cross-sectional region (high or low CCA retention) on bonding shear strength, wood failure, and delamination. In this study, 6-ply laminated beams having the same composition as those of the previous study were made and then pressure-treated (i.e., retreated) with CCA prior to being evaluated in the same manner as in the previous study. This study revealed that gains in CCA retention (as a result of retreatment with CCA) for beams made from decommissioned utility pole wood were similar to the gains for beams made from untreated virgin wood. CCA retreatment had little overall effect on either glue-line shear strength or wood failure of beams made from decommissioned wood utility poles, but overall substantially increased shear strength and wood failure of beams made from virgin wood. CCA retreatment also reduced the delamination of both beams made from decommissioned utility pole wood and beams made from virgin wood. Additional testing is warranted to further investigate the bonding performance of decommissioned CCA-treated transmission utility pole wood.

Reusing decommissioned treated wood provides the opportunity to extend the service life of the wood and would be the most favorable environmental option. The reuse and re-engineering of decommissioned treated wood, however, could be problematic because of the interference of preservatives in the wood with the bonding of synthetic resins (Janowiak et al. 1992, Prasad et al. 1994, Vick 1994, Munson and Kamdem 1998, Wang et al. 2001, Herzog et al. 2004, Lorenz and Frihart 2006). In a previous study (Part I), we investigated the gluability of decommissioned chromated copper arsenate (CCA)–treated utility pole wood (Piao et al. 2009). The objective of this study was to investigate CCA retention and glue-line performance after retreatment with CCA.

Materials and Methods

Procedures for the evaluation of bonding decommissioned utility pole wood were described in detail in the previous article (Piao et al. 2009) and will be briefly summarized here. Six southern pine (*Pinus* spp.) decommissioned CCA-treated wood utility poles were obtained from local power companies (Table 1), cleaned, and air-dried for 2 months. After air-drying, three 1.1-m (42-in.) sections were removed from each pole and cut into lumber pieces, each of which was planed to a final thickness of 19.1 mm (0.75 in.). Six contiguous pieces of 19.1-mm

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*Table 1.—Summary data of the CCA-treated decommissioned southern pine (*Pinus *spp.) utility poles; poles 2, 4, and 6 were used in this study.*

Pole no.	Class	Original length (m)	Actual length (m)	Missing sections	Year marked	Service period ended
1	3	13.7	11.4	Bottom	1995	2007
2	3	13.7	9.6	Top	1995	2007
3	3	15.2	15.2	—	2000	2007
4	5	9.1	9.1	—	2000	2007
5	5	13.7	7.9	Top, 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.

(0.75-in.)-thick planed lumber were taken from each 1.1-m section, stacked in their original order within the 1.1-m section, and kept in this order within the stack (Fig. 1) so that the two binding surfaces of each glue-line in the laminated test beam had, at least approximately, the same CCA content. In this configuration, the directions of the annular growth rings of all plies were the same. This arrangement differed from the American Society for Testing and Materials (ASTM) Standard D2559-04 (ASTM 2004), which mandates that the direction of the annular growth rings should alternate from ply to ply within the laminated beam when viewed on end (ASTM 2004). These planed lumber pieces were trimmed and cut. The resulting 1.0-m (41-in.)-long by 127.0-mm (5-in.)-wide by 19.1-mm (0.75-in.)-thick lumber 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 a resorcinol phenol-formaldehyde (RPF) resin (LT-5210 with 8% [wt/wt] powder hardener FM6210S) to form laminated beams, six plies per beam, three beams per decommissioned pole (a total of 18 beams: 3 beams per decommissioned pole by 6 decommissioned poles). 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 modifier MO-654. 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. For the modifier treatment, sample surfaces were brushed with the modifier at 116 g/m^2 (0.26 lb/ft^2). For incised beams, sample surfaces were incised at 10,000 incisions/m^2 (929 incisions/ft^2). The RPF resin LT-5210, hardener FM6210S, and MO-654 were obtained from Hexion Co. (Springfield, Oregon, and Highpoint, North Carolina).

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. Grade C lumber best matched the quality of the decommissioned utility pole wood. 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. 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, priming) were randomly assigned to the three clusters, with all 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. 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 LT-5210 was uniformly brushed to both surfaces of all plies of lumber assigned to the primed or untreated categories of surface preparation at the rate of 463 g/m^2 (1.02 lb/ft^2). For incised plies, 506 g/m^2 (1.11 lb/ft^2) of resin was uniformly brushed to both CCA-treated utility pole wood and virgin wood plies. These two amounts of resin may be higher than that typically used by the wood products industry. Beams were kept under pressure (0.86 MPa or 125 psi) at room temperature for 24 hours to cure

