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Long-Term Durability of Pressure-Treated Wood in a Severe Test Site

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ABSTRACT: Improved estimates of the long-term durability of treated wood products are needed to guide choices about construction materials and allow estimates of design life. This report summarizes the long-term decay and insect resistance of treated wood post and lumber specimens placed in ground contact at a test site of the U.S. Department of Agriculture, Forest Service, Forest Product Laboratory in southern Mississippi. Posts treated with relatively low levels of creosote had an estimated durability of 54 years, and slightly less durability was observed in creosote-treated lumber. Pentachlorophenol-treated posts exhibited durability in excess of 60 years, whereas lumber specimens treated to standard ground-contact retentions had no failures after 39 or 45 years. Posts treated with low retentions of copper naphthenate had an estimated 65-year longevity, but lumber specimens treated to higher retentions of copper napththenate had lower average lives of 27 to 30 years. Low-retention ammoniacal copper arsenate (ACA) posts had an estimated durability of 60 years, whereas stakes treated to retentions of 8 kg/m^3 (0.5 lb/ft^3) or greater with ammoniacal copper zinc arsenate (ACZA) or ACA have had no failures after 30 and 60 years, respectively. Posts treated with a range of retentions of chromated copper arsenate (CCA-C) have had no failures after 35 years, and stakes treated with CCA-A, CCA-B, or CCA-C to retentions above 7 0 kg/m^3 (0.43 lb/ft^3) have had no failures after 60, 61, and 40 years, respectively. As a whole, the post and lumber specimens indicate an expected durability of over 50 years for creosote-treated wood and over 60 years for wood treated with pentachlorophenol, copper naphthenate, ACZA, or CCA. Comparison of the results from this site to reports from other locations suggests that these results might underestimate the potential durability in more moderate exposures. In relating these findings to treated commodities, it should be noted that these test specimens have not been subjected to the same mechanical loads or wear and tear associated with in-service structures.

KEYWORDS: pressure-treated wood, long-term, durability, posts, stakes

Introduction

Pressure-treated wood has been widely used as a durable construction material in the United States for over a century. However, despite its long history of use, there are relatively few reports on the long-term decay and insect resistance of pressure-treated wood. Much of the data that are available are derived from replacement rate records of large users such as utilities [1–3]. In the case of utility poles, analysis of replacement rate data indicates that the average service life of poles is much greater than perceived by utility personnel. For example, Stewart [3] noted that his survey group reported an average perceived pole service life of only 33 years, whereas the replacement rate data indicated a service life in excess of 75 years. Similarly, Morrell [2] noted that based on reported replacement rates, pole service life would easily reach 80 years in many parts of the United States. Australian researchers conducted a statistical analysis of utility pole service life data and concluded that the expected service life of the poles would be in the range of 80 to 95 years [4]. A limitation of

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these types of survey data is the need to differentiate replacements caused by biodeterioration from those resulting from other causes, such as severe weather events or road construction. There is also a concern that the "decay" category might be used as a catchall for a range of physical wood defects or discolorations. Replacement rate data are largely unavailable for most other types of commodities, including critical components such as piles or posts.

Another source of long-term durability data for treated wood is field test plots established by university and government researchers. Although not truly "in service," commodity-size test specimens can provide valuable insight into long-term resistance to biodeterioration. Advantages of test specimens include controlled and documented preservative treatment, known exposure conditions, and frequent inspections by personnel with expertise in evaluating biodeterioration. The most common examples are posts or lumber specimens whose durability can be related to the potential service life of terrestrial piles, poles, or posts. Treated wood piles are used as critical support members in structures such as highway and railroad bridges, whereas posts and poles are used by utilities and in building and highway construction.

One of the oldest wood durability test plots was established near Corvallis, OR, by Oregon State University researchers in 1927. This site presents a moderately severe decay hazard, but it has little risk of termite attack. The majority of pressure-treated posts at this site are Douglas-fir, a species that is difficult to penetrate with preservatives. Despite these treatability challenges, groups of posts treated with creosote formulations have had no failures after either 57 or 67 years in test. Posts treated with early versions of waterborne preservative formulations have been somewhat less durable, with average times to failure ranging from 21 to 49 years [5].

