Long Term Durability of Solid Heartwood Stakes Treated with ACA or CCA

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ABSTRACT

Limited long-term field data exist evaluating the benefit of chemical wood preservatives on refractory wood species with abundant heartwood. The objective of this study was to determine the effectiveness of preservative-treated refractory solid heartwood comprised of southern pine, Douglas-fir, or Engelmann spruce. Non-incised and incised solid lumber of these species were treated to three different retentions of either chromated copper arsenate (CCA) or ammoniacal copper arsenate (ACA) and placed in ground contact (AWPA E7) at a Mississippi field test site in 1975. Field stakes were rated for decay and insect damage every two to five years. The 40-year rating data showed that incising improved long term performance of southern pine and Engelmann spruce samples treated to lower retentions with either CCA or ACA, although CCA treated material outperformed ACA. Incising had little to no effect on preservative uptake or performance of Douglas-fir heartwood treated with either preservative.

INTRODUCTION

There is limited long term field data regarding shallow preservative penetration in southern pine, Douglas-fir, and Engelmann spruce heartwood treated via conventional methods. This knowledge gap hinders improvement of standards for treated heartwood. This study was originally initiated to examine wood use for All-Weather Wood Foundation systems as there was concern that existing specifications placed unnecessary restrictions on the amount of heartwood permitted in 2-inch dimensional lumber of southern pine and ponderosa pine (Gjovik 1983). The wood-preserving industry once suggested that the refractory nature of pine heartwood could give it extended service life even though preservative penetration was not equal to that of the sapwood due to the high resin content in pine heartwood. Early research at the Forest Products Laboratory (FPL) examining the natural durability of the heartwood of several softwood species indicated only moderate decay resistance of longleaf and ponderosa pine compared to Douglas-fir (Clark 1957). Weaver and Levi (1979) showed that both southern pine and Douglas-fir heartwood were more easily penetrated by chromated copper arsenate type C (CCA-C) than by ammoniacal copper arsenate (ACA). However, a more recent study reported that ammoniacal copper preservatives achieved greater penetration than CCA in several refractory western wood species (Morris et al. 2002) and ammoniacal formulations of waterborne preservatives are commonly used to treat Douglas-fir (Freeman and McIntyre 2008). Past studies stressed the importance of obtaining improved performance from treated wood in certain uses (Bendtsen and Eslyn 1966; Gjovik and 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. Reports from FPL (Gjovik and Davidson 1979; 1982) were used to develop material and preservative requirements for wood foundation systems. The original objectives of this study were to determine, by treatment and ground contact exposure, the effectiveness of two preservative systems and incising on solid refractory heartwood of southern pine, Douglas-fir, and Engelmann spruce. This study is also part of a set of long term field studies monitored by FPL at five year intervals. In this paper, we present some of the original findings shortly after this study was initiated (Gjovik 1983) along with biodeterioration ratings over 40 years of evaluation of this test plot in Mississippi.

MATERIALS AND METHODS

Eight hundred lineal feet of nominal 2 x 4 inch southern pine, Douglas-fir, and Engelmann spruce were purchased 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 from Travers Lumber Company (Mobile, AL). The 2” x 4” material was stored for several weeks in the laboratory prior to treatment and reached a moisture content of 6-7% as determined by an electric resistance moisture meter at the time of treatment. Douglas-fir 2" x 4" was selected in 16' lengths at the Baxter plant, 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 before shipment. Engelmann spruce 2" x 4" was cut from peeler cores approximately 8" long. Half of the Engelmann spruce 2" x 4" received were selected for incising. Southern pine 2" x 4" was obtained in various lengths. All southern pine 2" x 4" was shipped green and dried in the laboratory kiln. After drying, each length of pine was numbered on the ends, cut in half, and one half was selected for incising. Specimens were taken to the Weyerhaeuser plant in Albert Lea, MN, and incised to a depth of 0.4" on all faces (Gjovik 1983).

Engelmann spruce and Douglas-fir were predominately heartwood. The southern pine contained some sapwood; an attempt was made to eliminate all sapwood when the material was cut to specimen size. Southern pine and Engelmann spruce 2" x 4" boards were cut to uniform specimen size after drying and incising. Individual specimen volumes were computed for preservative retention values for this material. Before cutting, a section of each southern pine board was taken for resin analysis. Insufficient material was received to end-match the specimens for treatment and specimens from each 2" x 4" 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 so their identity would not be lost during treatment. A felt tip marking pen was sufficient to identify specimens treated with CCA-C. After treatment, the specimens selected for installation were identified with stainless steel tags held in place with stainless steel nails (Gjovik 1983).

Preservatives

Chromated copper arsenate type III (CCA-III or CCA-C) was obtained from the Koppers Company. Ammoniacal copper arsenate (ACA) was obtained from the J. H. Baxter Company. The preservatives were received as concentrates of 47.6% for CCA and 18.6% for ACA (oxide basis). Chemical analysis indicated that CCA contained 19% CuO, 45%, CrO_3, and 36% As_2O_5; while ACA contained 52% CuO, and 48% As_2O_5. Concentrated solutions were diluted with water to make up the treating solutions. Medium preservative solution concentrations were selected to correspond with commercial treatment concentrations plus concentrations 50% higher and 50% lower to study the effect of preservative retention variables. 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

A full-cell treatment process 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. Immediately after the pressure was released, the tank was removed from the treating retort and pumped dry. 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. 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 at the Harrison Experimental Forest (HEF), Saucier, MS, in December 1975. The HEF soil type at the time of installation had a pH 0f 4.85 and is classified as Poarch soil, a fine sandy loam (Gjovik 1983).

