Incising and Site Effects on Long-Term Durability of Pressure-Treated Refractory Wood Species

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ABSTRACT

Field data examining the long-term effects of chemical wood preservatives on refractory wood species with abundant heartwood is limited. This study was initiated to determine, by ground contact exposure, the effectiveness of preservative-treated heartwood material comprised of refractory Douglas-fir, Engelmann spruce, or southern pine. The study compared incised and non-incised lumber treated at three retentions with either ammoniacal copper arsenate (ACA) or chromated copper arsenate (CCA) and placed in ground contact at Mississippi and Wisconsin field test sites in 1975 and 1976, respectively. Test stakes were examined and rated for decay at various intervals over a 40-year period. Results indicate that incising improved long-term performance in samples treated at lower preservative retentions, particularly southern pine and Engelmann spruce heartwood treated with CCA. Additionally, unexpected higher levels of decay were noted in some of the treatments at the Wisconsin site compared to the Mississippi site. Several factors that may contribute to these differences will be discussed including soil structure, site topology and drainage, and other microclimatic effects between the two sites. Previous metagenomics studies have shown considerable differences in fungal community composition at these two sites, which may also explain the differences in decay activity at the two sites. Proper exposure site characterization is often overlooked as an important consideration when performing long-term field testing.

INTRODUCTION

Long-term field data assessing shallow preservative penetration treated using typical treatment methods in refractory heartwood and wood species is limited. Since these data are lacking, the improvement of standards for treated refractory wood species is also limited. Initially this study was implemented to examine wood durability associated with All-Weather Wood Foundation systems as some specifications potentially restricted the amount of heartwood used in 2-inch pine dimensional lumber (Gjovik, 1983). Testing by the Forest Products Laboratory (FPL) to study heartwood natural durability indicated moderate decay resistance of various pine species versus Douglas-fir (Clark, 1957). Southern pine and Douglas-fir heartwood were shown to have better uptake of chromated copper arsenate type C (CCA-C) than by ammoniacal copper arsenate (ACA) (Weaver & Levi; 1979). Morris et al. (2002) showed that ammoniacal copper preservatives had greater penetration than CCA in several refractory western wood species and waterborne ammoniacal formulations were commonly used to treat Douglas-fir (Freeman & McIntyre, 2008). Other research showed that improved performance from treated wood in certain uses was highly important (Bendtsen & Eslyn, 1966; Gjovik & Baechler, 1970; Percival, 1968). All-Weather Wood Foundation construction increased the demand for the long-term use of treated wood (AWPB, 1975; AWPI, 1972; NFPA, 1973) in direct soil contact. FPL reports were used to develop preservative requirements for wood foundation systems (Gjovik & Davidson, 1979, 1982). This testing was initiated to determine the effectiveness of two preservative systems and incising on refractory heartwood of southern pine, Douglas-fir, and Engelmann spruce in ground contact exposure at two different locations in the United States: one location in Wisconsin and one location in Mississippi. This paper presents original data obtained when this study was first initiated (Gjovik, 1983) along with comparative biodeterioration ratings after 40 years of exposure in Wisconsin and Mississippi.

MATERIALS AND METHODS

Nominal 2 x 4 inch southern pine, Douglas-fir, and Engelmann spruce were used for this study. Douglas-fir was obtained from J. H. Baxter & Company (Eugene, OR), Engelmann spruce from Plumb Creek Lumber Company (Columbia Falls, MT), and southern pine was from Travers Lumber Company (Mobile, AL). The lumber was stored for several weeks prior to treatment and equilibrated to 6-7% moisture content determined by an electric resistance meter. Douglas-fir material was selected in 16’ lengths, end-numbered for identification, surfaced, and cut in two 8’ sections. One 8’ section from each 16’ length was incised to a depth of 0.4” on all faces. Engelmann spruce lumber was cut from peeler cores approximately 8’ long.

Half of the Engelmann spruce was incised. Southern pine lumber was shipped green and dried in a laboratory kiln. After drying, the pine boards were numbered, cut in half, with one half incised to a depth of 0.4" on all faces (Gjovik, 1983; Mankowski et al., 2017).

The Engelmann spruce and Douglas-fir selected were predominately heartwood. Southern pine and Engelmann spruce boards were cut to uniform specimen size after drying and incising. Individual specimen volumes were calculated for preservative retentions. Insufficient material was received to end-match the specimens for treatment and specimens were spread over as many treatments as possible to minimize the effect of growth characteristics. Copper tags were fastened to the specimens before treatment with ACA. After treatment, the specimens selected for installation were identified with stainless steel tags held in place with stainless steel nails (Gjovik, 1983).

Preservatives

The Koppers Company supplied chromated copper arsenate type III (CCA-III or CCA-C). J. H. Baxter Company provided ammoniacal copper arsenate (ACA). Concentrates of 47.6% for CCA and 18.6% for ACA (oxide basis) were received. CCA contained 19% CuO, 45% CrO_3, and 36% As_2O_5; while ACA contained 52% CuO and 48% As_2O_5. Treating solutions were made by diluting the concentrated preservative solutions with water. Medium preservative solution concentrations corresponded with commercial treatment concentrations. Concentrations 50% higher and 50% lower to study the effect of preservative retention variables were used as well. Preservative solution concentrations were 1.0%, 2.0%, and 3.0% for southern pine for both preservatives and 1.5%, 3.0%, and 4.5% for both preservatives for Douglas-fir and Engelmann spruce.

