Recycling of Pentachlorophenol-Treated Southern Pine Utility Poles. Part I: Preservative Retention and Mechanical Properties

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Abstract

Reusing decommissioned wood utility poles will extend the service life of the treated wood and offer economic and ecological advantages. The aim of this study was to evaluate pentachlorophenol (penta) retention and distribution, together with physical and mechanical properties of penta-treated southern pine (*Pinus* spp.) utility poles for reuse and recycling. Fifteen penta-treated decommissioned southern pine utility poles and pole sections were collected and studied. As expected, residual penta retention decreased from outside to the pith and from the top to the bottom of the poles. Of the 15 poles tested, penta retention averages at the two outer test zones varied from 3.9 to 5.6 kg/m^3, while the overall penta retention averages of these poles varied from 3.2 to 5.4 kg/m^3. The modulus of rupture (MOR) and modulus of elasticity (MOE) averages of the 15 poles and pole sections were 33.7 and 68.1 percent lower, respectively, than the published MOR and MOE values of virgin loblolly pine (*Pinus taeda*) wood. MOR and MOE varied in an M shape across the diameters of the poles due to surface aging. The shallow, aged surface layers, particularly of older poles, had low strength and relatively high penta retention, suggesting that surface layers should be removed from the recycled poles. However, most of the remaining pole portions had medium to high strength and were therefore reusable for other products.

Pentachlorophenol (penta) has been one of the major preservatives used to treat wood utility poles to protect them from decay fungi and insect attacks in various environments. Compared with wood utility poles treated using other preservatives, such as creosote and chromated copper arsenate (CCA), penta-treated utility poles are clean, easily climbed, not brittle, and not corrosive to metal fasteners. Penta is also a cost-effective choice and can protect wood utility poles for up to 40 years in service. However, disposal of penta-treated poles in landfills or by incineration is costly to the environment and the economy.

A high percentage of decommissioned wood utility poles retain sufficient strength to make them usable in other treated-wood applications (Huhnke et al. 1994, Cooper et al. 1996, Falk 1997, Munson and Kamdem 1998, King and Lewis 2000, Mengeloglu and Gardner 2000, Tascioglu et al. 2003, Li et al. 2004, Morrell 2004, Leichti et al. 2005, Clausen et al. 2006). Although 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. Reusing penta-treated utility poles will extend the service life of the treated wood and offer economic and ecological advantages, such as reductions in forest harvesting, toxic chemicals in the environment, and disposal costs of treated wood. Understanding the retention and distribution of penta

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in decommissioned wood utility poles will be beneficial not only to the reuse of decommissioned treated wood but also to the durability analyses of utility poles in service (Davis 1993, Munson and Kamdem 1998, Cooper et al. 2001). The residual CCA in decommissioned CCA-treated utility poles has been extensively studied (Arsenault 1975; Ruddick et al. 1991; Nurmi 1993; Osborne and Fox 1995; Cooper et al. 1996, 2001; Lahiry 2001; Piao et al. 2009). However, few references in the literature provide retention analysis of penta in decommissioned penta-treated utility poles (Cooper et al. 1996).

Wood poles deteriorate with time (Stewart and Goodman 1990). The reusability of decommissioned utility poles is primarily dependent on the residual strength of the timber, which is affected by service age, preservative type, and treatment quality, in addition to the variability inherent in wood, such as species, age and growth rate, etc. Determining the residual strength of utility pole wood is essential for reuse and recycling of quality decommissioned treated wood. Cooper et al. (1996) studied 456 poles and pole sections for reuse potential as round poles, posts, sawn posts, timber, lumber, and roof shingles. Major pole species (i.e., western red cedar [*Thuja plicata*], northern white cedar [*Thuja occidentalis*], red pine [*Pinus resinosa*], jack pine [*Pinus banksiana*], southern pine, Douglas-fir [*Pseudotsuga menziesii*], and lodgepole pine [*Pinus contorta*]) and preservative chemicals (creosote, penta, and CCA) were studied, and those authors demonstrated that the modulus of rupture (MOR) and the modulus of elasticity (MOE) of decommissioned treated wood were comparable to the average MOR and MOE of untreated virgin wood of the same species. Leichti et al. (2005) studied the residual strength of decommissioned Douglas-fir utility poles treated with penta or creosote and found that bending strength and stiffness of the utility pole wood were 10 percent below those of untreated virgin wood materials. The quality of the wood along and across a decommissioned pole may differ from what is expected from the wood across and along a virgin log because of degradation of the utility pole wood after long-term exposure in the environment. Therefore, evaluating the strength and stiffness of an entire decommissioned utility pole can provide important data for structural design and reuse of the pole. However, little information is available regarding the strength and stiffness of penta-treated utility pole wood across and along an entire pole after service.