Installation and Rating

Half of the samples from each species/treatment combination were placed at either Valley View, WI, or Saucier, MS. This paper will focus on data associated with the Mississippi site only. 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 AND DISCUSSION

The resin content of the southern pine, determined by ether extraction, ranged from 0.87% to 27.4% based on oven dry weight of the wood. No correlation was found between resin content and performance of the untreated pine controls. Preservative penetration was also variable with the southern pine showing better penetration than expected in some cases. Net preservative retentions varied from 1.8 to 39.7 pcf in the southern pine, 5.5 to 50.5 pcf in the Douglas-fir, and 7.3 to 50.3 pcf in the Engelmann spruce stakes. Douglas-fir and Engelmann spruce stakes treated with ACA had higher retentions than CCA-treated stakes (Table 1). The reverse was true, however, with the 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 (Table 1).

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. As in the CCA treatments, incising improved ACA retentions in Engelmann spruce at all treatment levels (Table 1).

Table 1. Average retention (n=10) determined by preservative solution uptake (pcf) for non-incised and incised southern yellow pine (SYP), Douglas-fir (DF), and Engelmann spruce (ES) heartwood 2" x 4" stakes treated with two preservatives at three solution concentrations.

		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 Yellow Pine

Figure 1 shows the average biodeterioration ratings over 40 years for non-incised and incised southern pine treated with CCA-C at three different retention levels. All untreated controls (0.00 pcf) failed after 10 years of ground contact in MS.

Average retentions for the non-incised stakes were 0.23, 0.29, and 0.47 pcf for stakes treated with low, medium, and high preservative concentrations, respectively, while those for incised southern pine stakes were 0.27, 0.47, and 0.62 pcf. Averages indicated that incising improved retentions in the medium and high treatments. Increased retention was associated with improved performance at the medium and high retentions for incised southern pine.

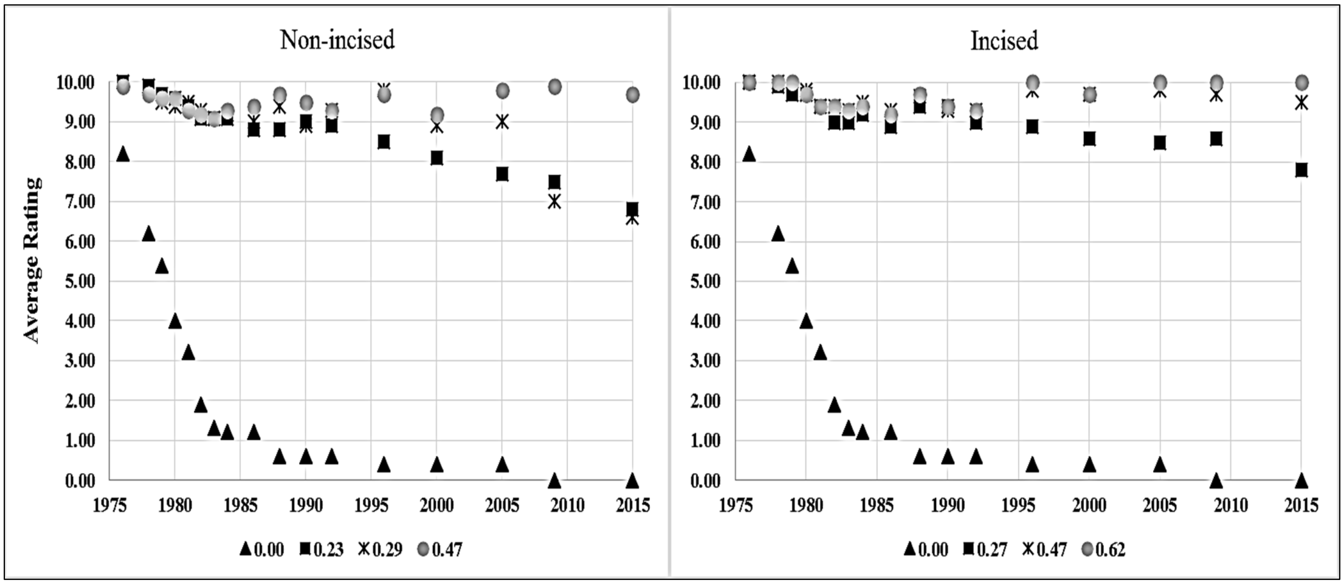

Figure 1. Mean biodeterioration ratings over a 40-year period for non-incised and incised southern pine heartwood stakes treated with three retentions of CCA-C and exposed in a ground contact (AWPA E7) field test in Mississippi.

Figure 2 shows the average biodeterioration ratings for southern pine heartwood, non-incised and incised, over the 40-year period for stakes treated with ACA. All untreated controls (0.00 pcf) failed after 10 years of ground contact. Average retentions for non-incised stakes were 0.11, 0.31, and 0.42 pcf corresponding to low, medium, and high preservative concentrations, respectively, while those for incised southern pine stakes were 0.14, 0.30, and 0.65 pcf for the same treatments. Incising was associated with improved ratings in all three treatments particularly at the medium and high levels of treatment. Ratings for ACA treated stakes were not as high as those for CCA-C treated southern pine indicating that CCA-C treated southern pine heartwood performed better than ACA. Non-incised southern pine with an ACA retention of 0.11 pcf failed at a much higher rate than the higher retentions but incising did seem to delay time to failure.