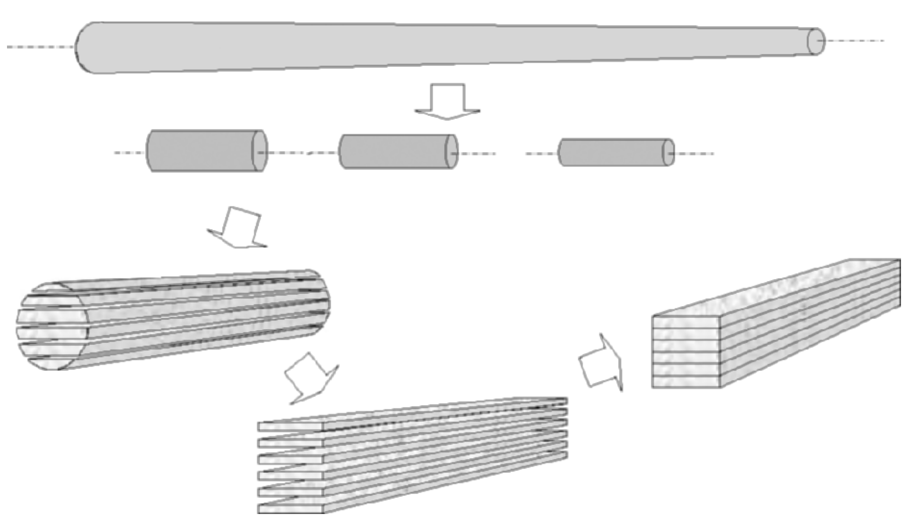

Figure 1.—A diagram showing the process of fabricating laminated beam samples from decommissioned wood utility poles.

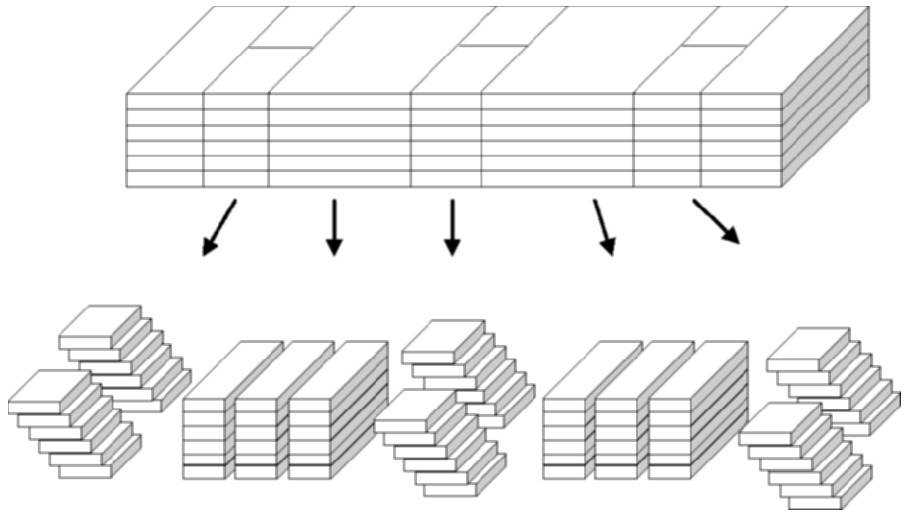

Figure 2.—Diagram illustrating stair shear samples and delamination samples cut from a laminated test beam (ASTM 2004).

the resin. After gluing, beams were conditioned to equilibrium MC at 23°C ± 2°C (73°F ± 4°F) and 50 to 65 ± 5 percent relative humidity.

A total of 36 beams were made. After environmental conditioning, 18 of the 36 beams (exactly nine of which were made of untreated virgin wood) were directly tested for glue-line shear strength and delamination. Results of this study were reported in the previous article (Piao et al. 2009). Of the remaining 18 beams, nine were made of untreated virgin wood plies and nine were made of plies cut from CCA-treated decommissioned utility poles. The nine utility pole beams were obtained by randomly selecting one of the two poles with the same year marking. Poles 2, 4, and 6 were the three that were selected for this investigation. The nine untreated virgin wood beams 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]). These 18 beams (nine of decommissioned utility pole wood and nine of untreated virgin wood) were sent to Arnold Forest Products Co. in Shreveport, Louisiana, for CCA treatment. CCA was impregnated into the beams by placing the beams into a cylinder and vacuuming the beams at 508 mm (20 in.) of mercury for 15 minutes, after which a solution of CCA and water was introduced into the cylinder. The contents of the cylinder were then pressurized at 0.52 MPa (75 psi) for 20 minutes, and then pressurized at 0.58 MPa (84 psi) for 20 minutes Finally, the beams were vacuumed in the cylinder at 635 mm (25 in.) of mercury for 5 minutes The CCA treatment conducted at Arnold Forest Products Co. was actually a retreatment with CCA for the utility pole beams, and a first treatment with CCA for the virgin wood beams. Nevertheless, throughout the remainder of this article, the CCA treatment conducted at Arnold Forest Products Co. will be referred to as the CCA retreatment (process) for the 18 beams of this study. In the interest of simplicity, no further distinction will be made between the actual retreatment with CCA (of the utility pole wood beams) and the first treatment with CCA (of the virgin wood beams).