Treatments

Full-cell treatment was used for the 12 treatments tested. Douglas-fir and Engelmann spruce were combined in three charges treated with ACA and three charges of CCA. Southern pine was treated separately in three charges of each preservative. Specimens were stickered in a 24.5" x 20" x 97" galvanized tank and treated in a 10-foot long retort to conserve preservative. The preservative was drawn into the tank by a vacuum (27" Hg) for 30 minutes. A pressure of 150 psi (gauge) was applied and held for two hours on the southern pine charge. The same vacuum and a pressure of 125 psi (gauge) was held for eight hours on the Douglas-fir and Engelmann spruce specimen charges. Treated specimens were allowed to drip or were wiped free of excess preservative before weighing for retention calculations. Heat was not applied during the treatments and an ambient room temperature of 80°F kept the solutions very close to temperature during all treatments.

Each charge of southern pine consisted of 30 non-incised stakes and 30 incised stakes. Charges of Douglas-fir and Engelmann spruce were separated by whether they were incised or not. Each non-incised or incised charge consisted of 30 Douglas fir stakes and 25 Engelmann Spruce stakes. After treatment, specimens were dried in a laboratory kiln to 19% moisture content or less.

Installation, Site Characteristics and Rating

Stakes from each species/treatment combination were placed either at the Harrison Experimental Forest (HEF) in Saucier, MS, in 1975, or at Valley View, WI, in 1976. Stakes were placed in ground contact, upright to half their length in rows set three feet apart with a spacing of three feet between rows. The soil type at the Saucier, MS, site is classified as well-drained Poarch, fine sandy loam soil with a pH range of 4.5 – 5.1 and variable organic litter. The soil type at the Valley View, WI, site is poorly-drained Troxel, silt loam with a pH range of 6.5 – 7.0 with thick, water-holding bunch grass covering the study plot. The Scheffer Indices are 86.5 and 43.6 for the Mississippi and Wisconsin sites, respectively. The average rainfall and temperature at the sites are 63.0" and 68.4°F for Mississippi and 31.0" and 46.3°F for Wisconsin.

Samples were rated for decay and insect attack at 1-2 year intervals from 1976-1992 and then 4-5 year intervals from 1992-2015 for a total of 17 rating points over a 40-year period. The lowest rating (of either decay or termite attack) for each rating point was compiled for this analysis. We considered that rating to be the 'biodeterioration' rating signifying the worst of the two ratings.

RESULTS

Table 1 shows the final average retentions for the various species, treatment levels, and incising parameters. Douglas-fir and Engelmann spruce stakes treated with ACA had higher retentions than CCA-treated stakes. The reverse was true, however, with southern pine. These data are contrary to that published by Weaver and Levi (1979). Incising improved retention in southern pine and Douglas-fir. However, penetration in many specimens was not adequate to bridge the incisions. Gjovik (1983) found that the chemical analysis and gain in weight retentions were similar.

Incising resulted in increased CCA-C retentions in southern pine heartwood treated at medium and high preservative concentrations. Incising only improved uptake in Douglas-fir in the high preservative concentration treatment. Incising resulted in increased uptake in Engelmann spruce heartwood at all three retention levels (Table 1). Incising resulted in increased retentions in southern pine in the high ACA concentration. Incising did not improve retentions in Douglas-fir treated with

ACA at any treatment level. Incising improved both CCA and ACA retentions in Engelmann spruce at all treatment levels. Overall, ACA penetration was equal to or better than CCA, except on southern pine treated at low and medium retentions (Table 1).

Table 1. Average retention (n=10) determined by preservative solution uptake (pcf) for non-incised and incised southern pine, Douglas-fir, and Engelmann spruce heartwood stakes treated with two preservatives at three solution concentrations (Mankowski et al., 2017).

		CCA-C		ACA	
Species	**Treatment Level**	**Non-incised**	**Incised**	**Non-incised**	**Incised**
Southern pine	Low	**0.23**	**0.27**	**0.11**	**0.14**
	Medium	**0.29**	**0.47**	**0.31**	**0.30**
	High	**0.47**	**0.62**	**0.42**	**0.65**
Douglas-fir	Low	**0.66**	**0.66**	**0.70**	**0.70**
	Medium	**1.24**	**1.28**	**1.42**	**1.41**
	High	**1.62**	**1.88**	**2.14**	**2.17**
Engelmann spruce	Low	**0.31**	**0.41**	**0.26**	**0.42**
	Medium	**0.50**	**0.66**	**0.63**	**0.97**
	High	**0.65**	**1.02**	**1.03**	**1.41**

Biodeterioration Ratings: Southern Pine

Figure 1 shows the average condition at 40 years for both CCA-C- and ACA-treated southern pine heartwood at the Mississippi site. Ratings for non-incised and incised southern pine indicate that incising helped performance, particularly for southern pine heartwood treated with CCA-C. Southern pine treated to low and medium retentions with CCA-C showed improved performance compared to non-incised material. Incised southern pine heartwood treated with ACA showed improved performance compared to non-incised material, but did not perform as well as CCA-C treated southern pine.

Figure 2 shows the average condition at 40 years for both CCA-C- and ACA-treated southern pine heartwood at the Wisconsin site. Ratings for non-incised and incised southern pine indicate that incising helped performance, but this was not as notable compared to the increased performance of incised samples at the Mississippi site. Incised southern pine treated to the medium retention with CCA-C did not perform as well as the same treatment in Mississippi. Both incised and non-incised southern pine treated with ACA performed better in Wisconsin when compared to Mississippi, particularly at the medium retention. Interestingly, southern pine treated at the low retention with CCA-C performed worse than the same treatment in Mississippi.

Biodeterioration Ratings: Douglas-fir

Figure 3 shows the average biodeterioration ratings at 40 years for both CCA-C- and ACA-treated Douglas-fir heartwood at the Mississippi site. Incising did not improve performance for Douglas-fir heartwood treated with CCA-C, while samples treated to the highest retention of ACA performed slightly better compared to non-incised samples. Incised Douglas-fir treated with ACA at low and medium retentions showed decreased and equal performance, respectively, compared to non-incised material.