The purpose of a series of projects undertaken by the authors was to evaluate the feasibility of, and the problems encountered when, reusing decommissioned penta-treated utility poles for other industrial products, such as bridge beams and utility pole crossarms. Results of studies on penta retention and mechanical properties of decommissioned southern pine (*Pinus* spp.) utility poles and pole sections appear in this report. Additional studies on laminated beams made from decommissioned penta-treated wood utility poles will be summarized in a future report.

Materials and Methods

Fifteen penta-treated decommissioned southern pine utility poles and pole sections were obtained from local power companies and used for penta retention and mechanical property evaluation. Various properties of these poles are presented in Table 1. Poles ranged between Grades 3 and 5, with year marks between 1970 and 2008 and usable length between 2.5 and 13.7 m. The poles were graded primarily based on the length and minimum circumference at the top according to American National Standard Institute (ANSI) Standard O5.1 (ANSI 2008) at the time when the poles were made. Poles 13, 14, and 15 had missing marked stamps. Therefore, installation dates and years in service for these three poles were not available. All poles or poles sections were decommissioned and collected from 2008 to 2010, making the estimated service ages from 1 to 39 years. Three poles (Poles 1, 8, and 9) were complete. The remaining poles were incomplete, missing either the top and/or the bottom sections or portions of the top and/or bottom sections. Most poles were decommissioned due to rot. Soft ends or hollow cores were found in some of these poles. Although Pole 1 was a complete pole, it had a hollow core from the bottom to the middle of the pole; therefore, test samples were taken only from the middle to the top of this pole.

Metal attachments, nails, and wires were removed from the poles after collection. Before cutting, all poles had been stored in the open air for 6 to 15 months. Soft, rotted, and/or broken ends were removed from each pole section and discarded (landfilled). Consecutive 2.4-m (8-ft) segments were marked off along the entire length of the remainder of each pole or pole section. After the poles/pole sections were cut into 2.4-m sections (only one 2.4-m section could be obtained from Poles 3, 4, 6, and 13, because the usable parts of these poles were less than 4.8 m in length), a center board free of knots and defects containing the pith was carefully removed from each 2.4-m section. Each center board was planed to a final thickness of 25.4 mm. A strip 25.4 mm in width, 25.4 mm in length, and 25.4 mm in height was removed from the bottom end of the board and was used to measure penta retention across the diameter of the pole. Each strip was then cut into block samples (25.4 by 25.4 by 19.1 mm) beginning at one surface of the pole and proceeding through the pith to the opposite surface. Between 7 and 12 block samples were obtained from each strip, depending upon the width of the center board. Each block sample was then dried in an oven at 60°C for an average of 36 hours before testing. After drying, each block sample was weighed to determine its density and then chopped and ground into powder that passing through a US standard 30-mesh sieve. The ground sample was compressed into a pellet using a compressor provided by the manufacturer. An x-ray spectrometer (ASOMA Instruments, Austin, Texas) was used to measure the penta retention of the ground sample according to American Wood Protection Association (AWPA) Standard A9-01 (AWPA 2006). Each block sample was a test (assay) zone across and down each pole/pole section, from which penta distributions across and down the poles/pole sections were obtained.

After strip removal, a section 41 cm in length (contiguous to the strip) along the length of each center board was removed. From this section, small clear bending samples free of knots and defects were produced by first removing 5 mm from each edge and then cutting the remainder into square beams 41 cm in length, 25.4 mm in width, and 25.4 mm in height. These beams were the small clear samples used to measure the bending properties across and along (or down) each pole. Before the bending test, beam samples were conditioned in an air-conditioned room at a constant temperature (24°C) to constant weight in about 5 weeks. After conditioning, each beam was then measured for

Table 1.—Summary data of the pentachlorophenol-treated decommissioned southern pine utility poles.

