Boron Distribution in Green Timbers Pre-treated with Boron Rods Followed by Creosote: 130 Week (2.5 year) Report

Mark E. Mankowski
Craig Bell
USDA, Forest Service, Forest Products Laboratory
Starkville, Mississippi

Grant Kirker
USDA Forest Service Forest Products Laboratory
Madison, Wisconsin

Gerald Presley
Matthew Konkler
Oregon State University
Corvallis, Oregon

James Renfroe
Wood Care Systems
Kirkland, Washington

Jeffrey J. Morrell
University of the Sunshine Coast
Brisbane, Australia

ABSTRACT

Unseasoned (green) red and white oak bridge timbers and crossties were pre-treated with boron rods installed at equal distances along the length of the timbers. Moisture content and boron levels were examined at 15, 30, 50, 80, and 130 weeks after rod installation and subsequent treatment with creosote. Moisture content for both wood species remained high (above 50%) for the duration of the test period, well above the 30% moisture content needed for boron diffusion. Passive dual treatment with fused borate rods resulted in high boron loadings in both hardwood species, particularly in the longitudinal direction from rod installation points. Boron levels were lower in the outer tangential locations away from where rods were placed. Substantial longitudinal boron diffusion was observed for white oak, suggesting supplemental treatment of low permeability hardwoods may be possible using this preservative system.

INTRODUCTION

The premature replacement of large bridge timbers and railroad crossties is very costly and labor intensive, thus extending their service life is of great importance (Edlund, et al., 1983; Amburgey and Sanders, 2009; Kitchens and Amburgey, 2015; Kim and Lloyd, 2017). Traditional creosote treatment of these wood products can be aided by an initial treatment with soluble borate applied via dipping or pressure treatment. The diffusible boron penetrates through the wood and gives added internal protection after the timber or tie is then over treated with creosote. This dual treatment has been shown to greatly extend the service life of the treated wood, especially in high biodeterioration hazard areas (Amburgey and Sanders, 2009; Kitchens and Amburgey, 2015). In 2012, the AWPA standardized dual creosote-borate treatments, specifying that borate pre-treatment retention must reach 0.17 PCF B_2O_3, which is equivalent to approximately 0.30 PCF BAE (boric acid equivalent). The borate treated member is then over treated with the regular AWPA standard retention of creosote or copper naphthenate (AWPA, 2018).

Even though the dual treatment process is now commonly used in the wood treatment industry, some facilities cannot perform this type of treatment because of the added costs associated with the installation of an additional pressure cylinder or dipping system for the initial borate treatment. One alternative is an internal treatment with borates via non-pressure applications similar to those used in remedial treatments of wood in-service. Substantial boron diffusion occurs when a boron source is added to ports drilled into timbers prior to pressure-treatment with copper naphthenate (Lloyd, et al. 2015). Some remedial borate treatments use more concentrated boron in the form of a fused borate rod, which can readily dissolve at wood moisture contents (MCs) above 30% (Smith and Williams, 1969; Morrell, et al., 1992; Morrell and Schneider, 1995; DeGroot, et al., 2000; Cabrera and Morrell, 2009). These rods are solid, fused borate containing 98% disodium octaborate tetrahydrate (DOT) and have been shown to readily diffuse in the remedial treatment of utility poles or timbers in service (Morrell and Schneider, 1995; DeGroot, et al., 2000). Other studies showed that fused borate rods diffused in treated timbers and that boron levels could be monitored using increment cores removed at various longitudinal and transverse points from the rod application point (Highley and Ferge, 1995; Mankowski, et al., 2019; 2020). Borate rods installed in green, high moisture content timber before the creosote or copper naphthenate treatment would most likely continue to diffuse after creosote treatment and after the member reaches its installation point. Rods placed at regularly spaced locations along the length of a large timber would allow boron to diffuse throughout the timber and potentially reach levels needed to prevent decay and insect attack.

This study objective was to examine a cost-effective method for dual treatment that could be utilized by smaller wood treating operations that cannot afford to install equipment for borate pressure treatment. Given that boron diffuses readily at MCs above 30%, we evaluated boron diffusion from borate rods placed in wet, freshly cut red and white oak bridge timbers and crossties, which were then overtreated with creosote over a 130 week (2.5 year) exposure period at a severe biodeterioration zone test site (Saucier, MS).