Figure 4 shows the average biodeterioration ratings at 40 years for both CCA-C- and ACA-treated Douglas-fir heartwood at the Wisconsin site. Incising slightly improved performance for Douglas-fir heartwood treated with CCA-C at the medium and high retention treatments. Low and medium CCA-C treatments performed slightly worse at this site compared to Mississippi. Samples treated with ACA performed similarly to the Mississippi samples at the medium and high retentions. Samples treated with ACA at the low retention performed worse than the same treatment in Mississippi.

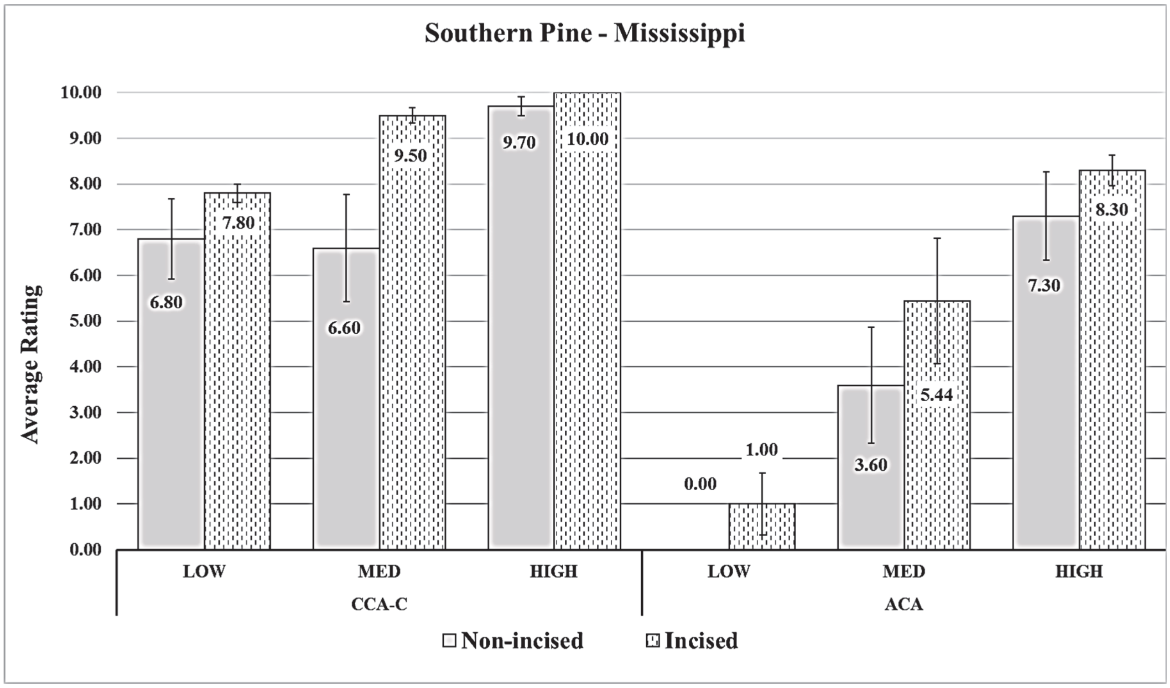

Figure 1. Mean ratings for non-incised and incised southern pine heartwood stakes treated with three retentions of CCA-C (left) or ACA (right) and exposed for 40 years in a ground contact (AWPA E7) field test in Mississippi.

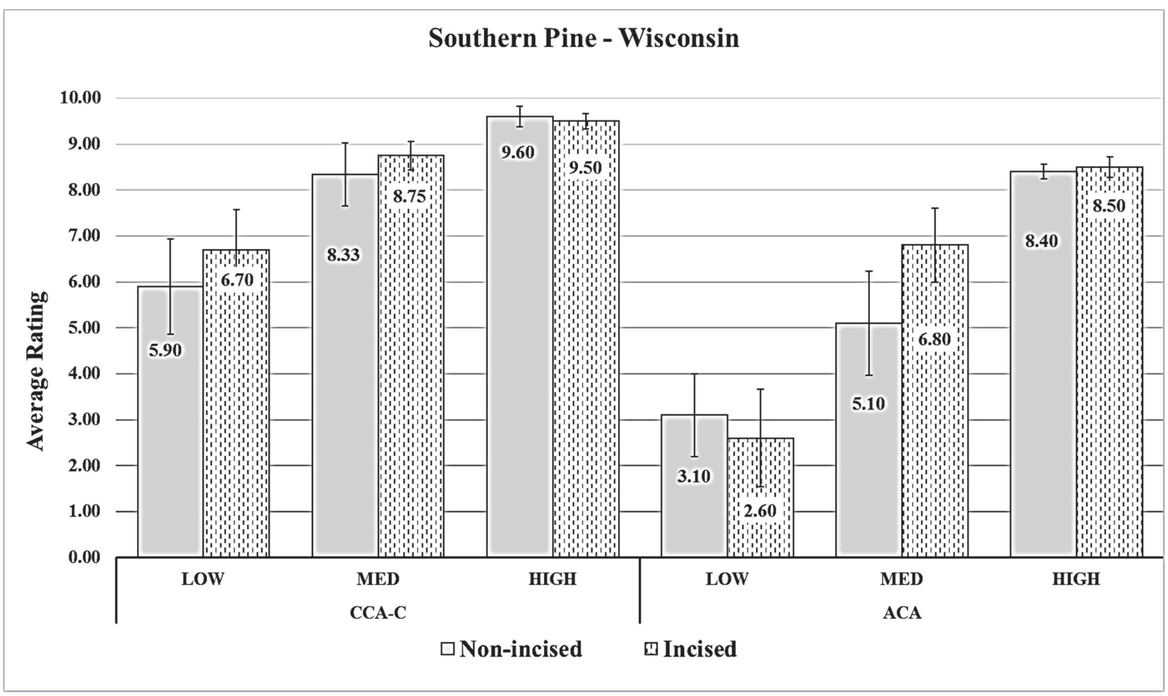

Figure 2. Mean ratings for non-incised and incised southern pine heartwood stakes treated with three retentions of CCA-C (left) or ACA (right) and exposed for 40 years in a ground contact (AWPA E7) field test in Wisconsin.

