Recycling of Pentachlorophenol-Treated Southern Pine Utility Poles. Part II: Mechanical and Delamination Properties of Laminated Beams

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Abstract

Reusing decommissioned utility poles and other preservative-treated wood reduces the total amount of preservatives in the environment and the need to fall the trees in the forest, offering economic and ecological advantages. In a previous study, the pentachlorophenol (penta) retention and mechanical properties of decommissioned penta-treated southern pine utility poles and pole sections were investigated. The current study evaluated the mechanical and delamination properties of laminated beams made of penta-treated utility pole wood. A total of 45 laminated beams and 15 solid-sawn beams were fabricated from decommissioned penta-treated utility pole wood and untreated southern pine virgin wood. Three composition schemes and two surface preparation methods were investigated for their effects on penta retention, bending, glue-line shear, and delamination properties of the laminated beams. Penta-treated utility pole wood absorbed more penta than virgin wood during retreatment. The bending strength of the laminated beams met American National Standard Institute Standard 05.3. However, percent delamination of the laminated beams failed to meet the standard requirement set by ASTM Standard D2559, and thus, penta-treated utility pole wood beams consolidated by resorcinol phenol formaldehyde resin cannot be used in exterior exposure conditions.

Due to the protection by preservatives, wood utility poles retain much of their strength after being decommissioned from service. The high-quality lumber and timber cut from decommissioned utility poles and pole sections can be recycled and used to make other exterior, industrial products, such as bridge beams and utility pole crossarms. Reusing decommissioned utility poles and other preservative-treated wood reduces the total amount of preservatives in landfills and eliminates the need to fall new trees from forests, offering economic and ecological advantages. In addition, due to the residual preservatives contained in decommissioned treated wood, less preservative is needed to re-treat the recycled wood, thereby further reducing the need for preservatives.

In the last three decades, extensive research has been conducted on reusing and recycling decommissioned preservative-treated wood. These studies include residual preservative retention in decommissioned utility poles (Arsenault 1975; Ruddick et al. 1991; Nurmi 1993; Osborne and Fox 1995; Cooper et al. 1996, 2001; Lahiry 2001; Piao et al. 2009a), interference of preservatives on glue bonding (Vick 1995; Vick et al. 1996; Munson and Kamdem 1998; Mengeloglu and Gardner 2000; Tascioglu et al. 2003; Li et al. 2004; Clausen et al. 2006; Piao et al. 2009b, 2009c), mechanical properties of decommissioned treated wood and their products (Smith and Morrell 1989, Stewart and

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Goodman 1990, Huhnke et al. 1994, Cooper et al. 1996, Falk et al. 2000, King and Lewis 2000, Shi et al. 2001, Wang et al. 2001, Leichti et al. 2005, Piao and Groom 2010), nondestructive evaluation of decommissioned treated wood (Wang et al. 2001, Piao and Monlezun 2010), and the economics of and potential markets for decommissioned treated wood (Stewart and Goodman 1990, King and Lewis 2000, Shi et al. 2001). Several engineered products made from decommissioned preservative-treated wood were proposed and investigated in the literature. Such products include particleboard and flakeboard (Vick et al. 1996, Munson and Kamdem 1998, Mengeloglu and Gardner 2000, Li et al. 2004, Clausen et al. 2006); timber columns (Falk 1997, Shi et al. 2001, Leichti et al. 2005); utility poles, posts, timber, and lumber (Cooper et al. 1996); and laminated utility pole crossarms (Piao and Monlezun 2010). The overwhelming majority of these investigators examined the reuse and recycling of decommissioned chromated copper arsenate (CCA)–treated utility poles. Few sources were found that examined the recycling potential of decommissioned pentachlorophenol (penta or PCP)–treated utility poles (Cooper et al. 1996).

Although the production and consumption levels of penta-treated utility poles have decreased over the years, a relatively large volume of penta-treated utility poles remains in service and will be disposed of in the near future. The current study is part of a series of studies focusing on the reuse and recycling of decommissioned penta-treated utility pole wood. The purpose of these studies was to evaluate the feasibility of reusing decommissioned penta-treated utility poles for other products, such as bridge beams and utility pole crossarms. In Part I of this research, penta retention and mechanical properties of decommissioned southern pine (*Pinus* spp.) utility poles and pole sections were evaluated (Piao et al. 2011b). It was found that a substantial amount of penta remained in decommissioned utility pole wood. Most of the recycled wood cut from decommissioned penta-treated utility poles and pole sections was of medium to high strength and was reusable for other products. The aim of the current study was to evaluate the mechanical and delamination properties of laminated beams made from decommissioned penta-treated utility pole wood.

Materials and Methods

Sixty beams were constructed for this study: 45 were laminated and 15 were solid sawn. All treated wood used in this study was cut from 15 poles and pole sections left from a previous study (Piao et al. 2011b).

All laminated beams consisted of six plies each. Each ply was made of either virgin southern pine or decommissioned penta-treated utility pole wood, following the three composition schemes used in a previous study (Piao and Monlezun 2010): two middle plies made of decommissioned penta-treated utility pole wood and four outer plies (two top and two bottom) made of virgin wood (Composition C), four middle plies made of decommissioned penta-treated utility pole wood and two outer plies (one top and one bottom) made of virgin wood (Composition D), and all six plies made of decommissioned penta-treated utility pole wood (Composition E). The 15 solid-sawn beams (Composition F) were made entirely of decommissioned penta-treated utility pole wood.

Utility pole wood plies for the laminated beams were obtained by initially cutting each pole segment into boards. The center board, containing the pith, was used to evaluate the penta retention and mechanical properties of the utility pole wood in a previous study (Piao et al. 2011b). Each of the other boards cut from the poles was surfaced with a planer and cut into either one, two, or three 102-mm-wide by 19-mm-thick by 2.44-m-long plies, depending upon the width of the board. A total of 180 penta-treated wood plies were processed and used to fabricate the laminated beams for this study. Each ply was measured for width, thickness, length, weight, moisture content, and acoustic properties (Carter et al. 2005). Stress wave acoustic velocity was measured five times for each ply and was used to determine the position of each ply within a beam (i.e., at the surfaces or within the core).