Pole	Year marked	Grade	Original length (m)	Usable length (m)	Section missing[a]	Service years[b]	Diameter (cm)[c]	Heartwood diameter (cm)[c]
1	1970	4	10.7	9.2	NA	39	24	10.2
2	1985	4	12.2	7.8	T	24	27	4.4
3	1991	4	13.7	2.8	T&B	18	30	5.1
4	1992	4	13.7	3.4	T&B	17	29	10.2
5	1998	5	9.1	4.5	T&B	11	22	5.1
6	2000	3	15.2	3.0	T&B	9	33	14.6
7	2000	3	19.8	7.2	T	9	32	7.6
8	2003	4	12.2	12.2	NA	6	28	3.2
9	2003	3	13.7	13.7	NA	6	30	11.4
10	2007	3	13.7	6.6	T&B[d]	2	30	3.8
11	2007	3	16.8	11.2	T	2	32	1.9
12	2008	4	12.2	9.9	T	1	26	2.5
13	—	4	13.7	2.5	T&B	—	29	6.4
14	—	4	13.7	6.7	T&B	—	29	5.1
15	—	—	—	7.6	—	—	28	4.4

[a] Sections were missing from the top (T) and/or bottom (B) of the poles, or the pole was complete (NA).

[b] Estimated years of service.

[c] Measured at stamped areas.

[d] Only a portion of the top and a portion of the bottom were missing.

length, width, thickness, and weight. The growth rings of each beam were counted and recorded. All of the small clear samples (or beams) were loaded to failure in static bending using an Instron testing machine according to American Society for Testing and Materials (ASTM) Standard D143-94 Section 8 (ASTM 2000). Each sample was loaded to the tangential surface nearest the pith in a span length of 35.6 cm at a rate of 1 mm/min. Both laterally adjustable supporting knife edges were provided with rollers. Figure 1 shows the setup for the bending tests of the small clear samples. From the 15 poles, a total of 286 small clear samples were prepared and tested. The number of clear samples cut from one 41-cm segment of a center board depended upon the width of the center board. All personnel were well protected with personal safety devices during handling and processing of the treated-wood materials. The processing residuals were carefully disposed of in a landfill.

Figure 1.—Testing setup for the flexural tests of small clear samples cut from pentachlorophenol-treated decommissioned utility poles.

Immediately after testing, a 25.4-mm section was cut from each small clear sample near the point of failure and was used for measurement of moisture content (MC) at test. The section was weighed and then dried in an oven at 60°C for 36 hours. The drying temperature (60°C) used in this study was higher than the 45°C required by AWPA Standard A9-01 for the drying of oil-based preservative–treated samples. Each section was weighed again after drying, and the MC of each sample at test was calculated.

Factorial analysis of variance (ANOVA) was used to analyze the penta retention, bending strength, and stiffness data. The analyses were carried out using the general linear model procedure of the SAS software (SAS 2010).

Results and Discussion

Penta retention across the poles

Figure 2 gives the penta distribution across a complete pole diameter having longitudinal location near the pole stamp for Pole 6. The data points in the figure represent the penta retention of 19-mm block samples beginning at the pole surface, continuing to the pith, and proceeding to the opposite surface. In Figure 2, location 114 mm (Zone 6) is at the center (but not necessarily the pith) of the pole, while locations 19 and 210 mm (Zones 1 and 11, respectively) are at the surfaces of the pole. As expected, penta retention in Figure 2 decreased in a curvilinear fashion from each outer surface to the pith of Pole 6.