After retreatment, beams were air-dried under a shed for 6 weeks. Shear stair and delamination samples were then cut from each beam according to ASTM D2559-04 (ASTM 2004). Figure 2 illustrates the shear stair and delamination samples that were cut from a laminated test beam. The three-cycle delamination test was conducted as follows (ASTM 2004):

1. The test samples were first submerged under water 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 1.5 hours. The drain was kept open during the entire 1.5-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.

Prior to the cutting of shear and delamination samples, a 76.2-mm (3-in.) section was cut from one end of each beam and discarded. A 25.4-mm (1-in.) contiguous section was then cut from the same end of each beam and used for CCA retention evaluation of the beam after CCA retreatment. Each beam section was separated by cutting along each of the five glue-lines. Each of the six resulting samples from each section was cut into 25.4-mm blocks for the CCA retention measurement. An x-ray spectrometer was used to measure CCA retention rate for each block according to American Wood Protection Association (AWPA) Standard A9-01 (AWPA 2006). The CCA retention in the poles prior to service was not available.

Statistical Models 1 and 2 used in the previous study (Piao et al. 2009) were also adopted in this study to analyze shear data and wood failure data for the test of CCA-retreated beams made of lumber cut from decommissioned

Table 2.—SG of laminated beams made from decommissioned CCA-treated utility pole wood by pole and surface preparation.

	Poles, mean (SE)		
	2	4	6
Control	0.61 (0.013)	0.61 (0.006)	0.52 (0.015)
Primed	0.63 (0.012)	0.55 (0.006)	0.58 (0.012)
Incised	0.63 (0.018)	0.55 (0.009)	0.52 (0.016)

utility poles and CCA retreated beams made of virgin lumber, respectively.

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

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

where

Y = glue-line shear/wood failure;

μ = the fixed effect for the combination of surface preparation with CCA retention for Model 1, but surface preparation only for Model 2;

ρ = the random pole effect;

δ = the random beam effect; and

ε = the random residual error.

The SAS procedures GLM and Mixed were used to process the glue-line shear data and wood failure data (SAS Institute Inc. 2008).

Results and Discussion

SG and MC

SG was estimated for each of the utility pole beams of this study (Table 2). SG of each beam ply was estimated (prior to retreatment with CCA) from the dimension, weight, and MC of the ply. The MC of all shear samples tested ranged from 12 to 15 percent. Since CCA could not be differentiated from wood, the weight used to estimate the SG of each ply included the weight of CCA in the treated ply, but did not include the weight of the moisture in the wood. Therefore, the actual wood SG of each ply would be less than the estimated SG of each ply because CCA is heavier than wood. Each SG value in Table 2 is the average of the six estimated SGs of the six plies in each of the nine beams made from the three decommissioned utility poles. The average SGs over all 18 plies (in the three beams) cut from Poles 2, 4, and 6 were 0.62, 0.57, and 0.54, respectively.

CCA retention

Table 3 displays CCA retention of the laminated beams of this study after and before CCA retreatment, as well as the gain in CCA retention due to retreatment. Each retention rate value is an average over 30 block samples (19 by 25 by 25 mm or 0.75 by 1 by 1 in.) and may be used to estimate the CCA retention rate of the entire beam. All of the beams made from utility pole wood were impregnated with more CCA after CCA retreatment than before the retreatment (Table 3). Average CCA retention (i.e., the average over the three surface preparations) after retreatment of beams made from Poles 2, 4, and 6 increased by 100, 81, and 109 percent, respectively, compared with average CCA retention before retreatment. Of the decommissioned pole beams, those made of lumber cut from Pole 4 had the highest initial average CCA retention (15.9 kg/m^3 or 1.0 pound per cubic foot [pcf]) before retreatment, and retained the highest CCA average retention (28.2 kg/m^3 or 1.8 pcf) after retreatment. Beams made from Pole 2 had the lowest initial average CCA retention (8.5 kg/m^3 or 0.53 pcf) before retreatment, and also had the lowest average CCA retention (16.5 kg/m^3 or 1.0 pcf) after retreatment. As previously mentioned, Pole 2 had the highest average SG of the three poles (Table 2). Examination of the cross-sections revealed that Pole 2 had the narrowest growth rings and contained more latewood than the other two poles. It is likely that high density, relatively thick cell walls, and low available lumen space limited the deposition of CCA, leading to low before and after retreatment CCA retention values for the beams made from Pole 2.

Table 4 gives CCA retention rates before and after retreatment for the outer and inner (close to the center) regions of the nine beams made from decommissioned utility pole wood, while Table 5 displays the CCA retention rate gains due to retreatment for the outer and inner regions. The terms outer and inner hereafter refer to the outer (sap) and inner (heart) regions of a pole in the radial direction outer to inner. Note that unlike the CCA pressurization of a pole in which CCA penetrates from the outer surfaces to the inside, the inner and outer regions of each ply of each beam were simultaneously exposed to the preservative (i.e., CCA) during pressurization. Therefore, inner wood had the same

Table 3.—CCA retention rates (kg/m^3) after CCA retreatment of beams made from decommissioned utility pole wood and beams made from untreated virgin wood.