Locations of utility pole wood plies within beams were determined as follows. Utility pole wood plies with stress wave acoustic velocity greater than 5,000 m/s were considered to be stronger and were, therefore, used as surface plies (top and bottom). Plies with stress wave acoustic velocity less than or equal to 5,000 m/s were used as core plies. Acoustic properties were measured using a handheld acoustic meter and a hammer. When measured, each ply was held at one end by a rubber stopper on a table. The acoustic meter receiver was pushed against the other (free) end of the ply. The sound wave produced by the hammer on the free end traveled through the ply, was reflected by the stopper end of the ply, and finally was received by the meter. Traveling velocity of the sound wave through the ply was calculated and viewed on the meter's LCD screen. Sound wave propagation velocity was measured five times across the free end of each ply.

To construct virgin wood plies for the laminated beams, 60 pieces of Grade 2 high ring density (i.e., four or more rings per inch), southern yellow pine lumber and 30 pieces of Grade 2 low ring density (i.e., fewer than four rings per inch), southern yellow pine lumber were obtained from a local lumber mill (all pieces were 140 mm wide by 38 mm thick by 2.44 m long). These 90 pieces were special pull by a trained person employed by the lumberyard. Each piece of lumber was first surfaced with a planer and then cut into a 102-mm-wide by 19-mm-thick by 2.44-m-long ply. Each of the 90 plies was measured for width, thickness, length, weight, moisture content, and acoustic properties, in the same manner as the treated wood plies.

Each of the 15 laminated beams of Composition C had the outermost top and bottom plies made of high ring density virgin southern pine wood and two core plies made of low acoustic velocity decommissioned penta-treated utility pole wood. The two plies between the core and outermost plies were made of low ring-density virgin southern pine wood. Each of the 15 laminated beams of Composition D consisted of high ring-density virgin southern pine outer plies (one top and one bottom) and four low acoustic velocity decommissioned penta-treated utility pole wood core plies. The two outermost plies (one top and one bottom) of each of the 15 laminated beams made entirely of decommissioned penta-treated utility pole wood (Composition E) were made of high acoustic velocity utility pole wood, while the four core plies were made of low acoustic velocity utility pole wood. The relationship between ring density, bulk density, acoustic velocity, and modulus of elasticity (MOE) for the plies of this study are given in Table 1. Note that the patterns are the same for each of these four variables.

Table 1.—Physical and acoustic property averages over all plies used to fabricate the laminated beams of this study.[a]

Materials	Ring density[b]	Bulk density (g/cm^3)	Acoustic velocity (m/s)	Acoustic MOE (GPa)
Penta-treated wood	High	0.65	5,453	19.7
	Low	0.61	4,368	11.7
Virgin wood	High	0.58	5,207	15.8
	Low	0.56	5,053	14.4

[a] MOE = modulus of elasticity; penta = pentachlorophenol.

[b] High = at least four rings per inch; low = fewer than four rings per inch.

Prior to the binding process, the binding surfaces of the six plies that were to comprise a laminated beam were either soap water washed, incised, or untreated. Of the 15 laminated beams that were constructed for each of the three composition schemes (i.e., C, D, and E), five were composed of plies that had been washed by soap water only, five were composed of plies that had been incised only, and five were composed of plies that were untreated (i.e., had been neither incised nor soap water washed). In several of our previous studies (Piao 2009b, 2009c), the surfaces of the wood plies were treated to possibly counteract the potential interference of the preservative CCA on the bonding strength of the synthetic resin. In this study, surfaces of wood plies were treated to possibly counteract the interference of penta on bonding strength. Incising was used to enlarge the glue-bonding areas between two plies, while soap washing was used to remove some of the penta on the surfaces of contiguous plies.

For the 15 laminated beams made of plies washed by soap water, each ply was first washed using a 5 percent AJAX detergent solution applied with a brush for 3 minutes. The washed plies were then flushed with water for 2 minutes to remove the soap from the plies. After rinsing, each ply was air dried for 24 hours prior to being glued into a laminated beam. For the 15 laminated beams made of incised plies, ply surfaces were incised at the rate 10,000 incisions per m^2 (929 incisions per ft^2) with a depth of 3 mm. Protocol for incising the plies of this study followed that of a previous study by the authors (Piao et al. 2009b).

A resorcinol phenol formaldehyde (RPF) resin was uniformly applied to the binding surfaces of each ply assigned to the soap-washed and untreated categories of the surface preparation treatment at the rate of 463 g/m^2 (43 g/ft^2), regardless of whether the ply was made of penta-treated utility pole wood or virgin wood. For the incised plies, 506 g/m^2 (47 g/ft^2) resin was applied to both the penta-treated wood and virgin wood plies. The RPF resin LT-5210 and hardener (curing agent) FM6210S were obtained from Hexion Co. (Springfield, Oregon). The resin/hardener mix consisted of 8 percent hardener. Beams were kept under pressure (0.86 MPa or 125 psi) at room temperature for 24 hours to cure the resin. Figure 1 shows some of the laminated beams that were constructed for this study.

The 45 laminated beams and the 15 solid-sawn utility pole beams were sawn and surfaced to a final dimension of 89 mm wide by 114 mm thick by 2.44 m long with a planer. All 60 beams were then air dried for 8 weeks. After air drying, all 60 beams were pressure treated with penta at a wood preservative treatment mill. The treatment procedure followed a Lowery empty cell process. Prior to the penta treatment, each beam was measured for width, depth, length, weight, and acoustic properties. After treatment, each beam was again measured for weight and acoustic properties. Five acoustic measurements were made on each beam before and after the penta treatment.

Figure 1.—Some of the laminated beams made of pentachlorophenol-treated southern pine utility pole wood and untreated virgin wood.