Another active long-term exposure site was established near Chalk River, ON, Canada, by the Eastern Forest Products Laboratory of the Canadian Forest Service and is currently administered by FPInnovations [6]. Like the site at Oregon State University, the Ontario site has moderate decay activity but little or no termite activity. Exposure data from this site provide insight into the durability of treated wood from tree species important to Canada and the northern United States. Notably, red and white pine posts that were soaked in creosote solution had an estimated service life exceeding 70 years, and jack pine posts pressure treated with copper naphthenate in heavy solvent have had only one failure in 58 years. Similarly, red pine posts pressure treated with CCA (type A) or pentachlorophenol in heavy solvent have had no failures after 57 and 41 years, respectively [6].

The U.S. Department of Agriculture Forest Service also maintains a long-term durability test site within Harrison Experimental Forest (HEF) in Southern Mississippi. This site, established in 1937, includes ground-contact tests of both lumber (nominal 2×4) stakes and round posts treated with preservatives. The predominant wood species under evaluation is Southern Pine, which is the most commonly treated wood species grouping in the United States. Because conditions at this site present a severe biodeterioration hazard, long-term durability at this location indicates the potential for similar or greater durability at most other locations within North America. This paper summarizes the long-term durability of posts or stakes treated with preservative formulations still in commercial use and discusses the relevance of these data to the expected service life of treated commodities.

Materials and Methods

Site Characteristics

HEF, near Saucier, MS, is a pine woodland with sandy loam soil and an average annual rainfall of 1.58 m (62 in.). The relatively high annual rainfall and warm temperatures (average annual temperature of 19.6°C [67 °F]) create a harsh decay environment. In addition, Eastern subterranean termites are active at the site. Copper-tolerant fungi are also present, but they are not uniformly distributed through all areas of all plots. The location is within American Wood Protection Association (AWPA) Deterioration Zone 5, Severe Hazard, which is the most severe hazard classification [7].

Post Evaluations

Round Southern Pine posts with lengths of 1.8 to 2.1 m (6 to 7 ft) and top diameters of approximately 76 to 178 mm (3 to 7 in.) were air- or kiln-dried and then pressure treated with preservative [8]. Typically, a full cell treatment schedule (initial vacuum) was used for water-based treatments, and an empty cell process (ambient or initial air pressure) was used for oil-type preservatives. The number of replicate posts per treatment group varied, although groups of 25 replicates were common. The retention of preservative in the posts was determined based on weight gain following treatment and analysis of borings removed from the posts [8].

The posts were buried to a depth of approximately 0.61 m (2 ft) in a randomized block pattern with 0.91 m (3 ft) spacing between posts [8]. Periodic evaluation involved applying a force to the post, by either forcefully pushing the top of the post or applying a 22.7 kg (50 lb) load with a pull test [9]. Posts were classified as either passing (unbroken) or failing (broken).

Lumber Evaluations

Preparation of Stakes

The stakes used for each of these treatments were Southern Pine sapwood nominal 2 × 4s with dimensions of 38 mm × 89 mm × 457 mm (1.5 in. × 3.5 in. × 18 in.). The stakes were pressure treated with either a full-cell (water-based preservatives) or empty-cell (oil-type preservatives) process. Typically, 10 replicate stakes were prepared for each treatment group. The retention of preservative was determined based on weight gain following treatment and the destructive analysis of extra stakes.

The stakes were buried, standing upright, to a depth of 225 mm (9 in.), with the placement of stakes randomized within the plot. The stakes were periodically removed and scraped to remove soil and facilitate inspection. The stakes were then visually evaluated for decay and termite attack and were considered to have failed if greater than 75 % of the cross-section was deteriorated or they could be broken by hand.