	Pole 2			Pole 4			Pole 6			Average		
	After[a]	Before[b]	Gain[c]	After	Before	Gain	After	Before	Gain	After	Before	Gain
Utility pole wood												
Control	15.1	7.6	7.5	26.9	13.2	13.7	23.3	11.7	11.6	21.8	10.9	10.9
Primed	16.0	6.7	9.3	25.9	16.5	9.4	20.6	8.5	12.1	20.8	10.5	10.3
Incised	18.3	11.2	7.1	32.7	18.7	14.0	21.1	12.0	9.1	24.0	13.9	10.1
Virgin wood												
Control	10.5	0	10.5	13.0	0	13.0	11.3	0	11.3	11.6	0	11.6
Primed	9.9	0	9.9	10.9	0	10.9	10.3	0	10.3	10.4	0	10.4
Incised	10.9	0	10.9	11.9	0	11.9	9.6	0	9.6	10.8	0	10.8

[a] CCA retention rate after retreatment.
[b] CCA retention rate before retreatment.
[c] CCA retention rate after retreatment minus CCA retention rate before retreatment.

Table 4.—CCA retention rates (kg/m³) after and before retreatment with CCA for outer and inner regions of beams made from decommissioned utility pole wood.

	Pole 2				Pole 4				Pole 6			
	Outer[a]		Inner[b]		Outer		Inner		Outer		Inner	
	After[c]	Before[d]	After	Before	After	Before	After	Before	After	Before	After	Before
Control	19.5	10.9	10.7	4.2	27.5	15.8	26.3	11.6	23.9	12.4	22.7	11.0
Primed	21.8	9.9	10.2	3.6	27.5	17.9	24.3	14.9	18.6	8.6	22.6	8.4
Incised	22.5	13.7	16.9	12.3	31.9	24.8	33.6	18.6	21.0	12.8	21.1	12.0

[a] Outer region (0 to 51 mm from outer surfaces).
[b] Inner region (51 to 102 mm from outer surfaces).
[c] CCA retention after retreatment.
[d] CCA retention before retreatment.

chance of being impregnated with CCA as outer wood during the CCA retreatment of the utility pole beams of this study. For each surface preparation, the inner and outer regions of the beams consisting of lumber cut from Poles 4 and 6 contained similar amounts of CCA after retreatment (Table 4). The relatively large disparity in CCA retention gains between inner and outer wood regions for the incised and control beams of Pole 4 and the primed beam of Pole 6 seen in Table 5 was due to the fact that, for these three beams, the inner wood was sapwood and had lower CCA retention than the outer wood prior to retreatment. For Pole 2 beams, however, CCA retention after retreatment was much larger for the outer region than the inner region (Table 4). Gains in the inner regions were lower than those in the outer regions of the Pole 2 beams (Table 5). This may be due to the fact that the inner wood of Pole 2 contained more heartwood, which is refractory to CCA penetration. Not only was the total CCA gain of Pole 2 beams the lowest total gain of the three poles after retreatment, but the six gains for the six combinations of surface preparation and wood type (i.e., outer wood, inner wood) were also the lowest of the three poles (with the exception of the two combinations outer wood/incised and outer wood/primed).

Table 3 reveals that after CCA retreatment, average gains in CCA retention for laminated beams made of CCA-treated decommissioned utility pole lumber were comparable to those of beams made of virgin wood: 10.9 vs. 11.6 kg/m³ for the control (i.e., untreated) beams, 10.3 vs. 10.4 kg/m³ for the primed beams, and 10.1 vs. 10.8 kg/m³ for the incised beams. This can be interpreted as follows. For each surface preparation, laminated beams made of decommissioned utility pole lumber can be expected to absorb the same amount of CCA as laminated beams made of virgin wood, after retreatment with CCA. Moreover, for the utility pole beams, there was no significant difference between the three CCA retention averages: 21.8 kg/m³ for the control beams, 20.8 kg/m³ for the primed beams, and 24.0 kg/m³ for the incised beams ($P = 0.3083$). Thus, the average of the nine CCA retention values of Table 3 for the nine decommissioned treated pole beams (22.2 kg/m³) may be used to estimate the single population average CCA retention rate of all beams made from (possible) poles that are similar (in grade, SG, etc.) to the poles of this study. Similarly, for beams made of virgin wood, there was no significant difference between the three CCA retention averages: 11.6 kg/m³ for the control beams, 10.4 kg/m³ for the primed beams, and 10.8 kg/m³ for the incised beams ($P = 0.3928$). Thus, the average of the nine CCA retention values of Table 3 for the nine virgin wood beams (10.9 kg/m³) may be used to estimate the single population average CCA retention rate of all beams that are made from virgin wood lumber similar to that used in this study.

Glue-line shear

After retreatment with CCA, three pairs of stair samples were cut from each of the 18 beams of this study and five glue-line shear strength values were averaged to obtain a single overall shear strength value for each stair sample, as in Part I (Piao et al. 2009). In Table 6, overall shear values for the nine stair samples (cut from three decommissioned utility pole beams) have been averaged for each of the six combinations of surface preparation and cross-sectional region. In Table 7, the six overall shear strength values obtained for the six stair samples cut from each virgin wood beam have been averaged for that beam.