MATERIALS AND METHODS

Timbers and borate rods were supplied by Wood Care Systems (Kirkland, WA). Five red oak (*Quercus rubra* L.) and 6 white oak (*Quercus alba* L.) timbers measuring 10in x 10in x 10ft (25.4cm x 25.4cm x 304.8 cm) were treated with borate rods. The rods measured 3 inches (7.63 cm) long and ¾-inch (1.9 cm) in diameter. Rods were placed in pre-drilled 5-inch (12.7 cm) deep ¾-inch (1.9 cm) holes spaced 13 ¼ inches (33.7 cm) apart along the length of green timbers. Three red oak and three white oak crossties measuring 9in x 9in x 10ft (22.9cm x 22.9cm x 304.8 cm) were treated with borate rods at a similar spacing to the bridge timbers described above. Number and spacing of rods were calculated to deliver a target boron retention of 0.10 PCF BAE. A total of 9 rods were used per bridge timber and a total of 5 rods were used per crosstie. Bore holes were plugged and the timbers were then pressure treated with creosote. In an earlier paper (Mankowski, et al., 2019), we had used a target loading of 0.17 PCF B_2O_3 but re-calculated our target boron loadings for this paper in PCF BAE and compensated for wood species density in our updated analyses.

Holes were drilled in line with the center of all timbers and crossties. Rods were inserted into pre-drilled holes that were sealed with an inch long ¾-inch (1.9 cm) diameter plastic plug. The unseasoned ties were subjected to an 18-22" Hg vacuum while filling the treatment cylinder with hot creosote. The timbers were boiled in the cylinder for 12 hours (Boultonized) after which the hot creosote oil was drained and a pressure of 40 psi applied to the wood. Hot creosote oil was then pumped into the cylinder and the pressure was raised to approximately 200 psi. The pressure was maintained for 12 hours until the AWPA gauge retention of 8.0 PCF for creosote was reached. The charge gauge retention was determined by dividing the weight of solution consumed by the total volume of wood in the charge. Once the desired gauge retention was achieved, the pressure was released, the solution was drained and a final vacuum of 18-22" Hg was drawn to recover excess solution, relieve internal pressure, and minimize post-treatment dripping. The freshly treated timbers were set on a drip pad under cover for 24 hours or until no dripping was observed. The assumption was that moisture in the interior of the timber would remain high during this process (80-100%) ensuring the initiation of boron diffusion after the creosote over treatment, as boron rods dissolve at or above the fiber saturation point (30%). The treated timbers were shipped to the Harrison Experimental Forest located in the Desoto National Forest near Saucier, Mississippi, where they were placed in the field test in September of 2018. Timbers were placed in an open field directly on the ground approximately two feet apart with plugged rod holes facing upward.

Moisture content of the timbers and crossties was measured 6 weeks after treatment by taking two 6-inch cores from each timber. Cores were placed in plastic drinking straws, with one end pre-stapled shut. The open end was then stapled shut in the field. The straws were placed in a plastic zip-lock bag to minimize moisture loss, kept on ice, and transported to the FPL laboratory in Starkville, MS. The cores were removed from the straws, weighed, and then dried at 60°C for 24 hours. This temperature was used as there was a concern that boron may be driven off at higher drying temperatures. The cores were conditioned in a desiccator for 5-10 minutes and then re-weighed to obtain the dry weight.

After 11 weeks, the condition of the borate rods was monitored by removing every other plug from the rod holes on the timbers and examining the rod condition using a flashlight. For the bridge timbers, increment cores were taken in a cruciform pattern from three red oak and three white oak timbers starting at the second rod hole away from the end of the timber (Figure 1). This was initiated at 15 weeks and repeated at the next rod hole from the end of the timber after 30, 50, 80, and 130 weeks (Figure 1). Sampling was conducted in a manner similar to that described by Highley and Ferge (1995), where cores were taken from longitudinal and tangential points in relation to the position of a boron treatment. Six-inch (15.24 cm) long cores were taken with an 8-inch (20.3 cm) increment borer. Cores were taken at 2, 4, and 6 inches (5, 10, 15 cm) in each longitudinal direction from the rod holes (Figure 2). The 6-inch (15 cm) distance cores were positions 1 and 2. The 4-inch (10 cm) distance cores were positions 5 and 6. The 2-inch (5 cm) distance cores were positions 9 and 10. Cores were also taken in the tangential direction from the edge of the rod hole. These cores were 1 ½ inches (3.8 cm) (positions 7 and 8) and 3 inches (7.6 cm) (positions 3 and 4) from the rod hole (Figure 2). Sampling was conducted in a progression that was assumed to be moving from areas of low to high boron concentration. Cores 6 inches from the rod hole were taken first – i.e., positions 1 and 2. The outer 3-inch tangential cores (positions 3 and 4) were taken next and so forth. The cores were carefully pushed out of the increment borer into a plastic drinking straw, stapled closed, bagged, and put on ice. The increment borer was cleaned with deionized water and blown out with canned air in between each sampling to minimize the risk of boron carry-over between samples. Samples were transported to FPL, weighed, dried at 60°C for 24 hours and re-weighed to obtain moisture content.