Of the 15 poles, penta retention at the piths was always greater than 2 kg/m^3. Therefore, no penta-free zones occurred in the penta-treated poles of this study. It is known that heartwood is not easily penetrated by preservatives because of the extractives in the wood. However, unlike Douglas-fir, southern pine is of low heartwood content. Table 1 contains the heartwood diameters and the total diameters of the 15 southern pine poles in this study. Since heartwood was covered by a thick shell of sapwood, preservative would have to travel a long distance before reaching heartwood during the initial treatment. The penta near the piths might not be due to penetration during the initial treatment but, rather, to migration and redistribution

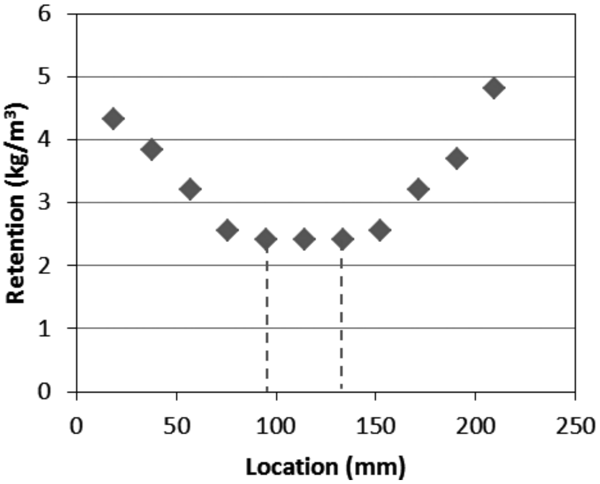


Figure 2.—Pentachlorophenol retention across a complete diameter (near the pole stamp) for decommissioned southern pine utility Pole 6 (Grade 3, 15.2 m in length, year 2000). The zone between the two dashed lines consisted of heartwood.

during the service lives of the poles. This low penta retention may have little effect on the adhesion of treated wood. The effects of penta retention on glue-line shear strength will be studied by the authors in the future.

The penta retention averages over the two test zones located at the outer surfaces for all diameters and overall penta averages over all test zones of the 15 poles and pole sections are presented in Table 2. It can be seen from the table that the penta retention averages of the two surface test zones were at least 3.9 kg/m^3, while the overall retention averages for the poles were greater than 3.2 kg/m^3. For the outer surface zones, AWPA Standard U1-06 Use Category 4A (AWPA 2006) requires that the minimum penta retention be 4.8 kg/m^3 for a new pole. Most of the older poles (Poles 1, 3, 4, 5, 6, and 8) failed to meet the minimum retention requirements of AWPA Standard U1-06 (Table 2).

The curvilinear distribution of penta across the diameter of a utility pole (see Fig. 2) may cause potential strength and delamination problems for laminated products made of decommissioned utility pole wood. A preliminary result demonstrated that high penta retention in wood could interfere with the performance of resorcinol phenol formaldehyde resin, a typical synthetic resin for gluing laminated wood beams. In the preliminary study, bonding shear strength averages for two-ply laminated beams made of decommissioned penta-treated utility pole wood were 6.8, 9.8, and 12.1 MPa for beams consisting of high-penta wood, medium-penta wood, and low-penta wood, respectively. In addition, the variation in bonding strength across the plies of a laminated beam will affect the bending strength as well as the delamination properties of the beam, resulting in large delamination at the glue lines between plies of utility pole wood. Mechanical and delamination properties of laminated beams made of decommissioned penta-treated wood will be examined in the next report of this research series.

Penta retention along the poles

Table 3 contains the penta retention averages along Poles 8 through 12. These were the poles from which 2.4-m sections of solid wood (without soft and/or rotted portions) could be cut from the top, middle, and bottom pole locations. Although Pole 1 was a complete pole when it was collected, the core of the pole had decayed and was hollow from the middle to the bottom of the pole. Therefore, Pole 1 was not included in Table 3 due to the unavailability of bottom samples.

A two-factor ANOVA revealed significant interaction between the factors Pole (Poles 8 to 12) and Location (bottom, middle, and top) for penta retention ($P = 0.0203$). With no interaction, patterns in penta retention population averages for the three locations would be identical for all poles. The *estimates* of the penta retention population averages (i.e., the sample averages of Table 3) indicate heterogeneous patterns in the population averages from pole to pole. For Poles 8, 10, and 11, penta retention sample averages increased from bottom to middle to top. For Pole 12, penta retention sample averages increased from bottom to middle, then decreased from middle to top. For Pole 9, on the other hand, penta retention averages decreased from top to middle, then increased from middle to top. Pole 12 was the only one of these five poles that had lower penta retention at the top than at the bottom. The unexpected along-pole penta variations from pole to pole will increase the work of classifying pole sections according to relative penta retention at different locations along the poles. As mentioned, penta variations will also result in glue bond strength variations, thereby reducing the performance of laminated products made from decommissioned penta-treated utility poles. Therefore, before being glued into laminated products, the surfaces of penta-treated lumber should be treated to reduce penta retention and/or variation in penta retention across the glue line.