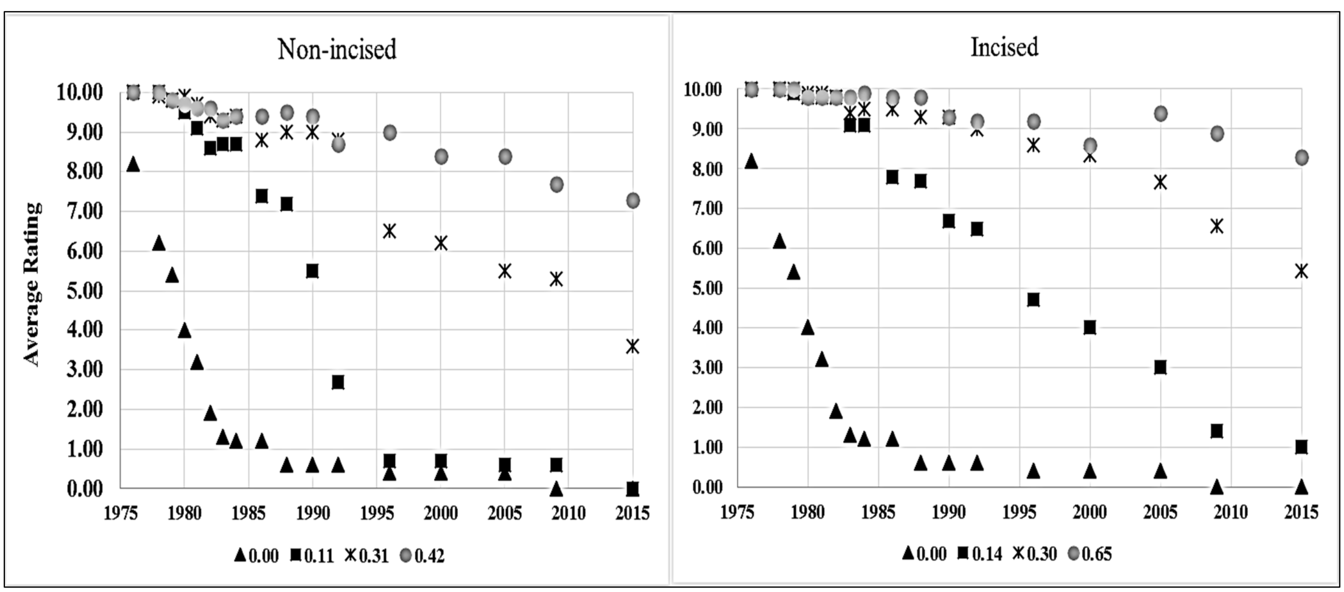

Figure 2. Mean biodeterioration ratings over a 40-year period for non-incised and incised southern pine heartwood stakes treated with three retentions of ACA and exposed in a ground contact (AWPA E7) field test in Mississippi.

Figure 3 shows the average condition at 40 years for both CCA-C and ACA treated southern pine heartwood. 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.

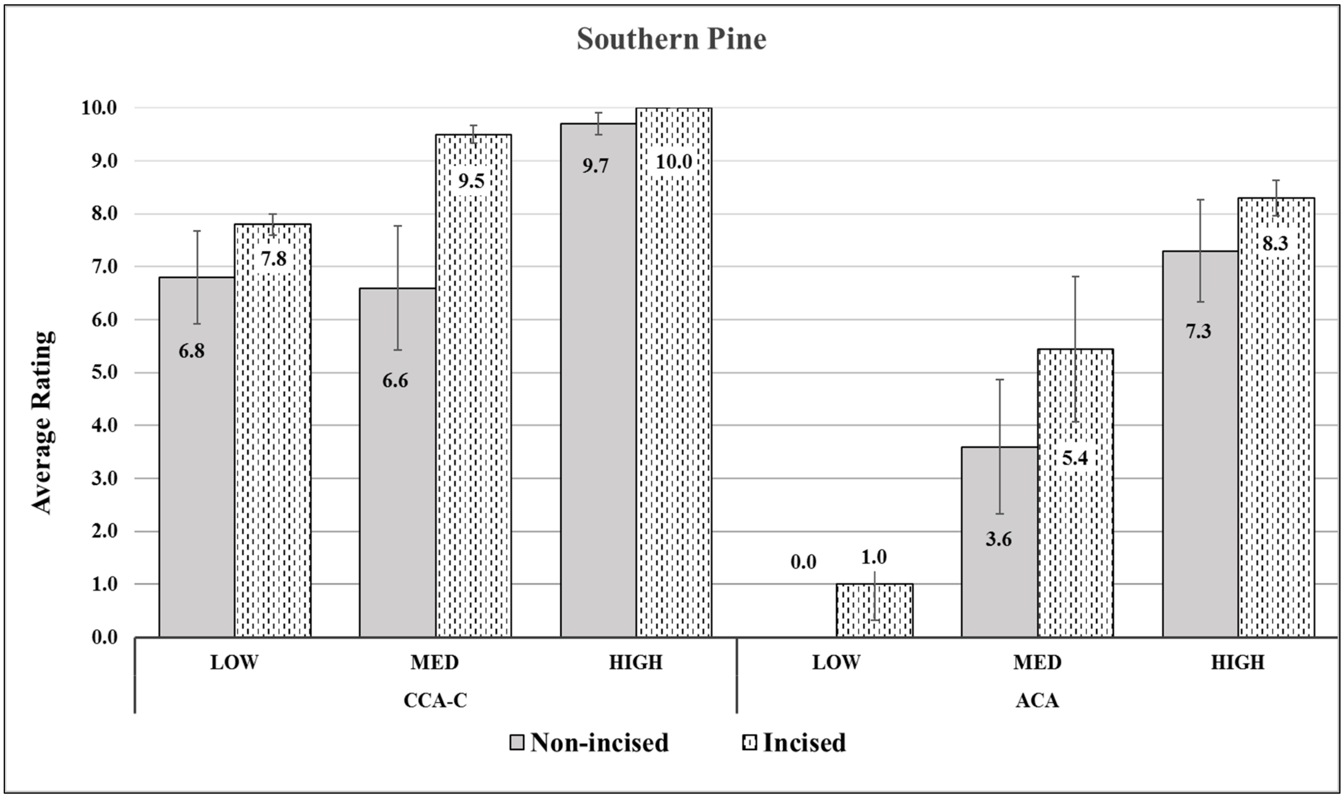

Figure 3. Mean ratings for non-incised and incised southern pine heartwood stakes treated with three retentions of CCA-C (left) or ACA (right) and exposed for 40 years in a ground contact (AWPA E7) field test in Mississippi.