Preservative Treatments

The post and lumber tests at HEF include a wide range of preservative formulations and treatment methods. The data presented in this paper are limited to posts or stakes pressure treated with preservative formulations that are similar to those in current commercial use.

Coal-Tar Creosote (Creosote)

Creosote is one of the oldest wood preservatives and is widely used for the treatment of piles, poles, and timbers. Creosote is a black or brownish oil made by distilling coal tar obtained after the high-temperature carbonization of coal. The character of the tar used, the method of distillation, and the temperature range in which the creosote fraction is collected all influence the composition of the creosote, and creosote's composition has varied over the years. It has also been mixed with hydrocarbon solvents or other preservatives, and some of the formulations within the HEF test site reflect this diversity. In this report, discussion is limited to the most commercially relevant creosote formulations without additives or additional solvents.

Pentachlorophenol

Pentachlorophenol has been used since the 1940s for the treatment of poles, terrestrial piles, timbers, and glued-laminated beams. Pentachlorophenol can be dissolved in either "heavy" (similar to #2 fuel oil) or "light" (similar to mineral spirits) solvents. Use of the heavy solvent is typical for ground-contact applications, and in this report discussion is limited to specimens treated with heavy solvent.

Copper Naphthenate

Copper naphthenate in heavy solvent has also been used to treat roundwood and timbers since the 1940s, although not as widely as creosote or pentachlorophenol. Like pentachlorophenol, copper naphthenate can be dissolved in multiple solvents, but in this report, discussion is limited to the heavy solvent typically used for ground-contact applications.

Ammoniacal Copper (Zinc) Arsenate

Ammoniacal copper arsenate (ACA) was used commercially, primarily on the west coast of the United States and Canada, from the 1930s to the 1980s and 1990s. It was then replaced with ammoniacal copper zinc arsenate (ACZA), which is the current commercial formulation. ACZA appears to be at least as effective as ACA, and the arsenic appears to have improved leach resistance [10,11]. This report includes data on the durability of both ACA and ACZA formulations.

Chromated Copper Arsenate Types A, B, and C

Chromated copper arsenate (CCA), or "green-treated" wood, has been widely used since the early 1940s and was the most widely used type of treated wood from the 1970s through the early 2000s. Although the use of CCA was partially restricted in 2004, CCA Type C (CCA-C) continues to be used for the treatment of poles, piles, and heavy timbers. CCA-C has a slightly different ratio of chromium:copper:arsenic than the earlier formulations (Types A and B) and became the predominate formulation because it was thought to offer the best combination of efficacy and leach resistance [12–14]. This report includes data on the durability of all three types of CCA formulations.

Preservative Retention

The preservative retentions (concentrations of preservative in the wood) needed to provide long-term durability have been established in the standards of the AWPA [7]. These standard retentions might vary depending on the type of preservative and the commodity being treated (Table 1). In many cases, the specimens included in this report have been treated to retentions above or below the current standard retention. Their durability is discussed here in comparison to the AWPA standard retentions.

Results and Discussion

Long-Term Durability in Post Tests

Sets of posts treated with creosote, pentachlorophenol, copper naphthenate, or ACA were installed in 1949 and most recently rated in 2003 (Table 2). A single retention was evaluated for each preservative, and the retentions were substantially lower than specified in AWPA standards (Table 1).

TABLE 1—*AWPA standard retentions (kg/m^3) for pressure-treated Southern Pine [7].*

	Type of Commodity and AWPA Use Category[a]								
	Timbers			Posts		Poles			Terrestrial Piles
Preservative	UC4A	UC4B	UC4C	UC4A	UC4B	UC4A	UC4B	UC4C	UC4C
Creosote	160	160	192	128	160	96	120	144	192
Pentachlorophenol	8.0	8.0	8.0	6.4	8.0	4.8	6.1	7.2	9.6
Copper naphthenate	0.96	1.2	1.2	0.88	1.1	0.96	1.28	2.1	1.6
ACZA	6.4	9.6	9.6	6.4	8.0	9.6	9.6	9.6	12.8
CCA-C	6.4	9.6	9.6	6.4	8.0	9.6	9.6	9.6	12.8

[a]Use categories designate the type of service condition. The number 4 indicates that the wood is in contact with the ground or fresh water. "A" indicates general use, "B" indicates heavy duty use, and "C" indicates an extreme duty application.