Averaging the five-pole (sample) penta retention averages of Table 3 at each location gives the three estimated Location main effects (4.6, 4.9, and 5.2 kg/m^3 for bottom, middle, and top, respectively). A significant difference was found between these three (estimated) penta retention Location main-effect averages ($P = 0.0448$).

Pairwise comparisons of these main effects revealed that penta retention at pole tops was significantly different from penta retention at pole bottoms ($P = 0.0130$), while penta

Table 2.—Pentachlorophenol (penta) retention averages (kg/m^3) in decommissioned penta-treated southern pine utility poles.[a]

	Pole														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Surface zones only[b]	4.3	5.1	3.9	4.1	4.8	4.2	5.2	4.4	5.3	5.4	5.4	5.0	3.7	4.3	5.6
All zones[c]	3.9	4.6	3.5	3.5	3.9	3.2	4.1	4.6	4.7	5.4	5.3	4.9	3.3	3.9	4.6

[a] Samples were dried at 60°C.

[b] Average penta retention over two outer zones for all diameters.

[c] Average penta retention over all zones for all diameters.

Table 3.—Average pentachlorophenol retention (kg/m^3) along the decommissioned utility poles.[a]

Pole	Retention			Main effects[b]
	Bottom	Middle	Top	
8	4.4	4.6	4.8	4.6
9	4.7	4.0	5.7	4.8
10	4.8	5.1	5.4	5.1
11	4.5	5.2	6.0	5.3
12	4.8	5.6	4.3	4.9
Main effects[c]	4.6	4.9	5.2	

[a] Samples were dried at 60°C.

[b] Each number is the average of the three numbers on the left.

[c] Each number is the average of the five numbers above it.

retention at pole tops and at pole bottoms was not significantly different from penta retention at pole middles ($P = 0.2013$ and $P = 0.2054$, respectively). No significant difference was found between the five (estimated) penta retention Pole main-effect averages ($P = 0.2949$).

The overall decrease in penta retention from pole tops to pole bottoms encouraged decay to be initiated at pole bottoms when penta retention was below a threshold (particularly in the core, where penta retention was low). The penta retention test results can be used to explain the decay of Pole 1, the core of which was hollow from the bottom to the middle of the pole after 39 years in service: Decay likely started in the low-penta core at the bottom and then proceeded upward.

Penta is not chemically bonded to the wood cells after preservative treatment. Therefore, migration of the penta in the poles begins right after treatment. The migration continues when in service, resulting in leaching of the chemicals. Leaching is a continuous process from top to bottom and from the pole to the surrounding soil. However, this process does not explain why the penta retention at the top of the poles was greater than the penta retention at the bottom of the poles. It was observed, however, that during rainy weather, the water flow on the surface of the lower part of a pole is greater than the water flow on the surface of the upper part of the pole. In addition to the water flow on the surface, water may seep into the pole and migrate from top to bottom. When water runs down along and inside a pole, penta may be washed out toward the bottom. Because water flow increases from the top to the bottom of the pole, the lower part of the pole in service will experience more water flow and, therefore, more penta migration than the upper part. Some washed-out penta may leach away from the pole into the surrounding soil. Therefore, water flow in these poles may have accelerated the migration of penta and the leaching of the chemicals while the poles were in service.

It is expected, therefore, that the MC of a pole in service increases from top to bottom. The high MC encourages decay at the lower part of the pole. Some bacteria, such as *Pseudomonas, Flavobacterium,* and *Actinetobacter* spp., and fungi, such as *Phanerochaete chrysosporium* and *Trametes hirsute,* are known to degrade penta (Lamar and Scholze 1992, Portier et al. 1996, Borazjani and Diehl 1998, Prewitt et al. 2003). These microorganisms degrade penta into less toxic chemicals, such as tetra-, tri-, di-, and monochlorophenols. Therefore, another contributing factor to low penta retention at the pole bottoms may well be penta degradation by microorganisms caused by high moisture levels.