Using Model 1 to analyze shear strength data (summarized in Table 6) for the decommissioned utility pole beams, it was concluded that after retreatment with CCA, neither surface preparation nor cross-sectional region significantly affected shear strength. Neither did the interaction between surface preparation and cross-sectional region significantly affect shear strength. *P* values for the main effects of surface

Table 5.—CCA gain (kg/m³) after CCA retreatment for outer and inner regions of beams made from decommissioned utility pole wood.

	Pole 2		Pole 4		Pole 6	
	Outer[a]	Inner[b]	Outer	Inner	Outer	Inner
Control	8.6	6.5	11.7	14.7	11.5	11.7
Primed	11.9	6.6	9.6	9.4	10.0	14.2
Incised	8.8	4.6	7.1	15.0	8.2	9.1

[a] Outer region (0 to 51 mm from outer surfaces).
[b] Inner region (51 to 102 mm from outer surfaces).

Table 6.—Shear stress averages (MPa) after CCA retreatment for beams made from decommissioned CCA–treated utility pole wood classified by surface preparation and cross-sectional region (outer wood or inner wood).[a]

Cross-sectional region	Surface preparation			Main effects
	Primed	Incised	Control	
Outer	10.3	9.8	8.9	9.7
Inner	10.7	10.3	9.3	10.1
Main effects	10.5	10.1	9.1	

[a] The minimum glue-line shear required by ASTM Standard D2559 for structural laminated beams is 8.60 MPa (ASTM 2004).

Table 7.—Glue-line shear stress and wood failure of beams made from decommissioned CCA–treated utility pole wood and beams made from untreated virgin wood.[a]

	Pole 2		Pole 4		Pole 6	
	Shear (MPa)	Wood failure (%)	Shear (MPa)	Wood failure (%)	Shear (MPa)	Wood failure (%)
Utility pole wood						
Control	9.3 (0.43)	86.2 (4.22)	8.7 (0.24)	23.6 (1.51)	9.4 (0.49)	72.4 (3.87)
Primed	10.1 (0.34)	72.7 (2.40)	8.8 (0.64)	66.8 (4.48)	12.5 (0.30)	57.0 (2.50)
Incised	11.6 (0.36)	84.3 (3.33)	9.3 (0.52)	76.3 (4.74)	9.5 (0.32)	80.0 (2.92)
Virgin wood						
Control	11.8 (0.12)	77.0 (2.21)	9.7 (0.14)	77.8 (4.07)	9.7 (0.14)	80.0 (3.38)
Primed	10.3 (0.34)	54.6 (6.34)	11.1 (0.19)	43.5 (6.29)	10.7 (0.19)	81.8 (2.21)
Incised	10.0 (0.47)	68.8 (3.09)	10.4 (0.35)	78.5 (3.81)	9.8 (0.26)	79.0 (2.63)

[a] Values are means (standard errors). The minimum glue-line shear required by ASTM Standard D2559 for structural laminated beams is 8.60 MPa (ASTM 2004).

preparation and cross-sectional region, and the P value for the surface preparation by cross-sectional region interaction were 0.4436, 0.1430, and 0.9726, respectively. Thus, the shear averages for priming, incising, and control (10.5 MPa [1,523 psi], 10.1 MPa [1,465 psi], and 9.1 MPa [1,320 psi], respectively [Table 6]) may appear different due to sampling variability only, and not due to differences in the corresponding population main effects. Similarly, the shear averages for the outer and inner regions (9.7 MPa [1,407 psi] and 10.1 MPa [1,465 psi], respectively [Table 6]) were due to sampling variability only, and not due to differences in the corresponding population main effects. Due to the lack of significance of surface preparation, cross-sectional region, and the surface preparation by cross-sectional region interaction, the six population means of Model 1 collapse to a single population mean, which can be estimated by the average of all overall shear values for all stair samples cut from the nine beams made from utility pole lumber. This average value, namely 9.9 MPa (1,436 psi), may be used to estimate the expected overall shear value of a stair sample cut from a 6-ply laminated beam made from utility poles that are similar to the poles used in this study, regardless of surface preparation or cross-sectional location. After CCA retreatment, all of the beams made from decommissioned utility pole wood met the shear strength requirement (8.60 MPa) of ASTM Standard D2559 (ASTM 2004) (Table 7). Moreover, for each surface preparation, the shear strength of the Pole 4 beam was lower than that of the beams made from the other two poles after retreatment (again, Table 7). Not only was CCA uniformly distributed in the cross-sectional regions (inner and outer wood) of the three beams made from Pole 4 (Table 4), but also CCA retention was the highest in the three Pole 4 beams than in the beams made from the other two poles for each surface preparation after retreatment with CCA (Table 3). These elevated levels of CCA likely interfered with the bonding of the resin in the Pole 4 beams. Furthermore, for each of the surface preparations incised and control, wood failure for the Pole 4 beam was lower than that of the Pole 2 and Pole 6 beams; for the surface preparation primed, wood failure for the Pole 4 beam was lower than that for the Pole 2 beam. On the basis of this study and also that of Part I (Piao et al. 2009), it may be concluded that without any surface preparation whatever or with priming with MO-654 only, high CCA retention rates may cause substantial reduction in shear strength of structural laminated products for exterior use.