Despite their low retentions, the posts had estimated times to failure ranging from 54 years for creosote to 74 years for pentachlorophenol. Although an increase in durability is not necessarily directly proportional to an increase in retention, the longevity of these posts would have been expected to be much greater if they had been treated to current AWPA standards. In contrast, the untreated posts failed in less than 3 years. The durability of creosote-treated posts in the HEF plots is slightly below that reported for posts exposed in South Carolina. In that location, posts treated with creosote retentions ranging from 64 to 128 kg/m^3 (4 to 8 lb/ft^3) had approximately 30 % failure after 50 years of exposure [15]. Much greater durability was also reported for creosote-treated posts exposed near Corvallis, OR [5], or Ontario, Canada [6]. The durability of pentachlorophenol- and copper naphthenate–treated posts in this study is also slightly less than that reported by Morris and Ingram [6], who noted only one failure after 58 years in copper naphthenate–treated posts and no failures in pentachlorophenol-treated posts after 41 years. The greater durability reported for posts exposed near Corvallis, OR, and Ontario, Canada, might reflect the lower decay hazard in cooler northern climates. The Oregon test location falls into AWPA Hazard Zone 3 (Intermediate), whereas the more northerly Ontario site is in Hazard Zone 2 (Moderate). In contrast, the HEF location in Mississippi falls into AWPA Hazard Zone 5 (Severe) [7].

A subsequent post installation at the HEF test site in 1976 included 91 CCA-C-treated Southern Pine posts. The retentions of the posts (oxide basis) ranged from 3.52 to 16.82 kg/m^3 (0.22 to 1.05 lb/ft^3), with the retentions of the majority of the posts in the range of 8.0 to 14.4 kg/m^3 (0.5 to 0.9 lb/ft^3) (Fig. 1). The condition of the posts was assessed by means of pull tests in 1984 and again

TABLE 2—*Estimated years to failure for Southern Pine posts in Mississippi (25 replicates per treatment group).*

					90% Confidence Limits	
Preservative	Retention, kg/m^3	AWPA Pile Retention,[a] %	Failed, %	Estimated Years to Failure	Lower	Upper
Copper naphthenate	0.48	21–30	46	65	55	78
Coal-tar creosote	89.60	33–47	65	54	47	62
Pentachlorophenol	5.12	38–53	29	74	60	91
ACA	5.44	34–43	52	60	51	69
Untreated	0	NA	100	2.4	2.1	2.7

Note: Adapted from Refs 8 and 9.
[a]These posts were treated to the stated percentage of AWPA standard retention [7].

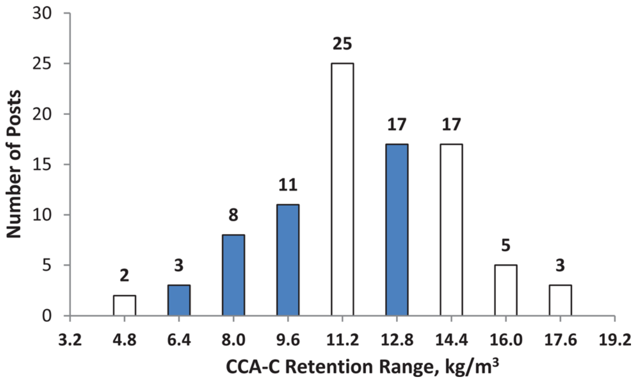

FIG. 1—*Histogram of the distribution of retentions in CCA-C-treated posts. Solid bars indicate the standardized retentions for CCA-C shown in Table 1.*