All beams were subjected to bending tests, according to ASTM Standard D198-02 (ASTM International 2003) and American National Standard Institutes (ANSI) Standard 05.3-1995 (ANSI 1995). Two-point loadings were applied symmetrically with 56 cm between load points on a 2.2-m span. Figure 2 illustrates the testing setup. Each beam was supported by two metal bearing plates, which were supported by fixed knife-edge reactions. The load was applied from the top of the beam through the two bearing blocks at a speed of approximately 8 mm/min. Each beam was loaded to failure in 6 to 10 minutes. Peak load, modulus of rupture (MOR), and MOE were recorded or calculated for each beam. None of the outer (i.e., top or bottom) plies of the laminated beams contained any knots to interfere with the bending tests. Solid-sawn utility pole wood beams

Figure 2.—Testing setup for the flexural tests of laminated beams (Composition D) consisting of four decommissioned pentachlorophenol-treated southern pine utility pole wood plies (middle) and two untreated southern pine virgin wood plies (top and bottom).

contained few knots, none of which interfered with the bending tests.

After flexural testing, two of the five failed laminated beams from each combination of composition scheme and surface preparation (a total of 18 beams from three compositions, three surface preparations, and two replications) were randomly selected and tested for preservative retention, glue-line shear, and glue-line delamination, in accordance with ASTM Standard D2559 (ASTM International 2004b) as follows.

From each of the 18 beams that were selected, a 152-mm section was removed from each end and discarded. A 25-mm contiguous section was then removed from one end of each beam and used for the penta retention evaluation. Each 25-mm section was separated into its component plies by cutting along each of the five glue lines. Each of the six component plies was cut into four or five 13-mm blocks (across the width of the ply). Each 13-mm block was then dried in an oven at 60°C for 48 hours prior to testing. After drying, blocks were chopped and ground into powder, passing through a US standard 30-mesh sieve. An X-ray fluorescence spectrometer was used to measure penta retention for each powdered block, according to American Wood Protection Association (AWPA) Standard A9-01 (AWPA 2006).

Glue-line shear strength was measured for six stair samples taken from each of the 18 laminated beams that were selected. Two stair samples were taken at three locations along the length of each beam. Two of the three locations were on one side of the failure spot and one was on other side of the failure spot. Two stair samples, each with wood grain direction parallel to the direction of loading during the test, were obtained at each location. A total of 108 shear stair samples (three surface preparation methods, three composition schemes, two beams, six stair samples per beam) were tested for glue-line shear strength according to ASTM Standard D2559 (ASTM International 2004b) using a shearing tool recommended by ASTM Standard D905-04 (ASTM International 2004a). 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 based on the bonded area between the two laminations.

In addition to the six stair samples that were cut from each of the 18 laminated beams, six delamination samples were also cut from each beam according to ASTM Standard D2559 (ASTM International 2004b). These delamination samples each measured 76 mm long by 127 mm wide by 114 mm high. Three samples were cut from one side of the failure spot and three were cut from the other side of the failure spot. A total of 108 delamination samples (three surface preparation methods by three composition schemes by two beams by six delamination samples per beam) were tested for glue-line delamination. The three-cycle delamination test was conducted as follows (ASTM International 2004b):

1. The test samples were first submerged under water using a screen and weight in a pressure vessel at room temperature. A vacuum of 0.085 MPa was drawn to the vessel and held for 5 minutes. Immediately after the vacuum was released, a pressure of 0.52 MPa was applied for 1 hour. The vacuum-pressure cycle was then repeated. The soaked samples were oven dried at 65.5°C for 21 hours.
2. After drying in Step 1, the samples were returned to the pressure vessel and steamed at 100°C 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 0.52 MPa was applied for 40 minutes. The samples were then oven dried at 65.5°C for 21 hours.
3. The first cycle was repeated again (once), making the duration of the complete test period 3 days.

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

Factorial analysis of variance was used to analyze the MOR, MOE, preservative retention, glue-line shear, and glue-line delamination data.

Results and Discussion

Penta retention after retreatment

Table 2 contains penta retention averages for the laminated beams after penta retreatment. Each number in Table 2 is the average of two penta retention values, one for each of the two failed beams at each combination of surface preparation and composition scheme that were selected (from the total of five). The penta retention value for each beam is the retention averaged over the approximately 30 13-mm blocks cut from the beam. Since four or five 13-mm blocks were cut across the width of each ply, the penta retention value for each beam is the retention average both across the beam and down the six plies of the beam.

An analysis of variance F test revealed that at least two of the three composition main effect penta retention averages of 5.1, 6.4, and 7.7 kg/m^3 for Compositions C, D, and E, respectively (see Table 2), were significantly different from each other ($P < 0.0001$). Furthermore, pairwise comparison analysis found that any two of these three averages (i.e., 5.1 and 6.4 kg/m^3, 5.1 and 7.7 kg/m^3, and 6.4 and 7.7 kg/m^3) were significantly different from each other ($P \leq 0.0015$). The number of virgin wood plies in each beam decreased from four (Composition C) to zero (Composition E) as the number of treated wood plies in each beam increased from two (Composition C) to six (Composition E). Therefore, the increased penta retention from Compositions C to E was likely due to the increased number of treated wood plies in the beams.

Table 2.—Pentachlorophenol (penta) retention averages (in kg/m^3) over two laminated beams at each combination of beam composition and surface preparation.[a]

	Beam composition[b]			
Surface preparation	C (2/6)	D (4/6)	E (6/6)	Main effect avg.
Washing	5.2	6.4	8.3	6.6
Incising	5.4	6.1	6.8	6.1
Control	4.6	6.7	8.0	6.4
Main effect avg.	5.1	6.4	7.7	6.4[c]

[a] Model standard deviation for laminated beams $\sqrt{\mathrm{MSE}} = 0.51$. For the 15 solid-sawn utility pole beams, penta retention average = 7.6 kg/cm^3 and penta retention standard deviation = 1.35 kg/cm^3.

[b] Composition schemes with number of utility pole wood plies/6 total plies presented in parentheses.

[c] Overall average.