It is also noted that the amount of resin applied on the utility pole wood of this study was higher than the amount of resin typically applied on industrial wood products. The excessive resin squeezed out from the glue-lines in consolidating the plies may potentially mask some of the effects of CCA retention and the primer MO-654.

Using Model 2, it was concluded that surface preparation had no effect on the shear strength of beams made of untreated virgin wood ($P = 0.6033$). The shear strength averages of the primed, incised, and control beams (10.5 MPa [1,523 psi], 9.9 MPa [1,436 psi], and 10.4 MPa [1,508 psi], respectively) may appear different due to sampling variability only, not to any differences in the three corresponding population means. The overall average of 10.3 MPa (1,494 psi) may, therefore, be used to estimate the expected overall shear strength of a stair sample cut from a 6-ply laminated beam made of virgin wood that is similar to the wood used in this study, regardless of the surface preparation of the plies. After CCA retreatment, shear strength of all virgin wood beams met the shear strength requirement of Standard ASTM D2559 (ASTM 2004).

Although the average wood failure percentage for the primed virgin wood beams (i.e., 60%) was lower than that of both the incised virgin wood beams (75.4%) and the control virgin wood beams (78.3%), it was not significantly lower. These three percentage averages were not significantly different ($P = 0.2091$ using Model 2). Therefore, it may be concluded that surface preparation had no effect on the three population average wood failure percentages for the virgin wood beams.

In the previous study (Piao et al. 2009), all of the beams were directly tested without retreatment with CCA, whereas, in this study, all of the beams were retreated with CCA prior to testing. Since the experimental designs for the direct test and the test after retreatment with CCA were the same for utility pole beams, Model 1 was used to analyze utility pole shear strength and wood failure in both studies. Likewise, Model 2 was used to analyze virgin wood beam shear strength and wood failure in both studies. Therefore, conclusions regarding shear strength and wood failure of utility pole beams made in each of the two studies can be compared, as can the corresponding conclusions regarding virgin wood beams. For utility pole beams, there was no surface preparation by cross-sectional region interaction in shear strength for either the directly tested beams of Part I ($P = 0.7954$) or the CCA-retreated beams of Part II ($P = 0.9726$), nor were the three shear strength surface prepara-

Table 8.—Delamination (%) after CCA retreatment for beams made from decommissioned CCA–treated utility pole wood and beams made from untreated virgin wood.[a]

	Pole 2		Pole 4		Pole 6		
	Mean (SE)	P/F[b]	Mean (SE)	P/F	Mean (SE)	P/F	Average
Utility pole wood							
Control	0.84 (0.35)	P	1.25 (0.49)	F	1.05 (0.52)	F	1.05
Primed	0.39 (0.22)	P	0.67 (0.29)	F	3.55 (1.16)	F	1.54
Incised	0.65 (0.28)	F	0.68 (0.34)	P	0.66 (0.21)	P	0.66
Virgin wood							
Control	1.94 (0.59)	P	1.61 (0.38)	F	3.62 (0.86)	F	2.39
Primed	7.64 (1.07)	F	5.15 (1.00)	F	1.97 (0.67)	F	4.92
Incised	5.35 (1.90)	F	0.98 (0.33)	F	3.72 (0.86)	F	3.35

[a] The standard for delamination for structural softwood laminated beams requires that no more than 1 percent may occur for any one bondline (ASTM 2004).
[b] P = the beam met (passed) the maximum 1 percent single glue-line standard delamination requirement; F = the beam failed to meet (failed) the maximum 1 percent single glue-line standard delamination requirement.