in March of 2012 (after just over 35 years in test). None of the posts had failed, including five posts that were treated to below the AWPA specified Use Category 4A retention of 6.4 kg/m^3 (0.4 lb/ft^3) for CCA-C treated timbers or posts. In addition, 24 of the posts were treated to below the AWPA specified Use Category 4B retention of 9.6 kg/m^3 (0.6 lb/ft^3), and 66 of the posts were treated to below the AWPA specified minimum of 12.8 kg/m^3 (0.8 lb/ft^3) for terrestrial piles. Untreated Southern Pine post specimens fail within 2 to 4 years at this site.

Long-Term Durability in Lumber (Stake) Tests

The durability of lumber specimens treated to a range of creosote retentions is shown in Fig. 2. The data include values from two separate plots that have been evaluated for either 55 or 60 years. Stakes treated to above 192 kg/m^3 (12 lb/ft^3) have been durable, with at least 80 % remaining in test. Stakes treated to lower retentions have been less durable, with failure rates ranging from 50 % to 90 % for stakes treated to higher retentions than other AWPA standard minimum retentions. The creosote-treated lumber specimens appeared less durable than the posts, probably because of their smaller specimen volume [16]. In post specimens (and in commodity-size material in general) there is a much larger reservoir of creosote above the groundline area to replenish that which has been degraded at the wood surface.

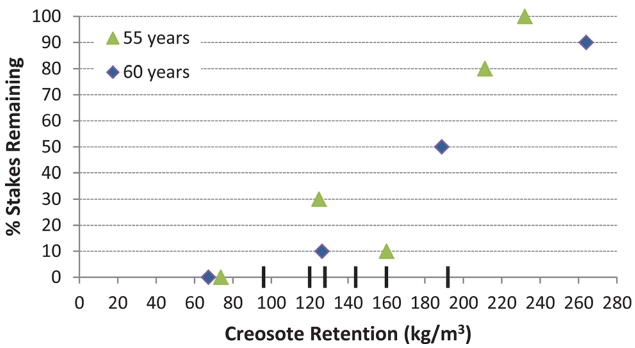

FIG. 2—*Percentage of creosote-treated stakes remaining in test after 55 or 60 years of exposure. Marks on x-axis correspond to the standard retentions for creosote shown in Table 1. Each treatment group had 10 replicates.*

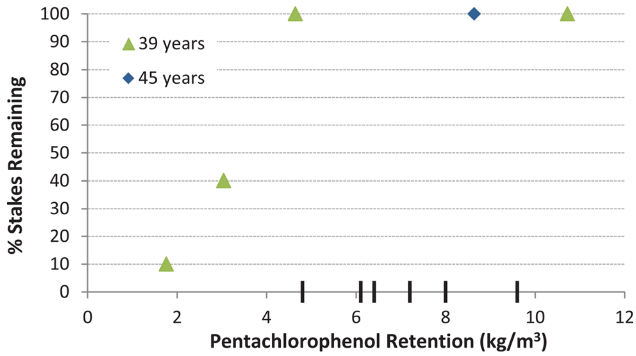

FIG. 3—*Percentage of pentachlorophenol-treated stakes remaining in test after 39 or 45 years of exposure. Marks on x-axis correspond to the standard retentions for pentachlorophenol shown in Table 1. Each treatment group had 9 or 10 replicates.*

Stakes treated with pentachlorophenol have been highly durable after 39 or 45 years of exposure (Fig. 3), with no failures in stakes treated to any of the AWPA standardized retentions. This finding extends to one treatment group that was treated to 4.6 kg/m^3 (0.29 lb/ft^3), which is slightly below the lowest standardized retention (4.8 kg/m^3 or 0.30 lb/ft^3) for pentachlorophenol-treated wood to be used in contact with the ground.