Analysis of variance also revealed that the penta retention averages of Table 2 for the three surface treatment methods, namely 6.1, 6.6, and 6.4 kg/m^3 for incising, washing, and control (untreated), respectively, were not significantly different ($P = 0.2642$). Thus, neither incising nor soap washing had any influence on penta absorption.

Table 3 contains the penta retention averages of the plies from the top (Ply 1) to the bottom (Ply 6) of the beams for each composition scheme. Each number in Table 3 is the average of six penta retention values, one value for each of two beams at each of three surface preparation methods; for each beam the retention value is the average over the four or five 13-mm block samples cut from the ply in question. For Composition C, the two center plies were made of decommissioned utility pole wood and the four outer plies (two at the top and two at the bottom) were made of virgin wood. It can be seen from the table that the penta retention of the two center plies was two to three times the penta retention of the four outer plies for Composition C. Results similar to Composition C were found for Composition D: the penta retention averages of the four center plies made of decommissioned utility pole wood were 60 to 90 percent larger than those of the two outer virgin wood plies. Therefore, utility pole wood plies absorbed more penta than did virgin wood plies during penta retreatment, indicating that recycled penta-treated wood can be more easily retreated and can be expected to absorb more penta than wood being treated for the first time.

For virgin wood plies, ply location in a beam also affected penta retention in the ply. The top and bottom plies, for example, had greater surface areas directly exposed to the penta during retreatment than the plies in the middle. Therefore, the top and bottom virgin wood plies absorbed more penta after treatment than the virgin wood plies closer to the middle. This can be observed in the values presented for Composition C in Table 3. The penta retention averages of the top and bottom virgin wood plies registered higher than the penta retention averages of the virgin wood plies next to them. For the same reason, the two outer block samples cut across each ply were found to be significantly higher in penta than the samples in the middle of the ply.

Physical and flexural properties

Physical properties of the laminated and solid-sawn beams are summarized in Table 4. The nine bulk-density averages of the laminated beams after penta retreatment ranged from 0.63 to 0.75 g/cm^3. The bulk-density average of the 15 solid-sawn beams after penta retreatment was 0.75 g/cm^3. The 10 moisture content averages (at test) for laminated and solid beams ranged from 11.8 to 15.4 percent.

Table 3.—Pentachlorophenol retention averages (in kg/m^3) for laminated beams by beam composition and ply number.[a]

	Beam composition[b]			
Ply	C (2/6)	D (4/6)	E (6/6)	Main effect avg.
1	3.9	4.5	7.4	5.3
2	2.6	8.0	7.9	6.2
3	7.4	7.6	9.0	8.0
4	9.0	7.2	6.6	7.6
5	2.7	6.8	7.6	5.7
6	4.3	4.2	7.6	5.4
Main effect avg.	5.0	6.4	7.7	6.4[c]

[a] Except for main effect averages (and the overall average), each number in the table is an average over six beams, two at each of the three surface preparation methods. Model standard deviation $\sqrt{\text{MSE}} = 1.63$.

[b] Composition schemes with number of utility pole wood plies/6 total plies presented in parentheses.

[c] Overall average.

MOR averages for the laminated beams appear in Table 5. The overall MOR average for the 45 laminated beams was 66.5 MPa. The minimum fiber stress required for communication and power crossarm beams designated by ANSI Standard 05.3-1995 is 54 MPa (ANSI 1995). The nine MOR averages for the laminated beams ranged from 58.2 to 76.4 MPa (Table 5). These nine MOR averages ranged from 108 to 142 percent greater than the minimum strength of 54 MPa required by the ANSI standard. A visual summary of the MOR averages over the 15 beams of each composition scheme is presented in Figure 3. The dashed line in the figure is at the ANSI minimum strength value. The three MOR averages for the laminated beams exceeded the ANSI minimum strength value. Although the MOR average for the 15 solid-sawn utility pole wood crossarms (barely) failed to meet the ANSI standard of 54 MPa, 8 of the 15 individual MOR values for these solid-sawn crossarms exceeded 54 MPa. An analysis of variance *F* test indicated that the three MOR main effect averages 71.4, 63.1, and 65.0 MPa for Compositions C, D, and E, respectively (see Table 5), were statistically not all the same ($P = 0.0225$). The MOR average for Composition C (two treated plies, 71.4 MPa) was found, by pairwise comparisons analysis, to be significantly different from the MOR averages for Composition D (four treated wood plies, 63.1 MPa, $P = 0.0087$) and Composition E (six treated wood plies, 65.0 MPa, $P = 0.0394$). This can be explained as follows. The bending strength of a laminated beam is largely dependent on the strength of the outer two plies at the top and bottom of the beam. The outer two plies on either side of the core were made of high-density virgin wood at both surfaces and low-density virgin wood next to the core for Composition C, high-density virgin wood at both surfaces and low-density treated wood next to the core for Composition D, and high-density utility pole wood at the surfaces and low-density utility pole wood next to the core for Composition E. Therefore, the combination of a high-density virgin wood ply and a low-density virgin wood ply was stronger than either the combination of a high-density virgin wood ply and a low-density utility pole wood ply or the combination of a high-density utility pole wood ply and a low-density utility pole wood ply. In Part I of this research, we found that a substantial amount of penta-treated utility pole wood was of medium strength when compared with typical untreated virgin wood (Piao et al. 2011b). Thus, laminated beams made of low- to medium-strength penta-treated utility pole wood may need reinforcement for applications in which bending strength is a primary concern.

An analysis of variance *F* test also indicated that the MOR averages of Table 5 for the three surface preparation methods (63.5 MPa for washing, 68.8 MPa for incising, and 67.1 MPa for control) were not statistically different ($P = 0.2098$), suggesting that incising and soap washing had little influence on the strength of the laminated beams.

Table 5 also contains the MOE averages for the laminated beams. The MOE average for the 45 laminated beams was 12.2 GPa, which was higher than the MOE average (10.2 GPa) of the solid-sawn beams cut directly from the decommissioned utility poles. The MOE averages for the

Table 4.—Physical properties of beams made for this study.