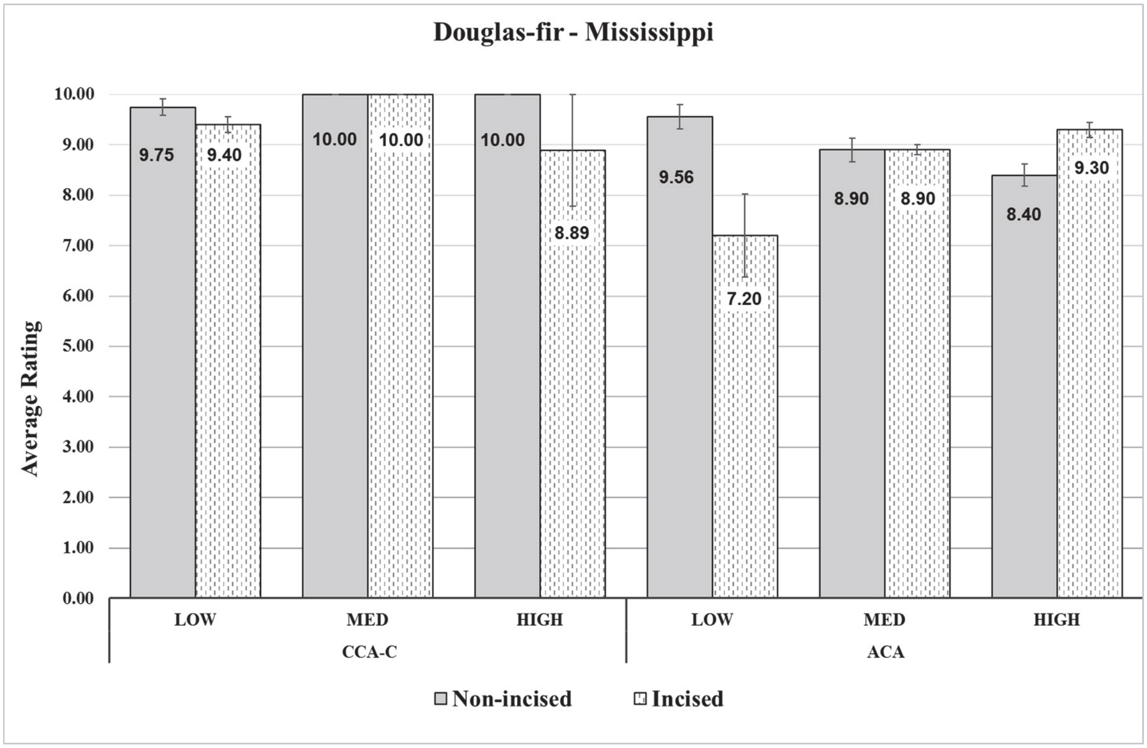

Figure 3. Mean ratings for non-incised and incised Douglas-fir heartwood stakes treated with three retentions of CCA-C (left) or ACA (right) and exposed for 40 years in a ground contact (AWPA E7) field test in Mississippi.

