Properties of Aging Pentachlorophenol-Treated Douglas-Fir Crossarms

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Abstract

Wooden crossarms play a major role in supporting electric distribution lines in North America, but relatively few data exist on their condition as they age. The residual capacity of Douglas-fir crossarms in service in western Oregon for 45 to 60 years was investigated. Arms were sampled for residual preservative retention, the presence of visible decay fungi, and residual flexural properties; these results were then compared with three nondestructive tools. A majority of the arms tested had preservative levels well below those required for new arms, but only one decay fungus was isolated, and only five arms removed and dissected had any evidence of visible internal decay. Moduli of rupture for the arms were generally below the minimum levels required by national standards, but most still retained at least 67 percent of this value. Nondestructive evaluation tools were generally poorly correlated with flexural properties, possibly because of the heavily weathered and checked exterior condition.

Crossarms are widely used on electric utility poles in North America to support the wires and create separation between the electrical phases. Although a variety of materials can be used for crossarms, including fiberglass and aluminum, wood crossarms remain the most common material and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) is the most common species used for this application. Crossarms were originally used without supplemental preservative treatment, but nearly all arms are now treated with pentachlorophenol in a heavy oil to protect them against fungal and insect attack as well as provide some degree of resistance to weathering (American Wood Protection Association [AWPA] 2019a).

Wood is susceptible to biodeterioration when exposed to moisture conditions above the fiber saturation point, which would characterize the crossarm environment in most uses (US Department of Agriculture 2010, Zabel and Morrell 2020). However, unlike direct soil contact, the aboveground environment presents a much-reduced risk for fungal decay since the arms can dry between wetting periods. The absence of direct soil contact also markedly reduces the risk of fungal propagules contacting the timber. Decay, when it occurs, is likely to develop in checks that open on the top and trap water to create conditions suitable for fungal attack or at locations where untreated wood is exposed, such as in holes drilled after treatment. A properly treated Douglas-fir crossarm presents a preservative barrier surrounding a moderately durable heartwood core, resulting in anecdotal suggestions from utility engineers that two crossarms will be used on an average pole with a service life of 60 to 80 years.

While arms are generally perceived to perform well, surprisingly few data exist on the condition of older arms in service. This occurs for several reasons, the most important being the cost of accessing and assessing an arm in service. As a result, most arms are changed out on an appearance basis, mostly due to weathering or checking, or they are routinely replaced when wires are changed or upgraded.

Developing a better understanding of the residual properties of older crossarms would help utilities make more informed decisions regarding these critical elements. The objective of this study was to assess the condition and

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residual properties of Douglas-fir crossarms in service for 45 to 60 years in lines located in western Oregon.

Materials and Methods

Crossarms on Douglas-fir poles ranging from 18 to 23 m long in transmission lines located in the Willamette Valley of western Oregon were examined. The area has a Mediterranean climate with cool, moist winters and hot, dry summers and receives approximately 1.4 m of rainfall per year, mostly in the winter months. The area would be classified as having a moderate aboveground decay hazard (Scheffer 1971). The crossarms were in a unique configuration called a wishbone where two arms were attached to the pole and each other in a unique angle pattern (Fig. 1). The arms measured 137.5 mm wide by 200 mm tall by 4.2 m long. All arms had been pressure treated with pentachlorophenol in heavy oil, but it was not known if the holes for various attachments were drilled prior to or after treatment.