Beam composition[a]	Ply surface preparation	No. of beams	Bulk density posttreatment, mean (SD) (g/cm^3)	MC at test, mean (SD) (%)
C (2/6)	Washing	5	0.67 (0.02)	14.7 (0.85)
C (2/6)	Incising	5	0.66 (0.03)	11.9 (0.63)
C (2/6)	Control	5	0.66 (0.02)	11.9 (0.84)
D (4/6)	Washing	5	0.65 (0.03)	14.3 (0.56)
D (4/6)	Incising	5	0.70 (0.02)	13.2 (1.32)
D (4/6)	Control	5	0.63 (0.03)	12.2 (0.75)
E (6/6)	Washing	5	0.73 (0.02)	15.4 (1.25)
E (6/6)	Incising	5	0.75 (0.01)	11.8 (0.75)
E (6/6)	Control	5	0.74 (0.03)	13.5 (0.97)
F[b]	—	15	0.75 (0.05)	15.4 (1.92)

[a] Composition schemes with number of utility pole wood plies/6 total plies presented in parentheses for the laminated beams.

[b] Solid-sawn utility pole wood beams.

Table 5.—Modulus of rupture (MOR) and modulus of elasticity (MOE) averages over five laminated beams at each combination of beam composition and surface preparation, and over 15 solid-sawn utility pole beams.

	Beam composition[a]			
Surface preparation	C (2/6)	D (4/6)	E (6/6)	Main effect avg.
MOR (MPa)[b]				
Washing	67.7	58.2	64.6	63.5
Incising	76.4	62.6	67.4	68.8
Control	69.9	68.5	63.0	67.1
Main effect avg.	71.4	63.1	65.0	66.5[c]
MOE (GPa)[d]				
Washing	12.4	11.7	13.6	12.6
Incising	13.7	11.1	13.1	12.7
Control	11.3	12.1	10.6	11.4
Main effect avg.	12.5	11.7	12.4	12.2[c]

[a] Composition schemes with number of utility pole wood plies/6 total plies presented in parentheses.

[b] Model MOR standard deviation $\sqrt{\text{MSE}} = 8.15$ MPa. For the 15 solid-sawn utility pole beams, average MOR = 53.7 MPa and MOR standard deviation = 9.8 MPa.

[c] Overall average.

[d] Model MOE standard deviation $\sqrt{\text{MSE}} = 1.16$ GPa. For the 15 solid-sawn utility pole beams, average MOE = 10.2 GPa and MOE standard deviation = 1.50 GPa.

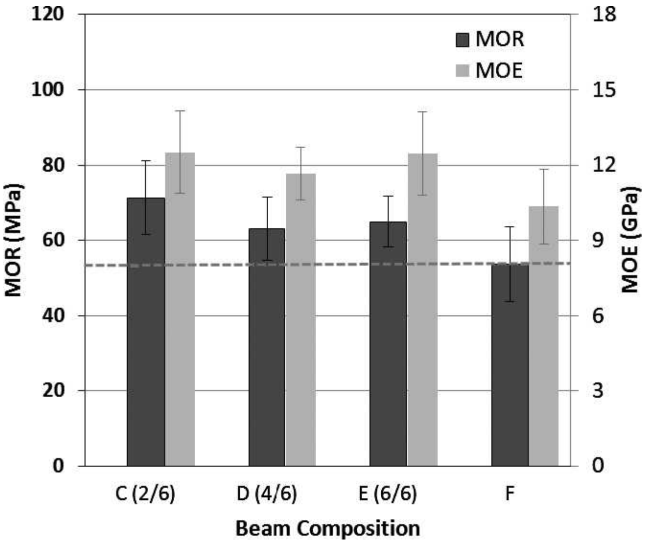

Figure 3.—Modulus of rupture (MOR) and modulus of elasticity (MOE) averages over 15 beams for each of Compositions C (two core utility pole wood plies/six total plies), D (four core utility pole wood plies/six total plies), E (six utility pole wood plies/six total plies), and F (solid-sawn utility pole wood beams). The dashed line is at the American National Standard Institute minimum required MOR strength of 54 MPa.

three composition schemes were 12.5, 11.7, and 12.4 GPa for Compositions C, D, and E, respectively. These three MOE averages were not statistically significantly different ($P = 0.0947$), indicating that the number of recycled utility pole wood plies had little effect on the stiffness of the beams. MOE averages for the three laminated beam compositions, as well as for the solid-sawn utility pole beams, are also depicted graphically in Figure 3. The three surface preparation MOE averages (12.7, 12.6, and 11.4 GPa for surface incising, soap washing, and the control, respectively) were found by an analysis of variance F test to not all be statistically the same ($P = 0.0069$). Pairwise comparison analysis revealed that the MOE incising and washing averages were not significantly different from each other ($P = 0.8638$), but both were significantly different from the MOE control average ($P = 0.0047$ for incising and $P = 0.0073$ for washing). Although statistically different from zero, the magnitude of the differences between the MOE averages for incising and control ($12.7 - 11.4 = 1.3$ GPa) and washing and control ($12.6 - 11.4 = 1.2$ GPa) are fairly small. Therefore, we conclude that incising and soap washing may have only a minor (although significant) influence on the stiffness of laminated beams.

Glue-line shear and wood failure

Table 6 contains glue-line shear strength values and glue-line wood failure values for the 18 randomly selected failed laminated beams. Each shear (i.e., failure) value is the average of two shear (failure) measurements, one for each of the two beams at each combination of surface preparation and composition scheme. The shear (failure) measurement on each beam is the average shear (failure) over approximately 30 glue lines per beam. High shear strength was found between glue lines of the laminated beams. The overall average of the glue-line shear strength of the 18 beams was 12.2 MPa, which was greater than the overall glue-line shear strength average (10.8 MPa) of CCA-treated laminated utility pole wood beams (Piao et al. 2011a); the overall average of the glue-line wood failure of the 18 beams was 80.8 percent, which was greater than the minimum value of 75 percent required by ASTM Standard

Table 6.—Glue-line shear and wood failure averages over two laminated beams for each combination of beam composition and surface preparation.