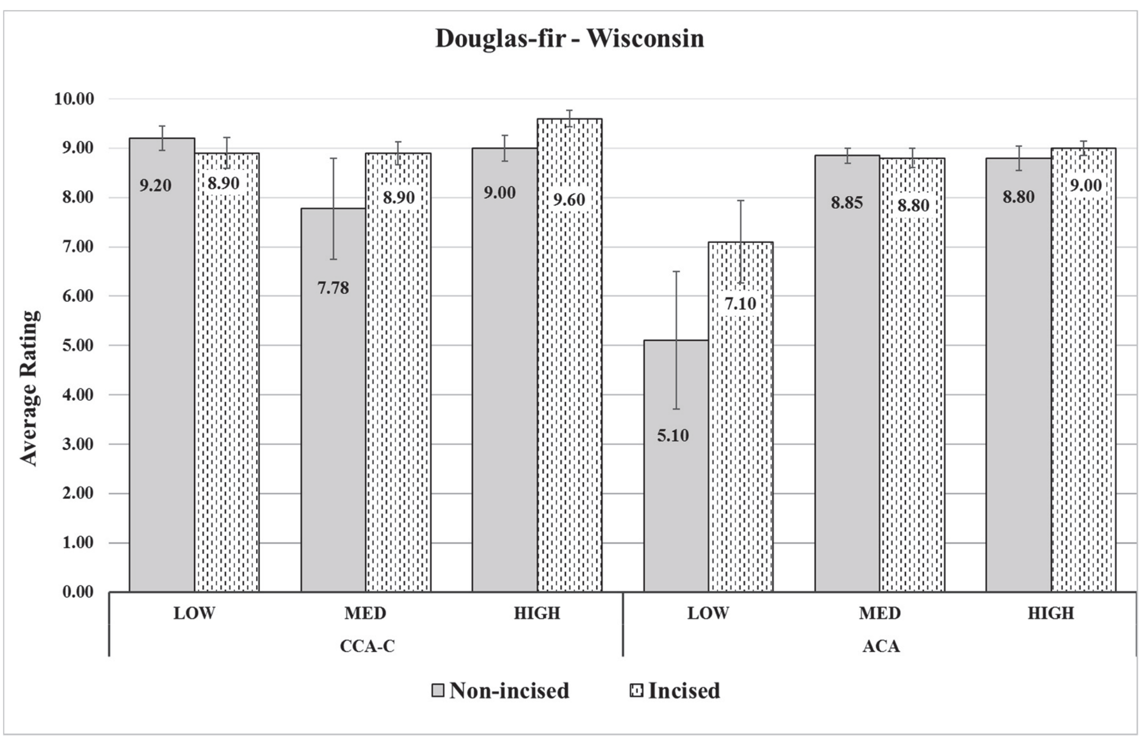

Figure 4. Mean ratings for non-incised and incised Douglas-fir heartwood stakes treated with three retentions of CCA-C (left) or ACA (right) and exposed for 40 years in a ground contact (AWPA E7) field test in Wisconsin.

Biodeterioration Ratings: Engelmann Spruce

Figure 5 shows the biodeterioration averages at 40 years for both CCA-C- and ACA-treated Engelmann spruce heartwood at the three different preservative levels at the Mississippi site. Ratings for non-incised and incised Engelmann spruce indicate that incising improved performance, particularly for Engelmann spruce heartwood treated with CCA-C. Engelmann spruce treated with CCA-C at low and medium retentions particularly showed improved performance compared to non-incised material. Incised Engelmann spruce heartwood treated with ACA showed improved performance compared to non-incised material, particularly at the low and medium preservative retention levels, but did not perform as well as Engelmann spruce treated with CCA-C.

Figure 6 shows the biodeterioration averages at 40 years for both CCA-C- and ACA-treated Engelmann spruce heartwood at the three different preservative levels at the Wisconsin site. Ratings for non-incised and incised Engelmann spruce indicate that incising improved performance, particularly for Engelmann spruce heartwood treated with CCA-C. Engelmann spruce treated with CCA-C at the low retention particularly showed improved performance compared to non-incised material. Incised Engelmann spruce heartwood treated with CCA-C at the medium and high retentions did not show the difference in performance that the same treatments did in Mississippi where there was a more defined difference between incised and non-incised samples. Incised Engelmann spruce heartwood treated with ACA showed improved performance compared to non-incised material, particularly at the low and medium preservative concentration levels, but did not perform as well as Engelmann spruce treated with CCA. Ratings for both low retentions of CCA-C or ACA were unexpectedly lower in Wisconsin compared to the same treatments in Mississippi. This result was counterintuitive to current understanding of biodeterioration zones in North America.

DISCUSSION

In comparing the 40-year durability of incised and non-incised stakes for each wood species and preservative, several trends were apparent. All of the wood species were highly durable when incised and treated with medium or high retentions of CCA-C. Greater durability of stakes treated with CCA-C relative to those treated with ACA was observed. This is interesting considering that the ACA-treated stakes generally had higher retentions and ammoniacal formulations are thought to allow greater penetration of refractory wood species (Freeman & McIntyre, 2008). However, a similar trend is being observed for ACA- or CCA-C-treated eastern white pine, red pine, and eastern spruce stakes exposed for 24 years at the Mississippi site (Woodward et al., 2011). CCA-C has also provided greater protection than ACA for southern pine posts during 50 years of exposure (Lebow et al., 2015) although in this case the specimens were comprised of readily treated sapwood. In this study, ACA was fairly effective at high retentions as demonstrated by the durability of the Douglas-fir stakes (Figure 3). ACA efficacy has been previously reported in southern pine stakes that have performed well for over 60 years when treated to high retentions (Lebow et al., 2013; Mankowski et al., 2017; Woodward et al., 2011).

Although Douglas-fir stakes appeared to be the most durable species, the results were likely influenced by higher treatment retentions for both preservatives for these stakes, especially relative to southern pine (Table 1). Engelmann spruce appeared to be less durable than southern pine or Douglas-fir unless the spruce was incised, especially when treated with CCA-C. Incising also appeared to provide some benefit for southern pine, but did not increase the durability of Douglas-fir. The lack of benefit for incising Douglas-fir likely reflects the high retentions achieved without incising and the fact that even the low retentions of CCA-C and ACA in Douglas-fir were above those specified for treatment of wood foundations (AWPA, 2003).

Durability of stakes treated with ACA and CCA-C may in part be attributable to the relative leach resistance of the active ingredients. CCA-C is an acidic formulation, with copper fixed through adsorption on wood components and/or formation of copper chromates, while arsenic appears to be fixed primarily through formation of chromium arsenates and possibly copper arsenates (Dahlgren & Hartford, 1972; Hingston et al., 2001; Lebow, 1996; Pizzi, 1981, 1982). ACA is an ammoniacal formulation in which copper is thought to be stabilized through adsorption on wood reactive sites and formation of copper carbonate, copper oxide, or copper arsenate complexes (Lebow & Morrell, 1995; Ruddick, 1996). Fixation of arsenic in ACA is thought to occur primarily through copper arsenate complexes and research indicates that arsenic depletion may occur if insufficient copper is available to react with the arsenic (Best & Coleman, 1981; Lebow & Morrell, 1995). It is possible that arsenic depletion contributed to the lesser durability of the ACA-treated stakes, especially at lower retentions. Replacement of a portion of the arsenic with zinc in the subsequent ammoniacal copper zinc arsenate (ACZA) formulation appears to have improved arsenic fixation by increasing the ratio of metals (copper and zinc) to arsenic (Lebow, 1996).