Inspection of in-service arms

The study had two distinct phases: in-service inspection and flexural testing. In the first phase, line crews were asked to inspect 120 arms on 60 poles. Line personnel sounded each arm with a hammer to detect large voids or other defects. They then removed increment cores 5 mm in diameter by 100 mm long from areas immediately adjacent to each bolt hole on the upper and lower arms as well as from the attachment point for the two arms (Fig. 1). Four cores were removed from each arm (eight per wishbone configuration). The cores were placed into plastic drinking straws that were stapled shut and kept cold (~5°C) until they could be processed. Each core was examined for the presence of visible decay, and the depth of preservative penetration was visually assessed. The outer 15 mm of each core was removed, and these segments were combined for preservative analysis for a given arm. The core segments were ground to pass a 20-mesh screen, and the resulting ground wood was analyzed for residual pentachlorophenol by X-ray fluorescence per Standard A9 (AWPA 2019b). The original target preservative retention in these arms was 6.4 kg/m^3 to meet Use Categories UC3B/4A (AWPA 2019a). The untreated portion of the remainder of each core was then briefly flamed to minimize the risk of surface contamination and placed on 1 percent malt extract agar in plastic Petri dishes. The cores were examined over a 30-day period for evidence of fungal growth, and any growth was examined for characteristics typical of basidiomycetes, a group containing most of the important wood decay fungi. These fungi will be called decay fungi for the purpose of this study, although we recognize that other groups of fungi can also cause wood decay. Nonbasidiomycetes were classified as nondecay fungi, again recognizing that some of these fungi can cause soft rot attack.

Testing of arms removed from service

In the second phase of the test, 30 crossarm pairs used in the same configuration in the same region were removed from service. The arms were conditioned to a stable moisture content (~12%) prior to being tested to failure in bending. The samples were center loaded on the narrow face to failure with the load applied at a rate of 6 mm/min using a Universal Testing Machine following ASTM Standard D198 (ASTM International 2017). Load and deflection were continuously recorded and were used to calculate modulus of rupture (MOR) and modulus of elasticity (MOE). Prior to and during testing, arm condition was assessed using two nondestructive wood assessment tools. The Metriguard Model 239A stress wave timer (Metriguard Technologies, Pullman, Washington) sends a signal through the wood and measures the time it takes for the signal to return. The time of flight value can be used to

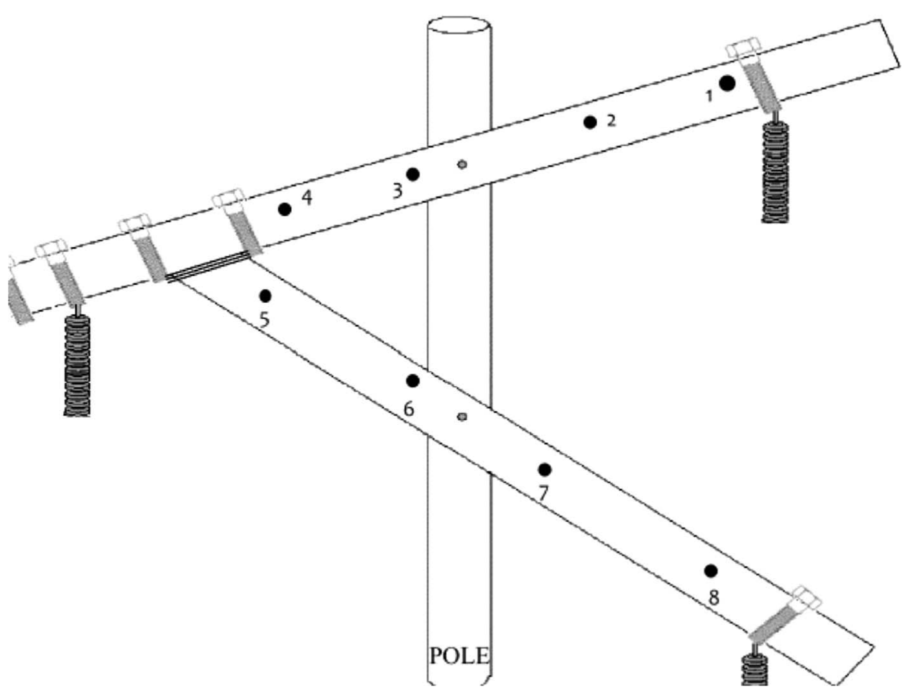

Figure 1.—Example of crossarms in a wishbone configuration. Increment cores (black dots numbered 1 to 8) were removed at sites near the ends of each arm as well as near the pole attachments to the pole.

infer density, which can in turn be used to estimate MOE (Ross et al. 2005, Defloria et al. 2008, Wang and Allison 2008). Since MOE and MOR are correlated, this device can provide an estimated strength. The MK-4 Hammer (Woodtest Research and Development Ltd, West Linton, UK) operates in a similar fashion, except that the device strikes the timber and provides a value from 1 to 10, where 1 is weak and 10 is sound. The devices were first evaluated when the arms were not yet subjected to a load as well as when the arms were loaded to 20.68 and 41.36 MPa. The tests in a loaded condition were performed since the arms would be in a loaded condition if they were evaluated with these devices while in service. These devices were evaluated to determine if they might be useful for assessing the condition of in-service arms.