Surface preparation	Beam composition[a] C (2/6)	D (4/6)	E (6/6)	Main effect avg.
Glue-line shear (MPa)[b]				
Washing	12.6	12.7	13.5	12.9
Incising	12.0	11.6	11.3	11.6
Control	11.5	12.6	12.1	12.0
Main effect avg.	12.0	12.3	12.3	12.2[c]
Glue-line wood failure (%)[d]				
Washing	78.0	88.9	86.8	84.6
Incising	87.1	81.8	76.9	81.9
Control	75.6	75.5	76.8	76.0
Main effect avg.	80.2	82.1	80.2	80.8[c]

[a] Composition schemes with number of utility pole wood plies/6 total plies presented in parentheses.

[b] Model shear standard deviation $\sqrt{\text{MSE}} = 0.69$ MPa.

[c] Overall average.

[d] Model wood failure standard deviation $\sqrt{\text{MSE}} = 6.03\%$.

D2559 (ASTM International 2004b). The interference of penta in the wood on glue-line bonding of penta-treated wood was not as great as the interference of CCA on glue bonding of CCA-treated wood.

Composition scheme had little influence on the glue-line shear strength of the beams. The averages 12.0, 12.3, and 12.3 MPa for Compositions C, D, and E, respectively, were found to be not significantly different from each other ($P = 0.7226$) by the composition main effect F test, indicating that bonding shear was not different between penta-treated wood plies, between virgin wood and penta-treated wood plies, and between virgin wood plies.

An analysis of variance F test found the shear strength averages 11.6, 12.9, and 12.0 MPa for beams that had been incised, soap washed, and untreated, respectively, to not all be statistically the same ($P = 0.0263$). The shear strength of the beams that had been soap washed was highly significantly different from the shear strength of the beams that had been incised ($P = 0.0095$) and marginally significantly different from the shear strength of the control beams ($P = 0.0552$). It is conjectured that for the plies washed by soap water, residual penta was reduced or removed from the gluing surfaces. Therefore, the interference of penta on glue bonds was reduced, resulting in increased glue-line bonding strength.

The glue-line wood failure averages were 81.9, 84.6, and 76.0 percent for the beams that were incised, soap washed, and untreated, respectively. An analysis of variance F test found no strong significant differences between these three averages ($P = 0.0902$). However, a mildly significant difference was found between the soap-washed wood failure average and the control wood failure average ($P = 0.0360$). Stronger bonding usually leads to greater glue-line wood failure. Therefore, washing with soap water may improve the bonding quality between penta-treated utility pole wood members.

Table 7 displays the shear strength averages for each combination of glue-line number and composition scheme. Each number in the table is the average of six shear values, one value for each of two beams at each of the three surface preparations. For each beam, the shear value is the average shear over six locations in the beam. An analysis of variance F test revealed that the five glue-line shear averages (i.e., 12.9, 12.1, 11.8, 12.0, and 12.2 MPa) are not statistically significantly different from each other ($P = 0.2584$). The smallest glue-line average, 11.8 MPa, occurred at glue line 3, in the center of the beams. This value is higher than the typical shear strength parallel to grain of longleaf pine (10.4 MPa; Koch 1972).

Table 7.—Glue-line shear and wood failure averages for laminated beams by beam composition and glue-line number.[a]

Glue line	Beam composition[b] C (2/6)	D (4/6)	E (6/6)	Main effect avg.
Glue-line shear (MPa)[c]				
1	11.8	13.7	13.1	12.9
2	12.2	12.2	11.9	12.1
3	11.3	11.5	12.5	11.8
4	11.6	12.9	11.5	12.0
5	13.0	11.2	12.3	12.2
Main effect avg.	12.0	12.3	12.3	12.2[d]
Glue-line wood failure (%)[e]				
1	74.9	79.2	73.7	75.9
2	75.4	84.9	82.6	81.0
3	83.8	83.5	83.4	83.6
4	86.3	83.0	81.9	83.7
5	79.9	79.9	79.9	79.9
Main effect avg.	80.1	82.1	80.3	80.8[d]

[a] Except for main effect averages (and the overall average), each number in the table is an average over six beams, two at each of the three surface preparation methods.

[b] Composition schemes with number of utility pole wood plies/6 total plies presented in parentheses.

[c] Model shear standard deviation $\sqrt{\text{MSE}} = 1.47$ MPa.

[d] Overall average.

[e] Model wood failure standard deviation $\sqrt{\text{MSE}} = 9.52\%$.

Glue-line delamination

Table 8 contains delamination averages for each combination of glue-line number, composition scheme, and surface preparation method. Each number in the table is the average of two delamination percentages, one for each of two replicate beams. The delamination percent for each beam is the average delamination over the six delamination samples cut from the beam. Of the 45 delamination averages given in Table 8, only 12 were less than, or equal to, the 1 percent required by Standard D2559 for beams in exterior applications (ASTM International 2004b). For glue lines 1, 2, and 5, beams made entirely of soap-washed utility pole wood plies had the lowest (or tied for the lowest) delamination average (Composition E in Table 8). Beams made entirely of soap-washed utility pole plies had the third lowest delamination average for glue line 4 and the fifth lowest average for glue line 3. Of the 18 laminated beams tested for delamination, none met the maximum 1 percent delamination requirement of D2559, and therefore, none of the beams was suitable for exterior use.