Another interesting trend was that there appeared to be a site effect in that several of the low retention treatments in Wisconsin performed worse than the same treatments in Mississippi. Southern pine low retention CCA-C, Douglas-fir low retention ACA, and Engelmann spruce low retention CCA-C and ACA performed worse in Wisconsin than the same treatments in Mississippi. These results are interesting in that they conflict with current AWPA decay hazard map shown in Figure 7 (AWPA, 2017).

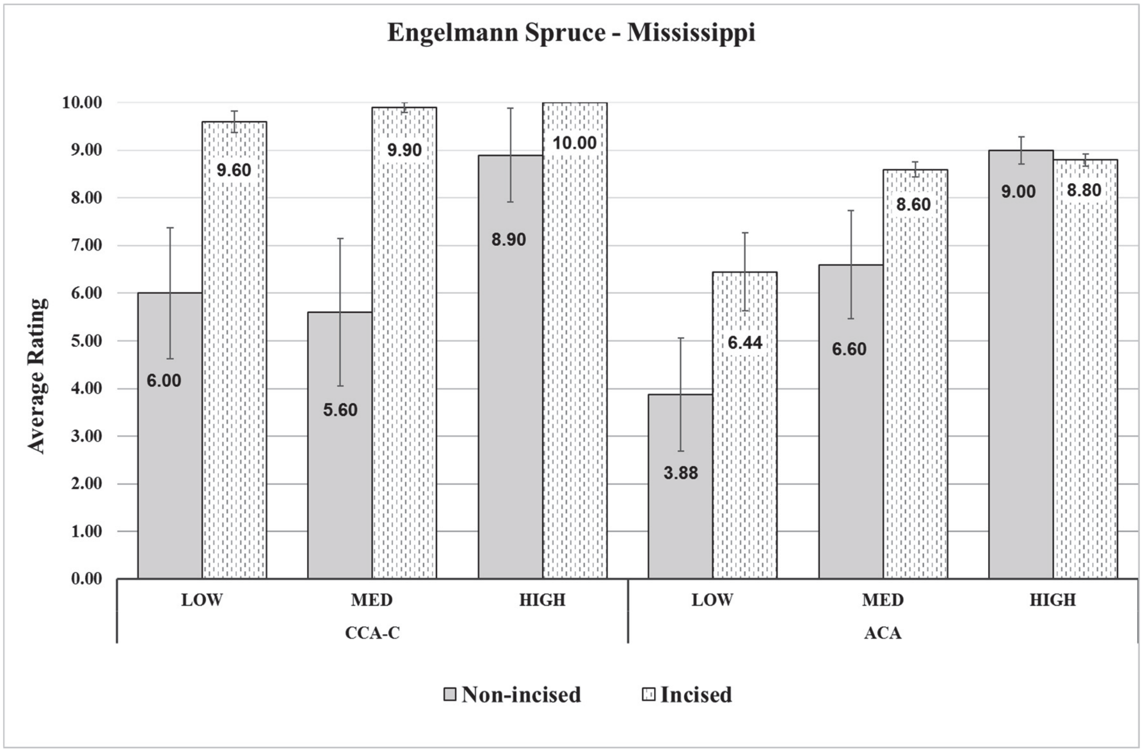

Figure 5. Mean ratings for non-incised and incised Engelmann spruce heartwood stakes treated with three retentions of CCA-C (left) or ACA (right) and exposed for 40 years in a ground contact (AWPA E7) field test in Mississippi.

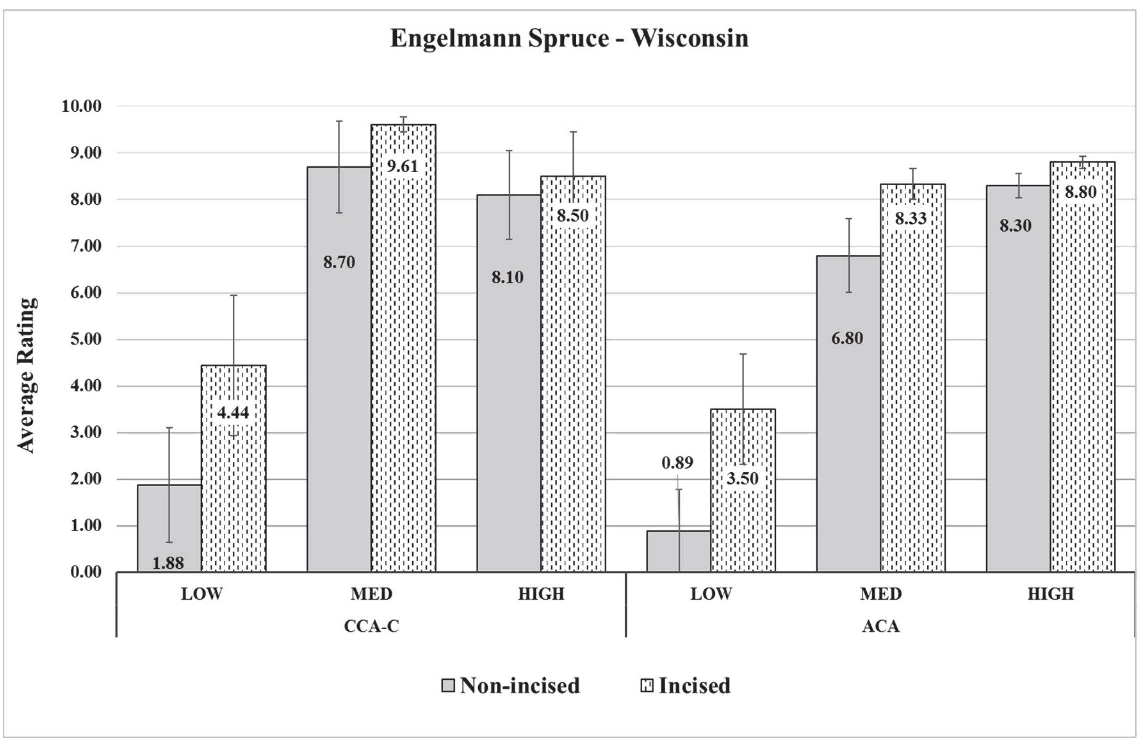

Figure 6. Mean ratings for non-incised and incised Engelmann spruce heartwood stakes treated with three retentions of CCA-C (left) or ACA (right) and exposed for 40 years in a ground contact (AWPA E7) field test in Wisconsin.