tion main effects significantly different ($P = 0.0994$ for the directly tested beams of Part I and $P = 0.4436$ for the CCA-retreated beams of Part II, although it was conjectured that with more poles in the study, a significant difference between surface preparations may have been found for directly tested beams). However, there was a significant difference in shear strength between the inner and outer regions (or heartwood and sapwood) for the utility pole beams that were directly tested ($P = 0.0220$), while no corresponding difference was found for the utility pole beams that were retreated with CCA ($P = 0.1430$). An analysis of the CCA retention rates by location found that the average outer (sap) and inner (heart) wood CCA retentions of the nine beams that were directly tested were 23.2 and 9.0 kg/m^3, respectively, while the average CCA retention rates of the outer and inner wood of the nine beams that were retreated were 14.1 and 10.7 kg/m^3 prior to retreatment, respectively. Apparently, the difference of 14.2 kg/m^3 (23.2 − 9.0 kg/m^3) between the outer and the inner regions for the utility pole beams that were directly tested led to the significant difference between shear strengths in the two locations, while the difference of 3.4 kg/cm^3 (14.1 − 10.7 kg/m^3) between the outer and the inner regions for the utility pole beams that were retreated with CCA caused no significant difference between the shear strengths in the two locations. The overall average shear strength for the nine utility pole beams that were directly tested was 9.9 MPa (1,436 psi), the same overall average shear strength for the nine that were retreated with CCA. Using Model 1, no significant differences were found in utility pole wood failure percentages between (1) the three surface preparations ($P = 0.9818$ for the directly tested beams and $P = 0.4693$ for the beams retreated with CCA) and (2) the two cross-sectional locations (i.e., inner and outer wood; $P = 0.1087$ for the directly tested beams and $P = 0.2734$ for the beams retreated with CCA), nor was there any surface preparation by cross-sectional location interaction in the wood failure percentages ($P = 0.0815$ for the directly tested beams and $P = 0.6660$ for the beams retreated with CCA). Overall wood failure percentage averages were 70.2 and 68.8 percent for the nine utility pole beams that were directly tested and the nine that were retreated with CCA, respectively. For virgin wood beams, surface preparation had no effect on expected shear strength, whether the beams were directly tested ($P = 0.9085$) or (re)treated with CCA ($P = 0.6033$). Both P values were obtained using Model 2. The overall average shear strengths were 9.8 MPa (1,421 psi) and 10.3 MPa (1,494 psi) for the nine virgin wood beams that were directly tested and the nine that were (re)treated with CCA, respectively. Again using Model 2, expected wood failure of virgin wood beams was found to be the same for the three surface preparations: $P = 0.2206$ for the nine virgin wood beams that were directly tested and $P = 0.2091$ for virgin wood beams that were (re)treated with CCA. Overall average wood failure percentage for the virgin wood beams increased from 58.6 percent for the nine directly tested beams to 71.2 percent for the nine that were (re)treated with CCA.

Delamination

In the CCA retreatment of the beams of this study, the treatment procedure was similar to the first impregnating cycle of standard ASTM D2559 (ASTM 2004) for determining the delamination percentage. Both involve impregnating wood by vacuum and pressure. The difference was that in the CCA retreatment, wood was impregnated with a CCA solution (i.e., CCA and water), while in the treatment for determining delamination, wood was impregnated with water only. The standard treatment was designed to destruct the laminated beams. Water was forced into wood under pressure. The wood began to swell after a short period of time. The different swell rates between two adjacent pieces of lumber across a glue-line created stress, which in turn caused delamination. The CCA treatment was designed to protect the laminated beam. When the CCA solution penetrated into the wood, chromium trioxide (CrO_3) formed cross-linked polymeric complexes (Kubel and Pizzi 1981), which covered some of the hydrophilic groups on cell-wall surfaces, imparting a hydrophobic property to the wood. It was reported in Part I (Piao et al. 2009) that CCA retention improved dimensional stability of utility pole beams (over virgin wood beams). Examination of the 18 beams after CCA retreatment found no significant swell. Severe swell, checks, and delamination found in the virgin wood beams after direct testing (Piao et al. 2009) were not found in the virgin wood beams after CCA retreatment. These results are consistent with the observation of the previous study that CCA in the wood of laminated beams enhanced dimensional stability by reducing wood swell.

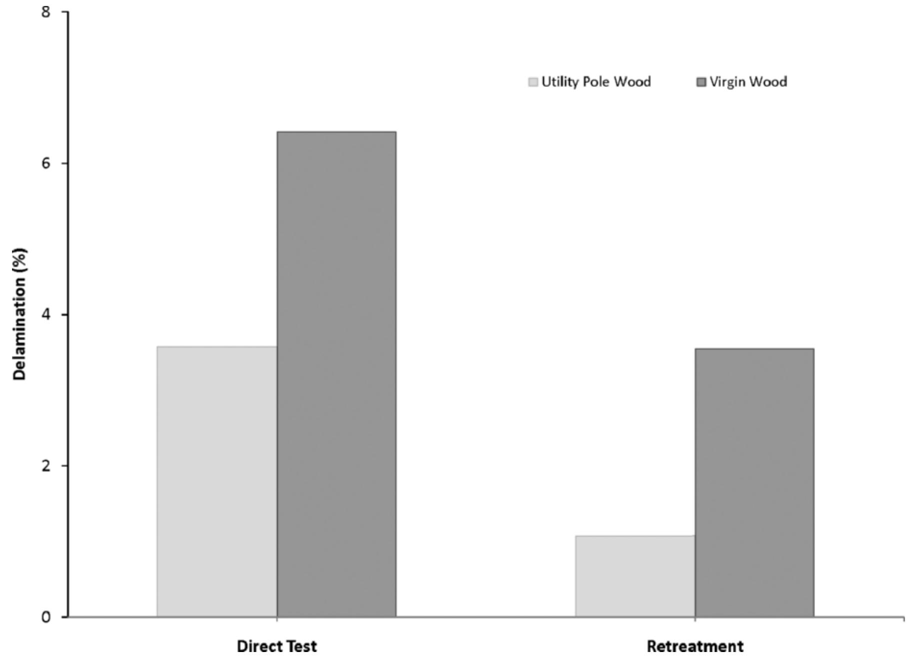

Figure 3.—Delamination comparison of decommissioned CCA-treated utility pole wood beams and untreated virgin wood beams before (direct test) and after CCA retreatment.