Copper naphthenate–treated stakes were markedly less durable than the posts, with average times to failure of 27 or 30 years for groups treated to within the range of AWPA standardized retentions (Fig. 4). The reason for the difference in durability between copper naphthenate–treated posts and stakes is unclear. It might partially result from the same reservoir effect noted for creosote, but the difference between stake and post durability is much greater than that observed for creosote. Because the durability of the posts is supported by the findings of Morris and Ingram [6], it appears that the stake data might not be representative of the durability of copper naphthenate–-treated wood. The copper naphthenate stake plot was established in 1941, 8 years prior to the post installation, and it is possible that the composition of the older copper naphthenate formulation was different than that of newer formulations. Naphthenic acids are usually obtained as byproducts of petroleum refining and can vary in composition and efficacy against decay fungi [17]. Although the composition of copper naphthenate is now standardized [18], it was not when either the stake or the post plot was established.

Stakes treated with waterborne preservative treatments (ACA, ACZA, and CCA formulations) have had few failures when treated at or above AWPA standard retentions (Figs. 5 and 6). There

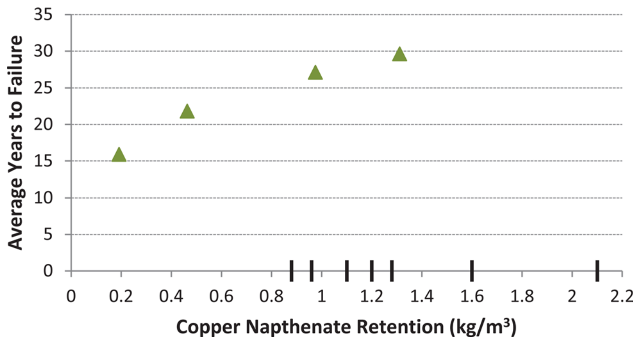

FIG. 4—*Average time to failure for stakes treated with copper naphthenate. Marks on x-axis indicate the standard retentions for copper naphthenate shown in Table 1. Each point is the average of 10 replicates.*

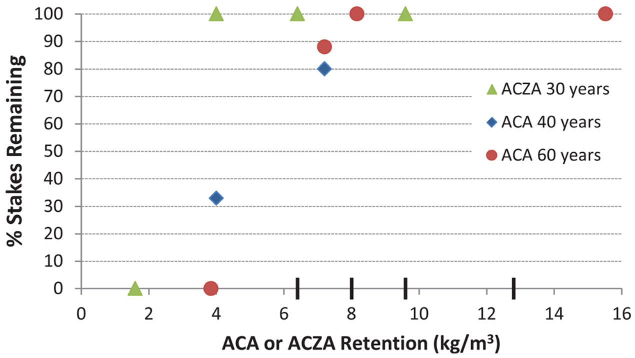

FIG. 5—*Percentage of ACA- or ACZA-treated stakes remaining in test after 30, 40, or 60 years of exposure. Marks on x-axis indicate standard retentions for ACZA shown in Table 1. Each treatment group had 9 or 10 replicates.*

have been no failures in stakes treated with ACA to retentions of 8.0 kg/m^3 (0.5 lb/ft^3) after 60 years, and no failures in stakes treated with ACZA to retentions of 4.0 kg/m^3 (0.25 lb/ft^3) after 30 years. Stakes treated to 7.2 kg/m^3 (0.45 lb/ft^3) with ACA have had 20 % and 10 % failures after 40 and 60 years, respectively.

Stakes treated with the CCA formulations also appear highly durable (Fig. 6). The CCA-C- and CCA-B-treated stakes have had no failures after 40 and 61 years, respectively, with retentions at or above the lowest AWPA standardized retention for wood in contact with the ground. The CCA-A formulation appears to be only slightly less effective, with 20 % failures in stakes treated to 7.0 kg/m^3 (0.43 lb/ft^3) after 60 years in test.