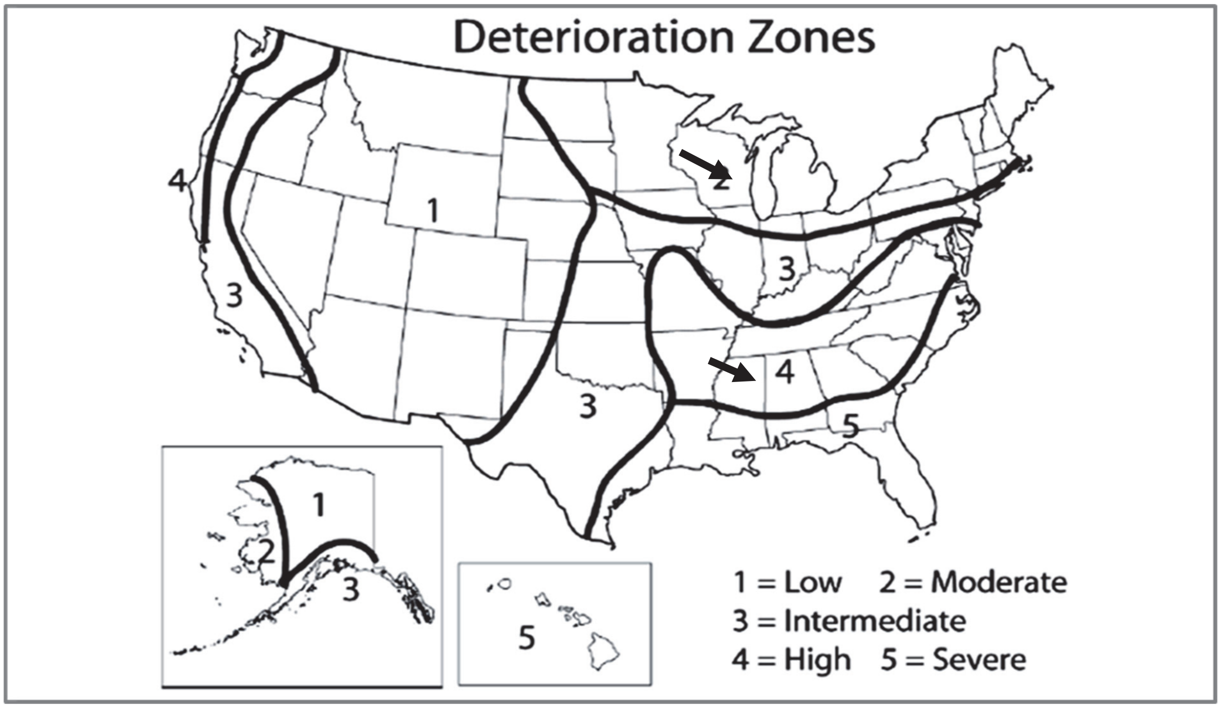

Figure 7. **AWPA fungal decay hazard zones in United States (AWPA 2017). Black arrows indicate the northern and southern test site locales.**

According to the map, the decay hazard (based on annual average temperature and rainfall) should be lower in Wisconsin. The unexpected lower ratings obtained at the Wisconsin site may be attributed to site characteristics outside of the decay hazard or Scheffer index. As stated earlier, the soil types and soil pH at the two sites are different. The Mississippi site has a pine over-story and semi-closed canopy. The Wisconsin site is in an open grassy area surrounded by hardwood trees. The grass at this site occurs as bunch grass and retains high moisture levels throughout the year. The Mississippi site soil contains higher levels of sand and drains more rapidly than Wisconsin, which has poorly-drained clay soils. Previous studies noted that the two sites had significantly different soil fungal species and distinct wood decay fungi were present at each site (Figure 8) (Kirker et al., 2017).

The Mississippi site has a greater number of brown rot fungi; whereas the Wisconsin site was found to have more white and soft rot fungi based on recent meta-barcoding studies of soil fungal communities (Kirker et al., 2017). This differential in fungal species between sites could have a profound influence on the decay rates of wood at the sites.

Another important consideration are microclimatic factors, which are not factored into the AWPA hazard map, but are alluded to in the AWPA Use Category system specifications: "*In certain modified environments such as banks along irrigation canals or irrigated residential or agricultural lands, a higher degree of protection might be needed than would be required in the local natural environment. It must also be recognized that natural environments such as river valleys or coastlines may present greater potential for wood deterioration than the region as a whole*" (AWPA, 2017). In tropical systems, degradation rates are more uniform (equally bad) at a given locale and have been shown not to vary in fungal species richness due to changes in elevation and along temperature gradients (Meier et al., 2010), but in more temperate environments, the effects due to microclimate may be more pronounced.