Biodeterioration Ratings: Douglas-fir

Figure 4 shows the average biodeterioration ratings over 40 years for untreated controls, non-incised Douglas-fir, and incised Douglas-fir treated with CCA-C to three different retention levels. All untreated Douglas fir controls (0.00 pcf) failed after 5 years in soil contact in MS. The poor performance of the Douglas-fir controls compared to the southern pine (Figures 1 and 2) may reflect the high resin levels in the southern pine heartwood used in this test. Average retentions for the non-incised stakes were 0.66, 1.24, and 1.62 pcf for the low, medium, and high preservative concentrations, respectively, while those for the incised Douglas-fir stakes were 0.66, 1.28, and 1.88 pcf for the same treatments. Non-incised CCA-C treated stakes performed equal to or slightly better than the incised stakes. This was not surprising since incising did not improve CCA-C retention levels as it did in southern pine or Engelmann spruce (Table 1). This reflects the highly refractory nature of Douglas-fir heartwood. All treatments of both non-incised and incised Douglas-fir were performing well and were still intact after 40 years of exposure. Incising had little effect on the performance of Douglas fir in this study.

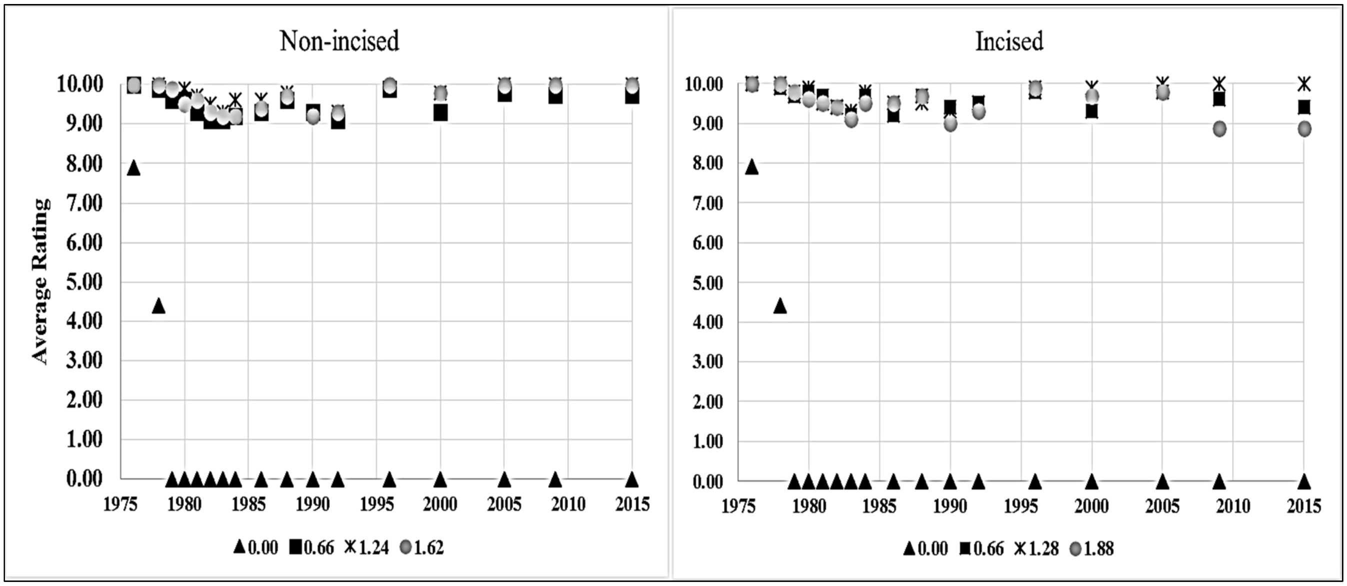

Figure 4. Mean biodeterioration ratings over a 40-year period for non-incised and incised Douglas-fir heartwood stakes treated with three retentions of CCA-C and exposed in a ground contact (AWPA E7) field test in Mississippi.

Figure 5 shows the average biodeterioration ratings for ACA treated non-incised and incised Douglas-fir over the 40 year period. Similar to CCA-C treated Douglas-fir, non-incised performed similar to incised Douglas-fir stakes treated with ACA, except at the lowest ACA retention. Average retentions for the non-incised stakes were 0.70, 1.42, and 2.14 pcf corresponding to low, medium, and high preservative concentration, respectively, while those for incised stakes were 0.70, 1.41, and 2.17 pcf for the same treatments. Average retentions for the non-incised and incised stakes were similar indicating that incising did not help retention or performance in this wood species. Incising appeared to have a negative effect on the ground contact performance at the lower retention rate.