Delamination averages were 4.1, 3.2, and 1.7 percent for Compositions C, D, and E, respectively. An analysis of variance F test indicated that the three corresponding population averages were not all the same ($P = 0.0169$). However, the only pairwise difference that was significantly different from zero was between Composition C and Composition E ($P = 0.0049$), indicating that laminated

Table 8.—Glue-line delamination (percent) averages over two laminated beams at each combination of glue line, surface preparation, and composition scheme.[a]

	Surface preparation									
	Incised			Washed			Control			
Glue line	C (2/6)[b]	D (4/6)	E (6/6)	C (2/6)	D (4/6)	E (6/6)	C (2/6)	D (4/6)	E (6/6)	Main effect avg.
1	**0.8**	1.1	2.5	7.5	**0.9**	**0.0**	2.2	6.1	2.2	2.6
2	2.8	4.3	**0.6**	5.0	3.1	**0.3**	2.3	2.3	3.5	2.7
3	3.1	**0.2**	**0.6**	9.3	5.9	3.8	4.0	4.2	1.5	3.6
4	4.6	5.3	2.9	0.8	6.9	1.2	3.7	3.0	1.1	3.3
5	**0.9**	**0.0**	2.4	9.4	3.9	**0.0**	5.7	**0.4**	3.5	2.9
Avg.[c]		2.1			3.9			3.0		3.0[d]

[a] Values less than 1 percent appear in bold font. Model standard deviation $\sqrt{\text{MSE}} = 3.09\%$.

[b] The main effect averages for beam composition were 4.1, 3.2, and 1.7 percent for Compositions C, D, and E, respectively. Beam composition is presented in parentheses as the number of utility pole wood plies/6 total plies.

[c] Surface preparation main effect averages.

[d] Overall average.

beams made entirely of utility pole wood plies delaminated less than the beams consisting of a mixture of utility pole wood plies and virgin wood plies. Therefore, the glue lines between utility pole wood tended to delaminate less than the glue lines between virgin wood plies and between virgin wood plies and utility pole wood plies.

The overall delamination of each of the five glue lines in the beams was examined. The delamination averages were 2.6, 2.7, 3.6, 3.3, and 2.9 percent for Lines 1 through 5, respectively. An analysis of variance indicated that the corresponding population averages were all the same ($P = 0.8433$).

The incised delamination average of 2.1 percent was smaller than either the delamination averages of 3.9 and 3.0 percent for soap-washed and control beams, respectively. These three surface preparation overall averages, however, were not statistically significantly different ($P = 0.1153$).

Previous studies reported that laminated utility pole crossarms made entirely of decommissioned CCA-treated utility pole wood, entirely of untreated virgin wood, and a mixture of CCA-treated and virgin wood failed to meet the delamination requirement by ASTM Standard D2559 (Piao et al. 2011a). The results of the current study also suggest that the delamination of penta-treated utility pole wood beams fails to meet the requirement of D2559. All of the results indicate that delamination is a concern for laminated beams for exterior applications, whether the beams are made of virgin wood or CCA- or penta-treated utility pole wood. It was also found that incising and preservative treatments were helpful in reducing delamination but could not stop it. Since beams consisting exclusively of utility wood plies delaminated less than beams consisting of both virgin wood plies and utility pole plies, the issue of delamination is not related to the use of penta-treated utility pole wood, but rather to the gluing method, particularly to the use of RPF resin. Because of their comparable strength to high-quality solid wood virgin beams, CCA- and penta-treated utility pole wood beams bonded by the RPF resin can be used only in places where the beams are not subjected to exterior exposure conditions.

Concluding Remarks

Forty-five laminated beams and 15 solid-sawn beams fabricated from decommissioned penta-treated utility pole wood were evaluated for penta retention after retreatment, bending strength, glue-line shear, glue-line wood failure, and glue-line delamination. Penta-treated utility pole wood plies absorbed more penta than virgin wood plies after penta retreatment. All of the laminated beams and 8 of the 15 solid-sawn beams directly cut from decommissioned utility poles and pole sections met the bending strength requirement of ANSI Standard 05.3-1995. However, laminated beams consisting of recycled penta-treated utility pole wood plies may need reinforcement with high-density virgin wood for applications in which the bending strength of the beams is a primary concern. Penta utility pole wood may be used to construct laminated beams without pretreatments (incising or soap washing). Laminated beams made in this study were not suitable for exterior applications, whether they were made of virgin wood or decommissioned utility pole wood. Large delamination (greater than 1%) is likely to occur in laminated beams exposed to outside weather. Because of their comparable strength to high-quality virgin solid wood beams, CCA- and penta-treated utility pole wood beams consolidated by RPF resin can be used in places where the beams are not subjected to exterior exposure conditions.

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Literature Cited

American National Standard Institute (ANSI). 1995. Solid sawn-wood crossarms and braces—Specifications and dimensions. ANSI 05.3-1995. ANSI, New York.

American Wood Protection Association (AWPA). 2006. Method for the determination of oil-type preservatives and water in wood. AWPA A9-01. *In:* Annual Book of Standards. AWPA, Birmingham, Alabama.

Arsenault, R. D. 1975. CCA-treated wood foundations: A study of permanence, effectiveness, durability, and environmental considerations. *AWPA Proc*. 71:126–148.

ASTM International. 2003. Standard test methods of static tests of lumber in structural sizes. ASTM D198-02. ASTM International, West Conshohocken, Pennsylvania.

ASTM International. 2004a. Standard test method for strength properties of adhesive bonds in shear by compression loading. ASTM D905-04. ASTM International, West Conshohocken, Pennsylvania.

ASTM International. 2004b. Standard specification for adhesives for structural laminated wood products for use under exterior (wet use) exposure conditions. ASTM D2559-04. ASTM International, Philadelphia, Pennsylvania.

Carter, P., D. Briggs, R. J. Ross, and X. Wang. 2005. Acoustic testing to enhance western forest values and meet customer wood quality needs. *In:* Productivity of Western Forests: A Forest Products Focus. General Technical Report PNW-GTR-642. C. A. Harrington and S. H. Schoenholtz (Eds.). USDA Forest Service, Pacific Northwest Research Station, Portland, Oregon. pp. 121–129.

Clausen, C. A., J. H. Muehl, and A. M. Krzysik. 2006. Properties of structural panels fabricated from bioremediated CCA-treated wood: Pilot scale. *Forest Prod. J.* 56(3):32–35.

Cooper, P. A., D. Jeremic, and J. L. Taylor. 2001. Residual CCA levels in CCA-treated poles removed from service. *Forest Prod. J.* 51(10): 58–62.