Physical properties

Air-dry density, MC at test, ring density, MOR, and MOE of the 15 decommissioned poles are summarized in Table 4. Each value in Table 4 is an overall average for all samples that were tested for a pole or pole section. Each density average in Table 4 includes not only the density of the wood but also the density of penta and moisture contained in the wood. In this study, the MC of the samples was calculated based on the weight of the samples oven dried at 60°C instead of 45°C as required by AWPA Standard A9-01 (AWPA 2006). Therefore, the actual MC of the samples may be less than the ones listed in Table 4 due to the evaporation of penta during drying. The density averages of the 15 poles/pole sections ranged from 0.49 g/cm^3 (Pole 10) to 0.76 g/cm^3 (Pole 6). The overall density average of the 15 poles/pole sections was 0.58 g/cm^3. The ring count averages ranged from 1.71 rings per cm (Pole 10) to 4.70 rings per cm (Pole 1). The overall ring count average of the 15 poles/pole sections was 2.46 rings per cm, which is greater than the pole minimum of 2.36 rings per cm in the outer 5.1 to 7.6 cm required by ANSI Standard O5.1 (ANSI 2008).

Surface aging was observed, particularly on older penta-treated poles. The aged surfaces were normally soft and pale in color. As previously mentioned, some of the poles were severely decayed.

MOR and MOE across the poles and surface aging

As shown in Table 4, MOR averages for the 15 decommissioned poles ranged from 50.7 to 95.5 MPa, while the range for MOE averages was from 5.3 to 10.3 GPa. The overall MOR and MOE averages for all 15 poles were 65.0 MPa and 7.2 GPa, respectively. The published values for loblolly pine are 86.9 MPa for MOR and 12.1 GPa for MOE (Koch 1972). The overall MOR and MOE averages for the 15 decommissioned utility poles of this study were 33.7 and 68.1 percent lower, respectively, than the published values. It is noted that most of the pole samples collected in this study were pole sections. The small

Table 4.—Physical and mechanical properties of pentachlorophenol-treated decommissioned southern pine utility poles.

Pole	Air-dried density (g/cm^3)	MC (%)[a]	Ring count (rings/cm)	MOR (MPa)	MOE (GPa)
1	0.57	8.0	4.70	60.9	7.7
2	0.62	10.0	2.34	72.7	7.9
3	0.69	10.0	4.33	88.1	7.7
4	0.74	10.1	2.60	73.0	7.8
5	0.60	10.6	2.67	78.1	9.0
6	0.76	9.7	4.26	95.5	10.3
7	0.61	11.4	3.16	71.9	8.8
8	0.60	11.4	2.86	77.1	8.1
9	0.62	10.9	2.06	68.6	8.6
10	0.49	11.7	1.71	50.7	5.3
11	0.57	13.2	2.21	56.4	5.7
12	0.62	12.2	1.94	73.8	7.4
13	0.64	12.2	2.89	83.1	9.2
14	0.62	11.2	3.57	67.5	7.3
15	0.52	8.5	2.82	55.1	7.0

[a] Samples were dried at 60°C.

clear samples cut from these sections may not represent well the actual properties of the population of full-size decommissioned utility poles. However, considering that the materials available for recycling are likely sections instead of full-size poles, the small clear cut samples may well exhibit the properties of the population of currently available pole materials.

Figure 3 exhibits MOR and MOE values across the complete diameter at the pole stamp for Pole 7. These M-shaped patterns are typical for all of the decommissioned utility poles and pole sections of this study: MOR and MOE values increased from pole pith to one or two assay zones (25.4 mm per zone) next to the surface, then decreased to the surface on either side of the pith.