After testing to failure, increment cores were again removed from the wide faces every 600 mm along each arm. These cores were processed for residual preservative retention and the presence of decay fungi as described for the field survey.

The presence of internal defects or deterioration was further assessed by drilling into the wide face of each arm at 600-mm intervals along the length using a Resistograph (IML, Kennesaw, Georgia). This device is a controlled torque drill that uses a small-diameter bit to drill into the wood and records the distance the bit travels as well as every rotation. The more turns required for a given depth, the denser the wood. The Resistograph has been used for detecting internal voids and other defects in a variety of applications, including live trees and standing utility poles (Johnstone et al. 2007, Wang and Allison 2008, Rinn 2013, Gezer et al. 2015, Reinprecht and Supina 2015). Following testing, the samples were cut into 600-mm sections at the same locations used to assess the Resistograph, and the presence of internal defects was noted.

Data from each test were summarized and compared to determine the relationships between arm condition, residual properties, and the results from the three inspection tools.

Results and Discussion

In-service inspection

The arms inspected while in service were heavily weathered and checked. Many arms had moss and plants growing on the upper surfaces. Increment cores removed from these arms tended to be broken, often a sign of some decay; however, none of the cores contained any evidence of internal decay. Decay fungi were isolated for only one of the 120 arms, and no fungi were isolated from the cores removed from 95 of the 120 arms. The results were surprising given both the age and external appearance of the arms. The results suggest that the shallow barrier of preservative treatment, coupled with the moderately durable heartwood, was sufficient to limit fungal attack out of direct soil contact even when deep checks opened. Thus, most of the surface damage was caused by weathering, not biological attack. It is important to note that deep checks were present in many arms; the sloping angle of the arms in the wishbone configuration likely helped drain water from the checks, thereby reducing the risk of moisture intrusion and fungal attack.

Penta retentions in the arms varied widely, ranging from 0 to 6.25 kg/m^3 (Fig. 2). None of the retentions would meet the retention specification. There were also sometimes retention differences between the upper and lower arms in the same pole, but there were no consistent patterns, suggesting that the differences were a result of the inherent variation among different wood samples rather than an effect of position in the wishbone on subsequent preservative migration. It is difficult to infer much from the data because no initial retentions were obtained. However, the results, coupled with the absence of visible decay in the increment cores and the presence of decay fungi in only one of the 120 arms, suggest that the combination of a shallow pentachlorophenol treatment, coupled with the moderate durability of Douglas-fir heartwood, presented an excellent barrier against fungal attack. Previous studies have also noted the excellent performance provided by relatively shallow penta treatments in aboveground exposures (Scheffer and Eslyn 1978).

Flexural properties of arms

As with the in-service inspections, the arms tested to failure were heavily checked and weathered. Five arms were found to have advanced internal decay when dissected after testing, but the remaining arms were free of visible decay. Penta retentions varied from none detected to up to 4.84 kg/