As in Part I (Piao et al. 2009) of this study, six 76.2-mm (3-in.)-long by 127.0-mm (5-in.)-wide by 114.3-mm (4.5-in.)-high delamination block samples were cut from each beam, and the delamination percentage was obtained for each block sample according to ASTM Standard D2559 (ASTM 2004). Table 8 contains the average delamination percentage of the six block samples for each of the 18 beams that were retreated with CCA. Standard D2559 requires that no more than 1 percent delamination can occur in any single glue-line individually for each of the six block samples taken from a particular beam. Only 5 of the 18 CCA-retreated beams (i.e., 28%) met the requirement for each of the six delamination block samples cut from the beam: the control and primed beams made from Pole 2, the incised beams made from Poles 4 and 6, and one of the control beams made of virgin wood.

In comparing delamination of the utility pole beams (Table 8), the Pole 2 beam exhibited the least amount of delamination of the three beams in each surface preparation group (priming, incising, and control). The average delamination of the beams made from Pole 6 (1.75%) was substantially greater than the average delamination of the beams made from Pole 2 (0.63%) and Pole 4 (0.87%). Note that Poles 2 and 4 had higher SG than Pole 6 (Table 2). It is not clear that low SG Pole 6 had a greater average delamination than Poles 2 and 4. Yet it was concluded in Part I (Piao et al. 2009) that high SG ($>$0.60) and high CCA retention ($>$16 kg/m^3) resulted in high delamination of laminated utility pole wood beams. Although the average SG of Pole 2 was 0.63, CCA retention of Pole 2 before the retreatment was only 8.3 kg/m^3 (Table 3). The SG of Poles 4 (0.57) and 6 (0.54) was well below 0.60. The CCA retention before the retreatment was 16.1 and 10.7 kg/m^3 for Poles 4 and 6, respectively. The relative small delamination of the utility pole wood beams after retreatment confirmed the aforementioned conclusion reached in Part I (Piao et al. 2009). After CCA retreatment, utility pole beams exhibited less delamination than virgin wood beams (Table 8). The overall average delamination of utility pole beams and virgin wood beams was 1.08 and 3.55 percent, respectively. This result is consistent with that of Part I (Piao et al. 2009). Surface preparation appeared to have little effect on the delamination of both utility pole beams and virgin wood beams.

Comparing the directly tested beams of Part I (Piao et al. 2009) to the beams that were retreated with CCA, CCA retreatment reduced the delamination of both utility pole beams and virgin wood beams (Fig. 3). The overall average delamination of utility pole beams with and without retreatment was 1.08 and 3.58 percent, respectively, while the overall average delamination of virgin wood beams with and without CCA treatment was 3.55 and 6.42 percent, respectively. These results indicate that CCA retreatment may reduce delamination, thereby improving the integrity of laminated beams made from utility pole wood, as well as untreated virgin wood.

Conclusions

Eighteen 6-ply laminated beams, nine consisting of decommissioned CCA-treated utility pole wood and nine of untreated virgin wood, were fabricated, tested, retreated with CCA, and evaluated for CCA retention, glue-line strength, and delamination. Results showed that both decommissioned CCA-treated utility pole wood beams and virgin wood beams were impregnated with more CCA after retreatment than before. Beams made from low SG decommissioned poles gained more CCA than beams made from high SG poles as a result of retreatment. The inner regions of the plies of decommissioned CCA-treated utility pole wood were usually impregnated with more CCA than the outer regions after CCA retreatment, especially for high density poles. Gains in CCA retention as a result of CCA retreatment for beams made from decommissioned CCA-treated utility pole wood were comparable to the gains for those beams made from untreated virgin wood. For this study, although all of the decommissioned utility pole wood beams and all of the virgin wood beams met the shear strength standard of ASTM D2559, it should be noted that most (i.e., 73%) decommissioned utility pole wood beams and almost all of the virgin wood beams (i.e., 89%) failed to meet the delamination standard. Similar results were obtained in the previous study (Piao et al. 2009). High CCA retention (over 16 kg/m^3 or 1.0 pcf) together with high SG could have a negative impact on the bonding strength and delamination of beams made from decommissioned utility pole wood. Regarding overall shear strength average values, CCA retreatment had no effect on utility pole beams and a small positive effect on virgin wood beams. For overall wood failure percentage averages, CCA retreatment had a small negative effect on utility pole beams but a substantial positive effect on virgin wood beams. CCA retreatment reduced the overall delamination percentage averages for both utility pole beams and virgin wood beams. This study was conducted under specific laboratory constraints, and sample sizes were relatively small. Further studies are warranted to examine the gluability of decommissioned CCA-treated transmission utility pole wood.

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