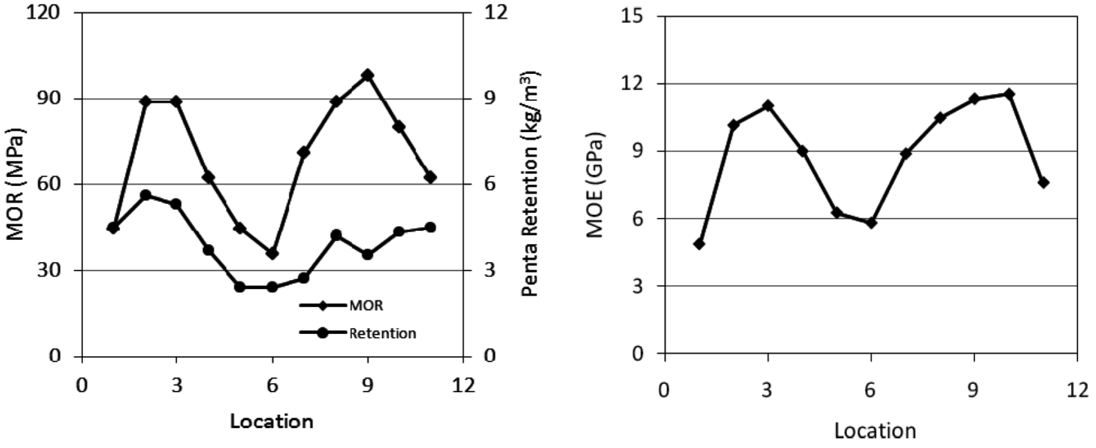
Penta retention of the small clear samples was also plotted in Figure 3a. The penta retention value of 4.5 kg/m^3 was obtained for both surface assay zones, slightly lower than the value of 4.8 kg/m^3 required by AWPA Standard U1-06 Use Category 4A (AWPA 2006) for utility poles. Because sufficient penta remains on the pole surfaces to prevent fungus attacks, the relatively low strength and stiffness of the wood on both Pole 7 surfaces were likely due to normal surface aging rather than decay.

Below the aged surface layer was the strong, intact sapwood with narrower growth rings and more latewood components. The wood in this location was thus the strongest across the diameter of a decommissioned pole. The strength of the wood then decreased with an increase of juvenile wood toward the pith of the pole. Therefore, the MOR profile across complete pole diameters displayed an M shape due to the symmetric characteristic of a log structure. On the other hand, the strength profile across a diameter of an untreated, freshly cut virgin wood log should have a V shape: Wood strength should decrease from both surface layers to the pith. For the poles of this study having relatively complete top and bottom sections (Poles 8 through 12), MOR at the surface test zones was significantly different than MOR in the zones immediately next to them ($P = 0.0007$). For these poles, the surface zones were considerably weaker than the zones immediately next to them. The MOR surface zones average was 23.6 percent lower than the MOR average for the zones next to them. The P value for the test of equality of MOE for surface zones and the zones next to them was 0.0624, not highly significant but small enough to indicate some difference. Measured MOE for the surface zones was 11.8 percent lower than that for the zones next to them.

The aged surface layers and decayed wood are of low strength. In particular, aged surface layers contain relatively high levels of penta. High delamination would occur when such plies were compressed into laminated beams. Therefore, the aged surface layers and decayed wood may not be reusable and should be removed from the materials for lumber, timber, or laminated beam production. Because the strong surface layers of the utility poles are aged and removed, a substantial amount of decommissioned penta-treated utility pole wood will be produced from core areas, particularly of smaller poles. Therefore, when a recycled pole is cut into lumber and timber, classification of the recycled materials is necessary in accordance to their strength using a nondestructive evaluation method. The high-strength wood materials can be reused in high-stressed areas, such as the top and bottom plies of a laminated beam, while the greater amount of medium-strength wood materials can be reused as low-stressed, center plies of the laminated beam.

MOR and MOE along the poles

Table 5 displays the MOR and MOE averages (over all test zones) at the bottom, in the middle, and at the top of Poles 8 through 12. Two-factor factorial ANOVA was conducted on the MOR and MOE measurements (separately) using Poles 8, 9, 10, 11, and 12 only. As for penta retention, the two factors were Pole and Location (bottom, middle, and top). Significant MOR Pole × Location interaction was found ($P = 0.0004$). With no Pole × Location interaction, any pattern in the MOR population averages for the three locations would be identical from pole to pole. The MOR (sample) averages of Table 5 suggest heterogeneous Location population average patterns from pole to pole. The bottom MOR (sample) average exceeds the top MOR (sample) average for Poles 8, 9, and 12, while the top MOR average exceeds the bottom MOR average for



(a) (b)

Figure 3.—Bending strength, pentachlorophenol (penta) retention, and stiffness across a complete diameter (near the pole stamp) of penta-treated decommissioned utility Pole 7 (Grade 3, 19.8 m in length, year 2000).