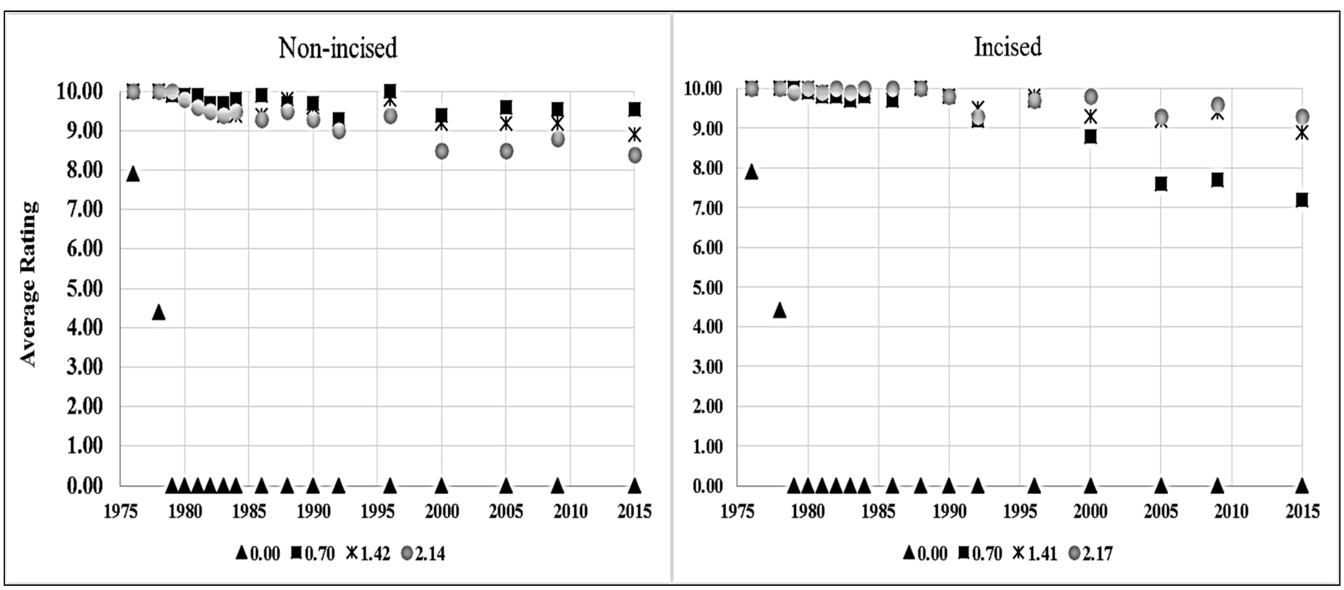

Figure 5. Mean biodeterioration ratings over a 40-year period for non-incised and incised Douglas-fir heartwood stakes treated with three retentions of ACA and exposed in a ground contact (AWPA E7) field test in Mississippi.

Figure 6 shows the average biodeterioration ratings at 40 years for both CCA-C and ACA treated Douglas-fir heartwood. 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.

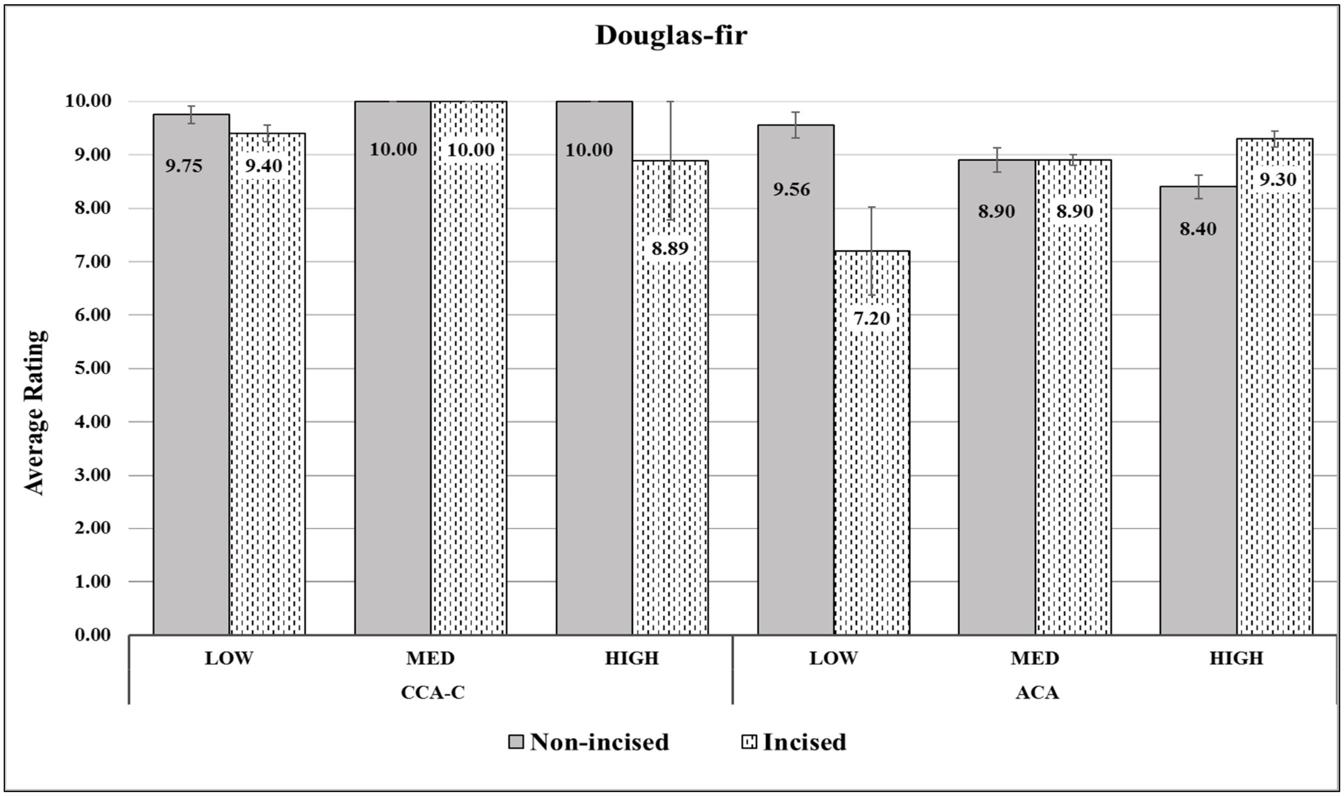

Figure 6. Mean ratings for non-incised and incised Douglas-fir heartwood stakes treated with three retentions of CCA-C (left) or ACA (right) and exposed for 40 years in a ground contact (AWPA E7) field test in Mississippi.

Biodeterioration Ratings: Engelmann Spruce

Figure 7 shows the average biodeterioration ratings over 40 years for non-incised Engelmann spruce and incised Engelmann spruce treated with CCA-C at three different retention levels. All untreated controls (0.00 pcf) failed in less than 5 years in MS. Average retentions for non-incised stakes were 0.31, 0.50, and .65 pcf corresponding to low, medium, and high preservative concentration, respectively, while those for incised Engelmann spruce stakes were 0.41, 0.66, and 1.02 pcf. Incising increased average retention and overall performance for all levels of CCA-C treatment for this wood species.