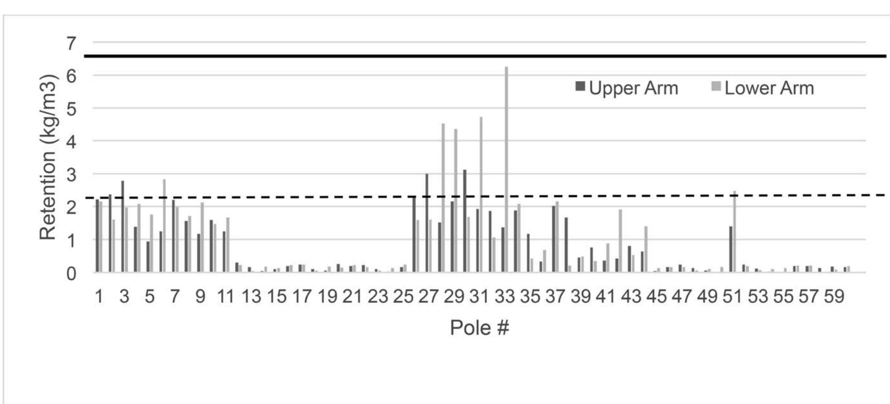

Figure 2.—Pentachlorophenol (penta) retentions in the outer 15-mm assay zone of 45- to 60-year-old Douglas-fir crossarms. The current American Wood Protection Association (AWPA) retention for penta for this application in Use Category 3B or 4A is 6.4 kg/m^3 (AWPA 2019a), representing the upper horizontal line, while the dashed horizontal line represents an approximate threshold for protection against fungal attack in field stake tests.

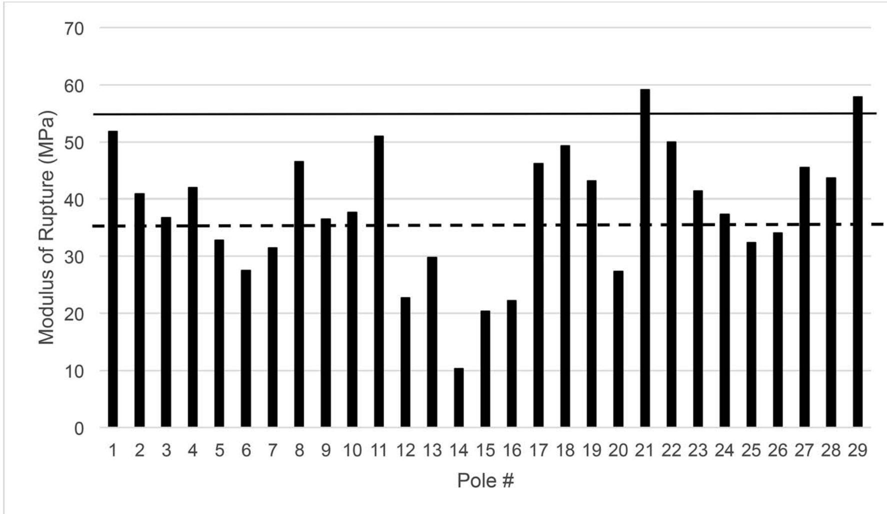

Figure 3.—Modulus of rupture (MOR) of 29 Douglas-fir crossarms exposed in a wishbone configuration for 45 to 60 years and tested to failure in third point loading. Solid arrow on the x*-axis corresponds to the assumed MOR of a new arm, while the open arrow corresponds to 67 percent of that value.*

m^3, but only three arms contained levels approaching the current lower AWPA target retention (AWPA 2019a). The results again suggest that relatively little preservative is required to protect timber exposed well above the ground in this environment.

MOR of the arms varied widely, ranging from 10.27 to 59.15 MPa with one arm breaking before it could be tested (Fig. 3). The current American National Standards Institute (ANSI) Standard 05.3 indicates that a crossarm less than 3.6 m long has a designated fiber stress of 53.78 MPa ANSI 2019). While this is an average value and not all arms would be expected to have this MOR, it provides a benchmark for assessing residual properties. Only 2 of the 29 arms tested met the benchmark value, suggesting that these arms needed to be replaced because they were below the minimum strength threshold. However, the National Electric Safety Code also allows timber to degrade to as little as 67 percent of its original capacity before replacement or restoration is required (ANSI 2017). This would result in a minimum required strength of 36 MPa. Eighteen of the 29 arms met these minimum criteria, suggesting that while the arms had experienced substantial declines in properties over time, most were not at risk of imminent failure under normal service conditions. MOR and MOE of the arms were weakly correlated with one another ($R^2 = 0.387$; Fig. 4). Only the MOR results are discussed further since similar trends were noted with MOE with respect to the ability of the inspection tools to assess properties.