Contrasting European approaches to decay modeling give careful consideration to microclimatic effects so that empirical models take into account a range of simultaneous factors including both macroclimate (prevailing weather) and meso-climate (nature of exposure, orientation, and material details) and ultimately consider ambient moisture to be the most important factor affecting the durability of wood (Viitanen et al., 2010). These complications make effective decay forecasts difficult and somewhat haphazard. Additionally, the concept of microclimate can also be applied in a temporal context where seasonal fluctuations impact the rate of wetting and drying, which can also influence local decomposition rates (Boddy et al., 1983). These are not currently reflected and may or may not be of concern in treated wood as the average site condition would no doubt capture the prevailing climatic patterns so long as the more extreme periods are given equal or weighted consideration.

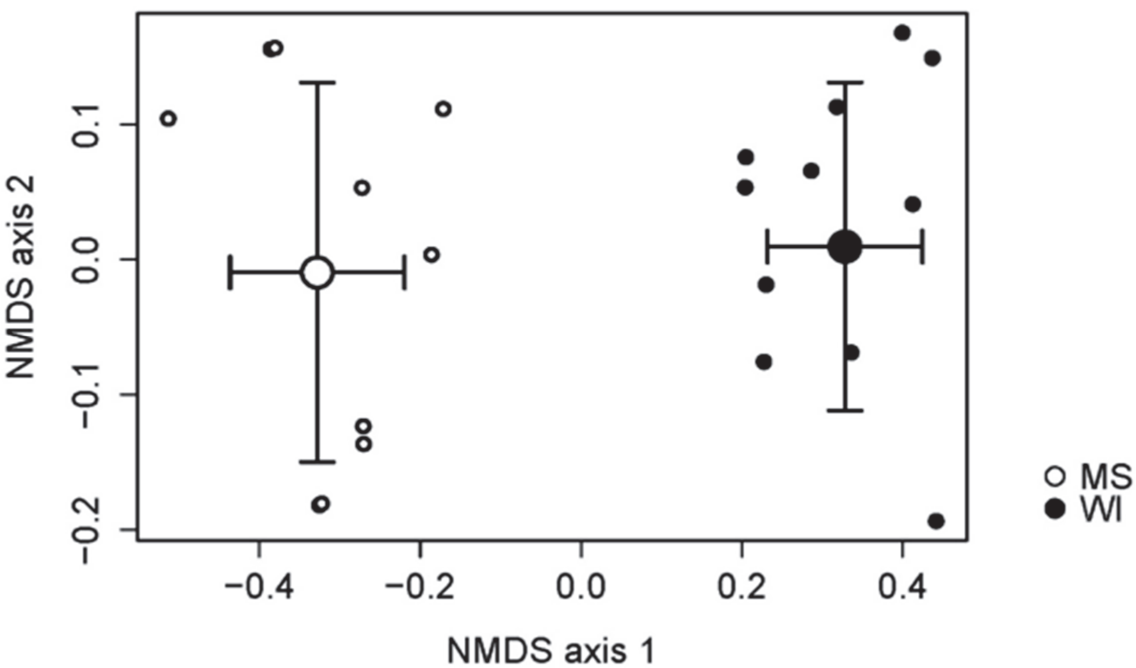

Figure 8. Non-metric multidimensional scaling (NMDS) plot indicating the effects of site on the fungal species composition. Sites were distinctly different and necessitated separate analyses of treatments. Distance between black and white crosses indicates differences in overall fungal species composition (Kirker et al., 2017).

As noted above, preservative resistance to leaching is an important factor in long-term durability. Although the greater annual rainfall at the Mississippi test site might be expected to increase preservative depletion relative to the Wisconsin site, other factors, such as soil properties, may also have a role (Lebow et al., 2006; Schultz et al., 2002; Wang et al., 1998). Increased leaching of biocides from wood in contact with the ground has been attributed to pH, inorganic soil constituents, and organic acids. One study reported that five to ten times more copper was depleted from treated stakes when exposed to soil at pH 4.7 than when exposed to soil at pH 8 (Wang & Kamdem, 2011). An earlier study also noted that leaching of copper from CCA-treated wood appeared to be lower in soils with high base saturation values (Wang et al., 1998). Inorganic components in soil have also been implicated in increasing or reducing leaching. Ruddick (1993) reported that copper and arsenic depletion from test stakes was associated with iron uptake and suggested that bacteria reacting to the high iron content of the soil secreted enzymes that solubilized copper compounds in the wood. Conversely, one report suggests that iron and aluminum in soil surrounding CCA-treated wood can retard arsenic leaching because these metals may migrate into the wood and irreversibly precipitate the arsenic (Evans et al., 1994).

CONCLUSIONS

Incising improved performance of southern pine treated heartwood and Engelmann spruce, particularly at medium and high retention levels. Incising had little effect on Douglas-fir heartwood treated with either preservative. After 40 years of ground contact exposure, some of the medium and many of the high retention treatments are performing well with ratings of 8 or better. The greater durability of the CCA-C-treated stakes relative to ACA is notable because the ACA-treated stakes generally had higher retentions and ACA is thought to allow greater penetration of western species than CCA. In general, the results indicated that, with incising, higher retentions of CCA-C can provide long-term protection for southern pine heartwood, as well as Engelmann spruce heartwood and Douglas-fir heartwood. This finding bodes well for a wide range of structures composed of sawn material, including wood foundations that were the initial impetus for the study. However, a note of caution is warranted because these test specimens were not exposed to saw cuts or drill holes that may occur in actual structures. In addition, their relatively short length resulted in a greater proportion of protection from end-grain penetration than would occur in commodity-size materials. It must also be noted that some of the low retention CCA-C and ACA treatments performed worse in Wisconsin, a lower decay hazard zone, than Mississippi. This was attributed to distinct site characteristics, particularly soil factors, microclimatic factors, and the occurrence of different types of decay fungi at each site. Further work examining cation exchange capacity of the soils at each site, effects of bacteria on copper leaching, and the different decay fungi present will be examined.

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