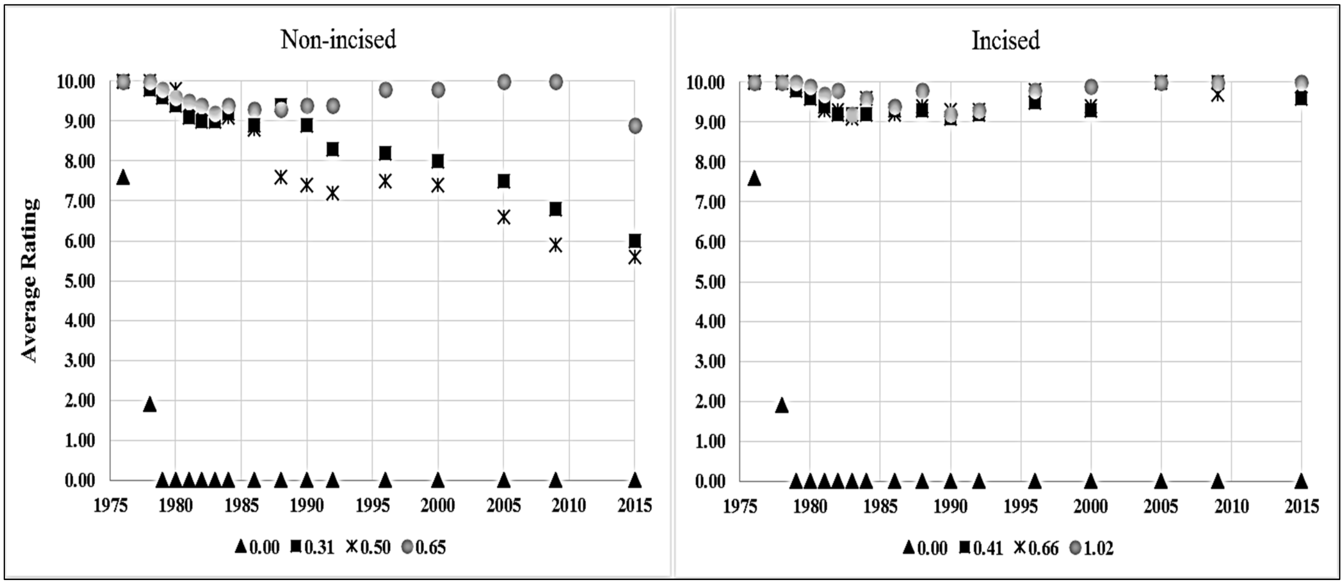

Figure 7. Mean biodeterioration ratings over a 40-year period for non-incised and incised Engelmann spruce heartwood stakes treated with three retentions of CCA-C and exposed in a ground contact (AWPA E7) field test in Mississippi.

Figure 8 shows the average biodeterioration ratings for non-incised and incised Engelmann spruce for the preservative ACA. The average retentions for the non-incised stakes were 0.26, 0.63, and 1.03 pcf corresponding to low, medium and high preservative concentration, respectively, while those for incised stakes were 0.42, 0.97, and 1.41 pcf. Incising improved average retention and performance compared to non-incised stakes, particularly at the medium level of preservative treatment. Ratings for ACA treated stakes were lower than those for CCA-C indicating that CCA-C treated Engelmann spruce heartwood performed better than ACA treated spruce heartwood.

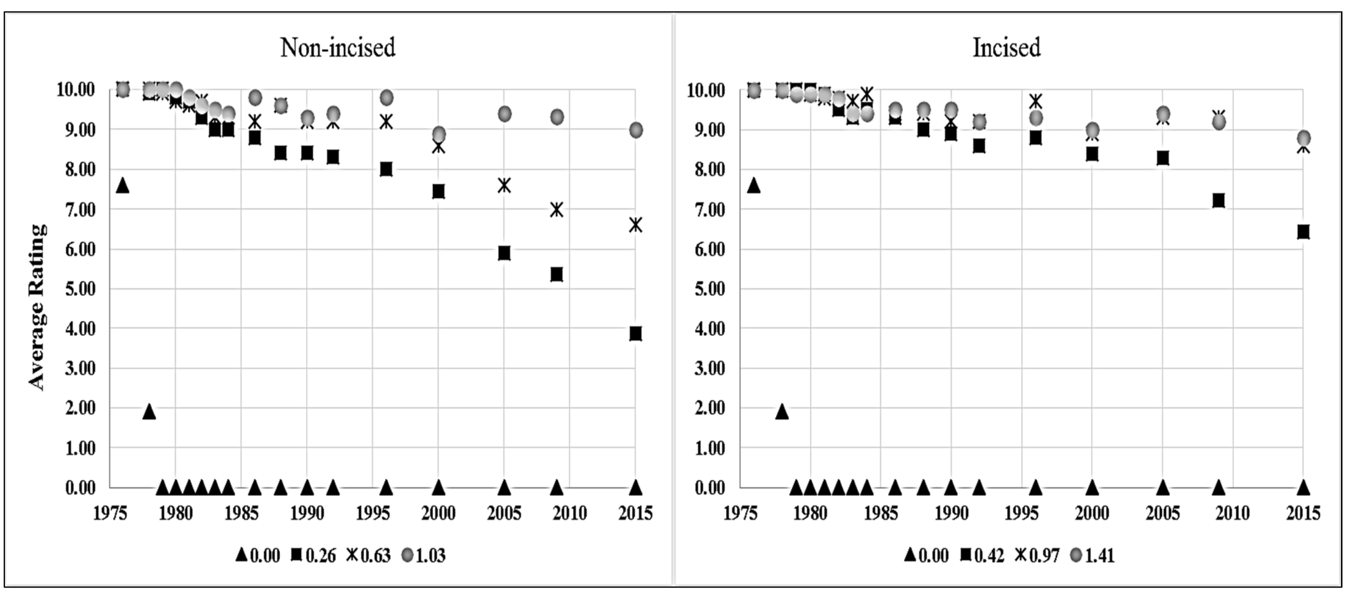

Figure 8. Mean biodeterioration ratings over a 40-year period for non-incised and incised Engelmann Spruce heartwood stakes treated with three retentions of ACA and exposed in a ground contact (AWPA E7) field test in Mississippi.