The weathered appearance of the arms made it difficult to accurately assess conditions visually. Nondestructive or semidestructive tools may be more useful in this regard. Using the devices on the arms prior to applying a load

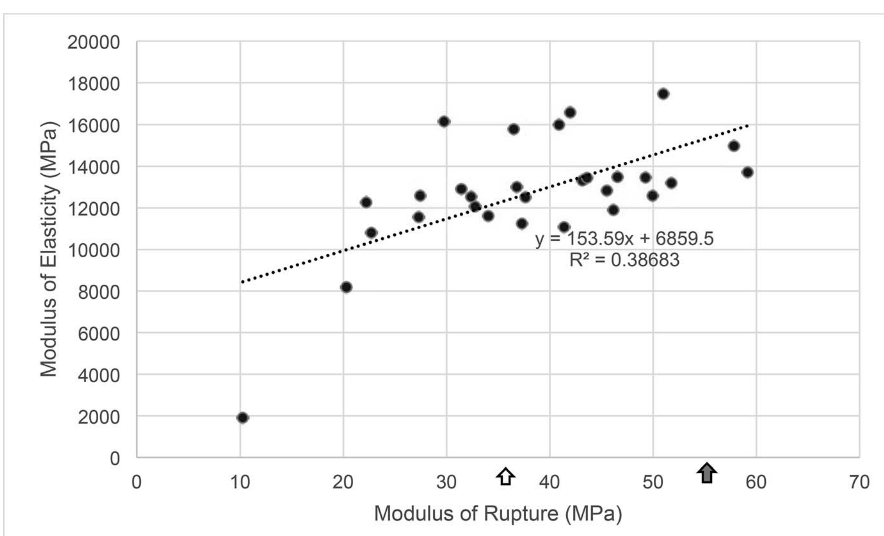

Figure 4.—Modulus of rupture (MOR) versus modulus of elasticity of Douglas-fir crossarms exposed in a wishbone configuration for 45 to 60 years and tested to failure in third point loading. Solid arrow on the x*-axis corresponds to the assumed MOR of a new arm, while the open arrow corresponds to 67 percent of that value.*

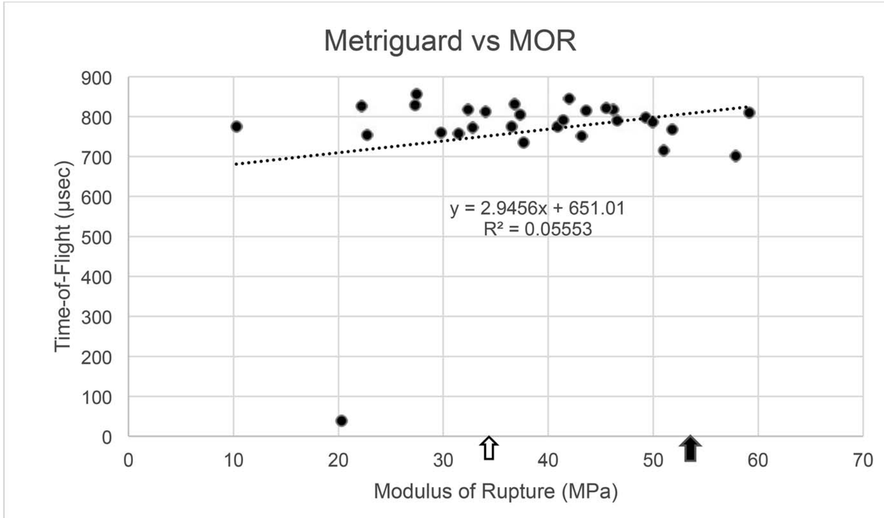

Figure 5.—Modulus of rupture (MOR) versus Metriguard time of flight assessment for 29 Douglas-fir crossarms exposed in a wishbone configuration for 45 to 60 years and tested to failure in third point loading. Solid arrow on the x-axis corresponds to the assumed MOR of a new arm, while the open arrow corresponds to 67 percent of that value.

versus loading the arms to 20.68 or 41.36 MPa prior to testing had no consistent effect on the results provided by either the Metriguard or the MK-4 Hammer, suggesting that these devices could be used on an in-service arm with no noticeable effect on results.