As a whole, the post and lumber specimen exposure data indicate that for general-use ground contact retentions, the expected durability of creosote-treated wood will be in excess of 50 years, and that of wood treated with pentachlorophenol, ACZA, or CCA will be 60 years or more. It is notable that specimens treated with pentachlorophenol, ACZA, or CCA appear to be at least as durable as those treated with creosote. Creosote has a long history of commercial use, and some users are reluctant to use other preservatives because of concerns that they might not be as effective as creosote [19]. The copper naphthenate data are more difficult to interpret because of the conflict between the high durability of the post specimens and the more moderate durability of the lumber specimens. If one assumed that the formulation used to treat the lumber specimens was substandard, the durability of copper naphthenate–treated wood would also be expected to exceed 60 years. Higher

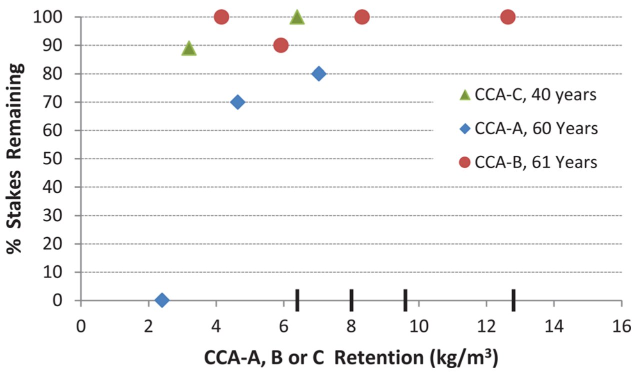

FIG. 6—*Percentage of CCA-treated stakes remaining in test after 40, 60, or 61 years of exposure. Marks on x-axis indicate standard retentions for CCA-C shown in Table 1. Each treatment group had 8 to 10 replicates.*

retentions, such as those standardized for Use Category 4C, would be expected to result in greater durability. Wood treated with the oil-type preservatives would also be expected to have greater durability when used in larger-size commercial commodities such as poles, piles, and timbers.

There are important differences between the durability of stake and post specimens and the expected service life of treated commodities. The specimens were treated under controlled laboratory conditions and thus probably do not reflect the range of treatment qualities that might be encountered in commercial practice. The specimens are also not subjected to the post-treatment cutting or drilling that can expose untreated wood in commercial structures. Untreated wood exposed during construction should be field-treated with preservative or physically protected (with pile caps, for example), or both, but these practices are not always followed. In this respect, the lumber and post specimens reflect the potential durability of wood products that meet the standards of treatment quality and are properly protected during construction. It is also notable that the test specimens are not subjected to the same types of mechanical loads and stresses that might be expected for treated wood in service. The post specimens were subjected to a pull test during inspection, but the evaluation of the lumber specimens was largely visual. Some types of decay fungi can cause substantial strength loss before the damage is readily apparent on the exterior of the wood. The HEF exposure site also represents only one set of conditions, although it is expected that these exposure conditions are at least as severe as those of most other locations within the United States. The lesser durability for creosote-, pentachlorophenol-, and copper naphthenate–-treated specimens at the HEF site relative to exposure sites in Oregon [5] or Canada [6] might partially reflect the severity of the exposure.

Conclusions

Long-term post and lumber durability tests provide insight into the expected durability of wood products that have been treated to AWPA standards and properly handled during construction. This review of the durability data from a test site in southern Mississippi indicates that the expected durability of creosote-treated wood is in excess of 50 years, and that of wood treated with pentachlorophenol, ACZA, or CCA exceeds 60 years. No failures have occurred in lumber specimens treated to intermediate or high retentions of pentachlorophenol, ACZA, or CCA formulations. The expected durability of specimens treated with copper naphthenate was more difficult to interpret because of conflicting results between tests with lumber and post specimens. However, the post specimens indicated durability in excess of 60 years, even at retentions substantially below those currently used commercially. Some caution is needed in extrapolating the durability observed in these test specimens to in-service structures, as the specimens are not subjected to the same mechanical loads or potential damage during construction. Conversely, comparison of the results from this site to reports from other locations suggests that these results might underestimate potential durability in more northern climates.

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