Figure 9 shows the biodeterioration averages at the 40 years for both CCA-C (left) and ACA (right) treated Engelmann spruce heartwood at the three different preservative levels (see table 1 for average retentions). 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 concentration levels but did not perform as well as Engelmann spruce treated with CCA.

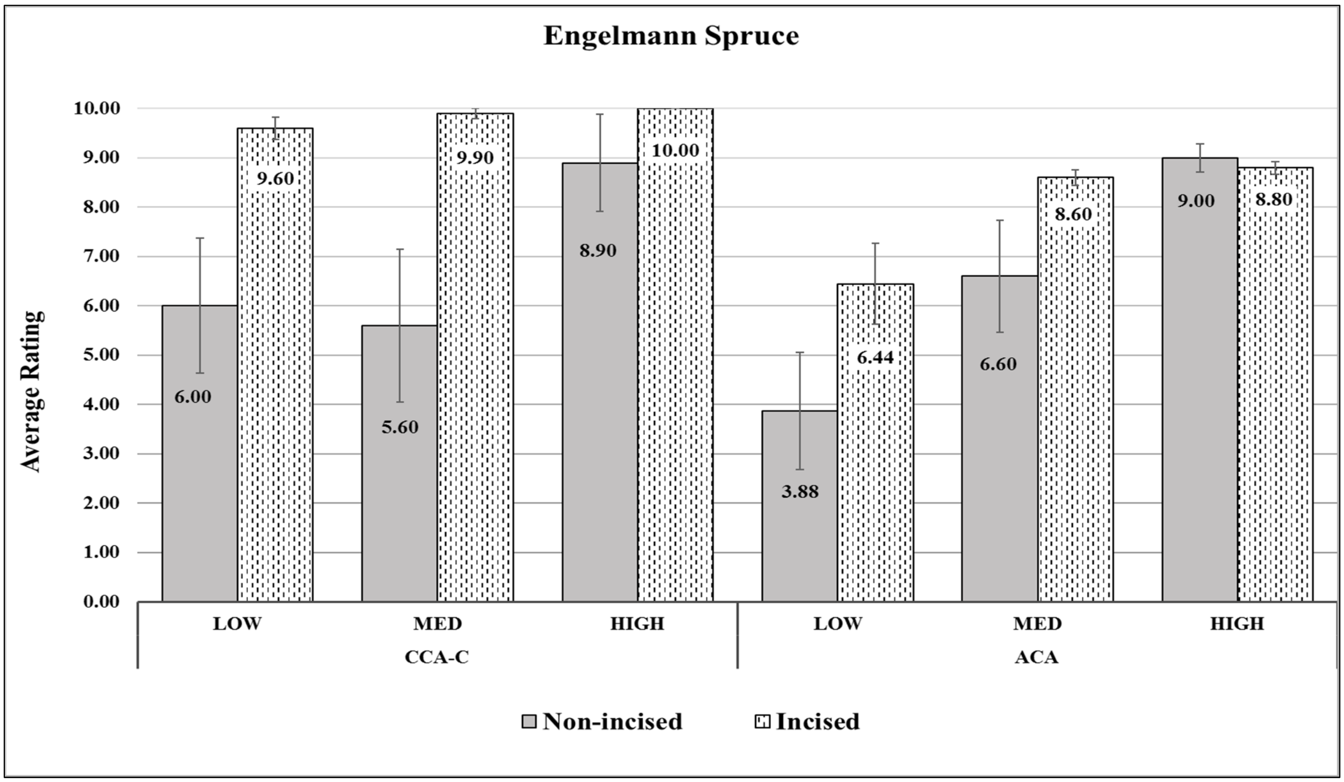

Figure 9. Mean ratings for non-incised and incised Engelmann spruce heartwood stakes treated with three retentions of CCA-C (left) or ACA (right) and exposed for 40 years in a ground contact (AWPA E7) field test in Mississippi.

Discussion

Several trends were apparent when comparing the 40-year durability of incised and non-incised stakes for each wood species and preservative. Perhaps the most notable finding is that all of the wood species were highly durable when incised and treated with medium or high retentions of CCA-C. Another consistent trend was the greater durability of stakes treated with CCA-C relative to those treated with ACA. This finding is somewhat surprising considering that the ACA treated stakes generally had higher retentions and ammoniacal formulations are thought to allow greater penetration of refractory wood species (Freeman and McIntyre 2008). However, a similar trend is being observed for ACA or CCA-C treated eastern white pine, red pine, and eastern spruce 2"x 4" stakes exposed for 24 years at the same test 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 largely 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 6). The efficacy of ACA has also been observed in southern pine 2" x 4" stakes that have performed well for over 60 years when treated to high retentions (Lebow et al. 2013; Woodward et al. 2011).

Douglas-fir stakes appeared to be the most durable species but this finding is 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).

Some of the differences in durability of stakes treated with ACA and CCA-C may be attributable to the relative leach resistance of the active ingredients. Although CCA-C and ACA both rely on copper and arsenic for decay and termite resistance, there are substantial differences in how the preservatives are formulated and how the copper and arsenic are stabilized or "fixed" in the wood. 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 and Hartford 1972; Hingston et al. 2001; Lebow 1996; Pizzi 1981; Pizzi 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 and 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 and Coleman 1981; Lebow and 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).