Table 5.—Average strength and stiffness along the decommissioned southern pine utility poles.

Pole	Bottom MOR (MPa)	Bottom MOE (GPa)	Middle MOR (MPa)	Middle MOE (GPa)	Top MOR (MPa)	Top MOE (GPa)
8	85.4	8.9	85.6	9.1	68.6	7.3
9	84.9	9.9	63.1	8.2	57.8	7.6
10	41.8	4.5	48.9	5.2	61.3	6.1
11	49.7	4.4	60.7	6.3	58.7	6.5
12	80.9	6.9	72.2	7.7	68.2	7.6
Main effects[a]	68.6	6.9	66.1	7.3	62.9	7.0

[a] Each number is the average of the five numbers above it.

Poles 10 and 11. The MOR averages were considerably more spread out at the bottom and middle locations than at the top. Averaging over the five poles, the Location main-effect strength (i.e., MOR) averages (68.6, 66.1, and 62.9 MPa for bottom, middle, and top, respectively) were not significantly different from each other ($P = 0.2610$). Averaging over the three locations, the Pole main-effect strength (i.e., MOR) averages (79.9, 68.6, 50.7, 56.4, and 73.8 MPa for Poles 8 through 12, respectively) were significantly different ($P < 0.0001$): The MOR main-effect averages for Poles 8, 9, and 12 were significantly different from those of Poles 10 and 11on a pairwise basis ($P \leq 0.0038$). The lower strength of Pole 10 was likely due to its smaller size (9.1 m) and the fact that it contained more juvenile wood than the other poles. Significant Pole × Location interaction was also found in the population average MOE values ($P = 0.0112$).

No significant correlations were found between pole strength and years of service or between pole strength and pole grade. According to ANSI Standard O5.1 (ANSI 2008), wood utility poles are classified (or graded) primarily based on their length and circumferences measured 1.8 m from the bottom after bark removal or shaving. The grade of a pole is not necessarily related to its strength, since a low-grade, old pole may be stronger than a high-grade, new pole.

The unexpected strength and stiffness variations in location pattern from pole to pole may cause problems when decommissioned penta-treated utility poles are recycled. This situation is even worse for poles that are decayed and for pole sections whose years of service and/or locations of the sections in the poles are not available. As mentioned previously, before being made into new products, lumber cut from decommissioned penta-treated utility poles or pole sections should be tested to evaluate the mechanical properties of the lumber. In addition to nondestructive methods such as acoustic techniques, properties such as service age (if available), ring count per centimeter, amount of decay, and sapwood content would also be useful in assessing strength to find the optimal application for a particular piece of lumber or timber.

Concluding Remarks

Fifteen penta-treated decommissioned southern pine utility poles were evaluated for penta retention, strength, and stiffness across and down the poles. It was found that penta retention decreased from the outside to the pith of each pole, especially in the middle and bottom sections. For each of the poles of this study having relatively complete top and bottom sections, penta retention was higher at the top of the poles than at the bottom of the poles, with one exception. Of all 15 poles tested, the penta retention averages of the two surface zones were greater than 3.9 kg/m^3, while the overall penta retention averages of these poles were greater than 3.2 kg/m^3. High penta retention in utility pole wood may interfere with the glue bonding between treated wood plies, resulting in unacceptably large delamination in laminated beam products. More research is therefore warranted to investigate the interference of penta on glue bonding and identify new glue systems for recycling penta-treated wood.

The average MOR of the 15 poles and pole sections was 65 MPa, and the average MOE was 7.2 GPa. The MOR and MOE averages of the 15 poles were 33.7 and 68.1 percent lower, respectively, than the published MOR and MOE values for virgin loblolly pine wood. Aged surfaces and decayed wood were found on some of the decommissioned poles of this study. The shallow (less than a test zone thick), aged surface layers, particularly on older poles and decayed wood, are not reusable for solid sawn or structural laminated products and should be removed. Although a substantial amount of recycled penta-treated utility pole wood materials was of medium strength, they are reusable in low-stressed areas, such as the center plies in a laminated beam.

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