Cooper, P. A., D. Jeremic, T. Ung, J.-P. Aucoin, and C. Timusk. 1996. The potential for re-use of preservative-treated utility poles removed from service. *Waste Manag. Res*. 14:263–279.

Falk, B. 1997. Wood recycling: Opportunities for the wood waste resource. *Forest Prod. J.* 47(6):17–22.

Falk, R. H., D. Green, D. Rammer, and S. F. Lantz. 2000. Engineering evaluation of 55-year-old timber columns recycled from an industrial military building. *Forest Prod. J.* 50(4):71–76.

Huhnke, R. L., F. Zwerneman, D. K. Lewis, S. Harp, G. A. Doeksen, and C. B. Green. 1994. Recycling wood utility poles. Oklahoma Center for the Advancement of Science and Technology (OCAST) Applied Research Program 1995. OCAST, Oklahoma City.

King, S. A. and D. K. Lewis. 2000. Manufacturing solid wood products from used utility poles: An economic feasibility study. *Forest Prod. J.* 50(11/12):69–78.

Koch, P. 1972. Utilization of the southern pines. Agriculture Handbook No. 420, V(1). USDA Forest Service, Southern Research Station, Pineville, Louisiana. 734 pp.

Lahiry, A. K. 2001. An environmental aspect relating to leachability of CCA from hardwood and softwood poles in Bangladesh. Doc. No. IRG/WP 01-50167. International Research Group on Wood Preservation Secretariat, Stockholm.

Leichti, R. J., M. Meisenzahl, and D. Parry. 2005. Structural timbers from retired Douglas-fir utility poles. *Forest Prod. J.* 55(3):61–65.

Li, W., T. F. Shupe, and C. Y. Hse. 2004. Physical and mechanical properties of flakeboard from recycled CCA-treated wood. *Forest Prod. J.* 54(2):89–94.

Mengeloglu, F. and D. J. Gardner. 2000. Recycled CCA-treated lumber in flakeboards: Evaluation of adhesives and flakes. *Forest Prod. J.* 50(2):41–45.

Munson, J. M. and D. P. Kamdem. 1998. Reconstituted particleboards from CCA-treated red pine utility poles. *Forest Prod. J.* 48(3):55–62.

Nurmi, A. J. 1993. A comparative study of CCA type C and B treated poles in service. *In:* Second International Symposium of Wood Preservation, Cannes. Doc. No. IRG/WP/93-50001. International Research Group on Wood Preservation Secretariat, Stockholm. pp. 91–100.

Osborne, P. D. and R. F. Fox. 1995. CCA type C depletion of southern yellow pine utility poles. Doc. No. IRG/WP/95-50049. International Research Group on Wood Preservation Secretariat, Stockholm.

Piao, C., M. Gibson, T. F. Shupe, and W. A. Nipper. 2011a. Laminated crossarms made from decommissioned chromated copper arsenate–treated utility pole wood. Part II: Preservative retention, glue-line shear, and delamination. *Forest Prod. J.* 60(7/8):659–667.

Piao, C., M. D. Gibson, C. J. Monlezun, and C. M. Smith. 2009a. Chromated copper arsenate distribution in decommissioned southern pine utility poles for recycling. *Forest Prod. J.* 59(9):67–73.

Piao, C. and L. H. Groom. 2010. Residual strength and stiffness of lumber from decommissioned chromated copper arsenate-treated southern pine utility poles. *Forest Prod. J.* 60(2):166–172.

Piao, C. and C. J. Monlezun. 2010. Laminated crossarms made from decommissioned chromated copper arsenate-treated utility pole wood. Part I: Mechanical and acoustic properties. *Forest Prod. J.* 60(2): 157–165.

Piao, C., C. J. Monlezun, C. Y. Hse, and W. A. Nipper. 2009b. Glue line bonding performance of decommissioned CCA-treated wood. Part II: Retreated with CCA. *Forest Prod. J.* 59(1):31–39.

Piao, C., C. J. Monlezun, and T. F. Shupe. 2009c. Glueline bonding performance of decommissioned CCA-treated wood. Part I: Without retreatment. *Forest Prod. J.* 59(7/8):36–42.

Piao, C., C. J. Monlezun, J. J. Wang, and L. H. Groom. 2011b. Recycling of pentachlorophenol-treated southern pine utility poles. Part I: Preservative retention and mechanical properties. *Forest Prod. J.* 61(1):38–45.

Ruddick, J. N. R., E. B. Jonsson, and E. M. A. Nilsson. 1991. Utility pole performance: Effect of service life on surface hardness and preservative retention of CCA-treated pine poles. *Forest Prod. J.* 41(6):21–27.

Shi, S. Q., D. J. Gardner, D. Pendleton, and T. Hoffard. 2001. Timber production from reclaimed creosote-treated wood pilings: Economic analysis and quality evaluation. *Forest Prod. J.* 51(11/12):45–50.

Smith, S. M. and J. J. Morrell. 1989. Comparing full-length bending strength and small-scale test strength of western redcedar poles. *Forest Prod. J.* 39(3):29–33.

Stewart, A. H. and J. R. Goodman. 1990. Life cycle economics of wood pole utility structures. *IEEE Trans. Power Del*. 5(2):1040–1046.

Tascioglu, C., B. Goodell, and R. Lopez-Anido. 2003. Bond durability characterization of preservative treated wood and E-glass/phenolic composite interfaces. *Compos. Sci. Technol*. 63(7):979–991.

Vick, C. B. 1995. Coupling agent improves durability of PRF bonds to CCA treated southern pine. *Forest Prod. J.* 45(3):78–84.

Vick, C. B., R. L. Geimer, and J. E. Wood, Jr. 1996. Flakeboards from recycled CCA-treated southern pine lumber. *Forest Prod. J.* 46(11/12):89–91.

Wang, X., R. J. Ross, J. R. Erickson, J. W. Forsman, G. D. McGinnis, and R. C. DeGroot. 2001. Nondestructive evaluation of potential quality of creosote-treated piles removed from service. *Forest Prod. J.* 51(2):63–68.