CONCLUSIONS

Southern pine heartwood was more difficult to treat than the Douglas-fir or Engelmann spruce. Incised CCA-C-treated southern pine heartwood performed better at low and medium retentions compared to non-incised southern pine. Incised ACA-treated pine performed slightly better than non-incised southern pine heartwood. Incising had little effect on Douglas-fir heartwood treated with CCA-C or ACA. Incised CCA-C- and ACA-treated Engelmann spruce heartwood performed better at low and medium retentions compared to non-incised spruce heartwood. 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.

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REFERENCES

1. American Wood-Preservers' Association. 2003. C22-03. Lumber and plywood for permanent wood foundations-preservative treatment by pressure processes. Book of Standards, American Wood-Preservers' Association, Selma, AL. 522p.
2. American Wood Preservers Bureau Standard. 1975. Quality control program for softwood lumber, timber, and plywood pressure treated with water borne preservatives for ground contact use in residential and light commercial foundations. FDN 75. AWPB, Arlington, VA.
3. American Wood Preservers Institute. 1972. All weather pressure-treated wood foundation: A new approach to reduce housing costs. AWPI, McLean, VA.
4. American Wood Protection Association. 2016. AWPA book of standards. American Wood Protection Association. Birmingham, AL.
5. Bendtsen, B. A., and Eslyn, W. E. 1966. House foundation of treated wood after 30 years' service. USDA Forest Serv. Res. Pap. FPL-98. Forest Prod. Lab., Madison, WI.
6. Best, C.W. and Coleman, C.D. 1981. AWPA Standard M11: An example of its use. In: Proceedings, American Wood Preservers' Association; 77: 35–40.
7. Clark, J. W. 1957. Comparative decay resistance of some common pine, hemlock, spruce, and true fir. Forest Sci 3(4), 314-320.

8. Dahlgren, S.E. and Hartford, W.H. 1972. Kinetics and mechanism of fixation of Cu-Cr-As wood preservatives. Part I. pH behaviour and general aspects of fixation. Part II. Fixation of Boliden K33. Part III. Fixation of Tanalith C and comparison of different preservatives. Holzforschung. 26: 62–69, 105–113, and 142–149.
9. Gjovik, L.R. 1983. Treatability of southern pine, Douglas-fir, and Engelmann spruce heartwood with ammoniacal copper arsenate and chromated copper arsenate. Proceeding of the American Wood Preservers' Association. 1983. Pp 18-30.
10. Gjovik, L.R., and Baechler, R. H. 1970. Treated wood foundations for buildings. Forest Prod. J. 20(5), 45-18.
11. Gjovik, L.R., and Davidson, H. L. 1979. Comparison of wood preservatives in Mississippi post study. USDA Forest Serv. Res. Note FPL-01. Forest Prod. Lab., Madison, WI.
12. Gjovik, L.R., and Davidson, H. L. 1982. Comparison of wood preservatives in stake tests. USDA Forest Serv. Res. Note FPL-02. Forest Prod. Lab, Madison, WI.
13. Freeman, M., and McIntyre, C. 2008. A comprehensive review of copper-based wood preservatives. Forest Prod. J. 58(11):6–27.
14. Hingston, J. A., Collins, C. D., Murphy, R. J. and Lester, J. N. 2001. Leaching of chromated copper arsenate wood preservatives: A review. Environ. Pollut. 111:53-66.
15. Lebow, S.T. and Morrell, J.J. 1995. Interactions of ammoniacal copper zinc arsenate (ACZA) with Douglas-fir. Wood and Fiber Science, 27(2):105-118.
16. Lebow, S. 1996. Leaching of wood preservative components and their mobility in the environment—Summary of pertinent literature. Gen. Tech. Rep. FPL–GTR–93. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 36 p.
17. Lebow, S., Woodward, B., Kirker, G., and Lebow, P. 2013. Long-term durability of pressure-treated wood in a severe test site. Advances in Civil Engineering Materials 2(1): 178–188.
18. Lebow S., Lebow P., Woodward, B., Kirker, G. Arango, R. 2015. Fifty-Year Durability Evaluation of Posts Treated with Industrial Wood Preservatives. Forest Prod. J. 65(7/8):307–313.
19. Morris, P. I., McFarling, S.M., and Zahora, A.R. 2002. Treatability of refractory species with amine and amine/ammoniacal formulations of ACQ. Forest Prod. J. 52(10):37-42.
20. National Forest Products Association. 1973. All weather wood foundation system: design fabrication-installation manual. NFPA, Washington, D.C.
21. Percival, D. H. 1968. The potentiality of pressure treated wood foundations for residential construction. Proc. AWPA 64, 39-44 (1968).
22. Pizzi, A. 1981. The chemistry and kinetic behaviour of Cu-Cr-As/B wood preservatives. I. Fixation of chromium on wood. Journal of Polymer Science. Chemistry Ed. 19: 3093–3121.
23. Pizzi, A. 1982. The chemistry and kinetic behaviour of Cu-Cr-As/B wood preservatives. II. Fixation of the Cu/Cr system on wood. III. Fixation of a Cr/AS system on wood. IV. Fixation of CCA to wood. Journal of Polymer Science. Chemistry Ed. 20: 707–724,725–738,739–764.
24. Ruddick, J.N.R. 1996. The fixation chemistry of ammoniacal copper wood preservatives. In: Proceedings, American Wood Preservers' Association; 77: 32–49.
25. Weaver, F. W, and Levi, M. P. 1979. Treatability of southern pine and Douglas-fir heartwood with creosote, modified creosote, chromated-copper arsenate, and ammoniacal-copper-arsenate. Proc. AWPA 75, 176-187.
26. Woodward, B. M., Hatfield, C. A., and Lebow, S. T. 20111. "Comparison of Wood Preservatives in Stake Tests: 2011 Progress Report," Research Note FPL–RN–02, U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, WI, 2011.

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