The Metriguard system found little difference between arms that were above or below the minimum ANSI threshold. MOR was poorly correlated with the results from this device ($R^2 = 0.056$), and most time of flight measurements were between 702 and 857 µs (Fig. 5). The heavily checked surfaces as well as the presence of the holes drilled to accommodate attachments may have affected the functionality of this device. The MK-4 Hammer provides a value between 1 and 10 to denote decayed or sound wood, respectively. All of the results from the 29 arms were between 1 and 2.7, suggesting that the device was also unable to accurately assess condition ($R^2 = 0.034$; Fig. 6). The MK-4 Hammer was able to detect the one heavily degraded arm, but it also tended to reject a number of other arms that full-scale destructive testing suggested still retained sufficient capacity. This conservative approach to sorting may be acceptable given the costs of an unplanned arm failure.

The Resistograph provided an excellent profile of the growth characteristics of the arms tested; however, like most drill-type inspection devices, its accuracy was limited by the choice of inspection location, which is user dependent. In this case, the boring was made at the approximate center of the wide face of the beam every 600 mm along its length. However, subsequent destructive cutting of the arms at the inspection sites revealed that only four arms contained visible internal decay, and the decay pockets were not

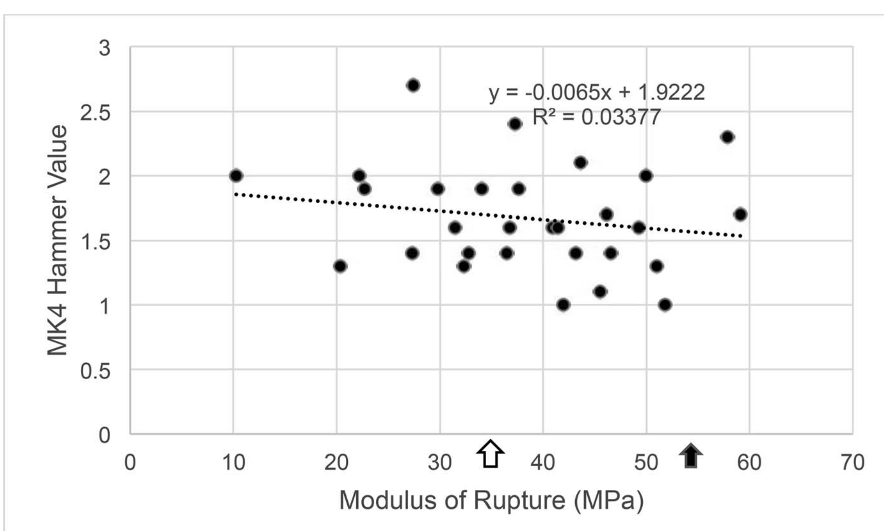

Figure 6.—Modulus of rupture (MOR) versus MK-4 Hammer assessment for 29 Douglas-fir crossarms exposed in a wishbone configuration for 45 to 60 years and tested to failure in third point loading. Solid arrow on the x-axis corresponds to the assumed MOR of a new arm, while the open arrow corresponds to 67 percent of that value.

located at the center in three of them. Thus, the probability of detecting relatively small pockets using this device would be limited by the ability of the inspector to choose a suitable test location. Detection is critical in this application because aboveground inspections are very costly and prolonged inspection times would be prohibitively costly, making replacement more economical. While the Resistograph could detect decay, the inability to use external features to determine inspection locations sharply reduced the functionality of this device in this application.

Conclusion

Field inspections of 45- to 60-year-old Douglas-fir crossarms showed that few had internal decay, although the preservative levels in most were well below those considered protective, and the arm surfaces were badly weathered and checked. MOR values from full-scale flexural tests on 29 similar arms removed from service mostly fell below the ANSI minimum for new arms, but a majority retained at least 67 percent of their original assumed capacity. Dissection of arms after flexural testing revealed a slightly higher but still relatively small level of internal decay (17%). Nondestructive evaluation tools were poorly correlated with either MOR or MOE, suggesting the need for additional research to develop more effective tools for in situ assessment of crossarm condition.

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