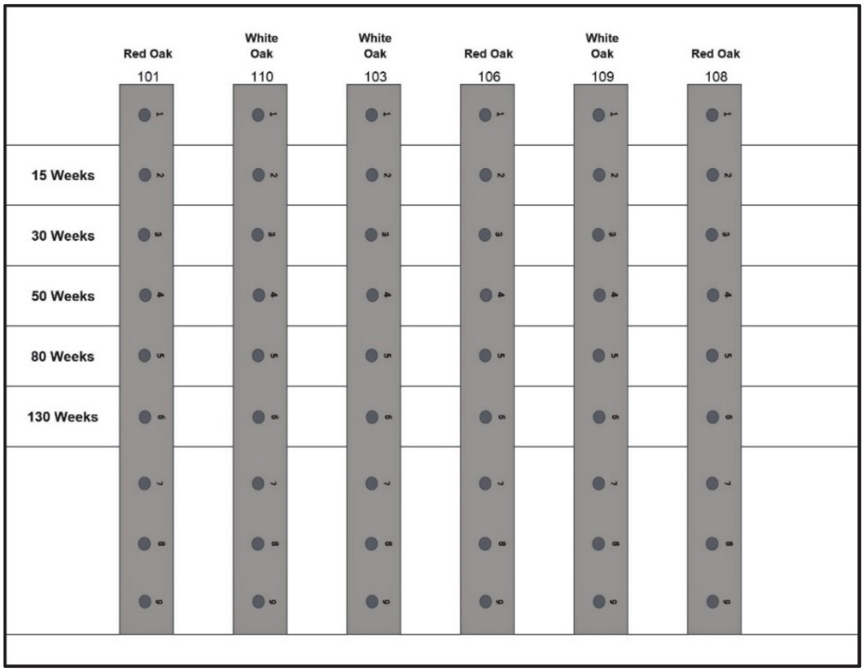

Figure 1. Field placement and sampling time scheme for borate rod and creosote treated bridge timbers placed in the field in Saucier, MS. Crossties were sampled at 50, 80, and 130 week time points.

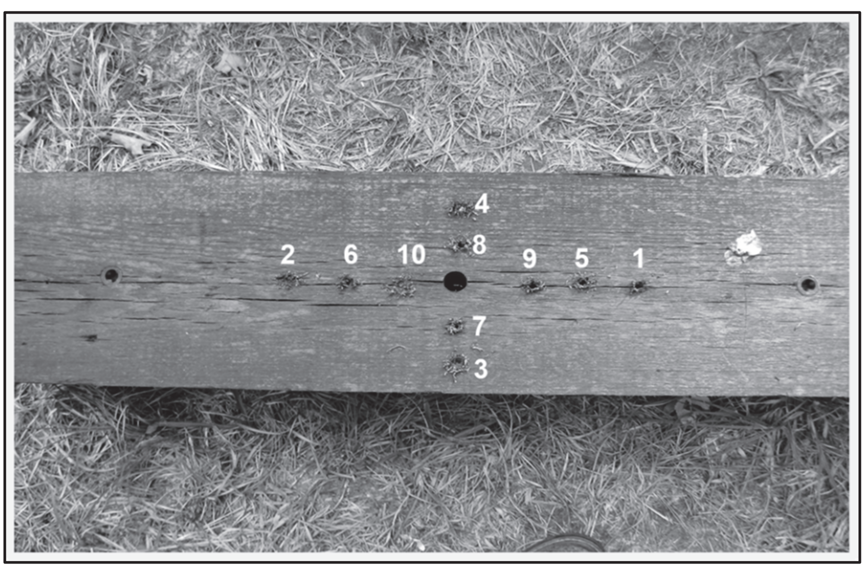

Figure 2. Longitudinal and tangential point sampling pattern around a hole that received a borate rod.

Crossties were sampled similarly to bridge timbers as described above, but with fewer sampling sites and times. Initiation of crosstie core sampling began at 50 weeks and was repeated at 80 and 130 weeks after treatment. At 50 weeks, crosstie cores were taken longitudinally from the rod hole at 4 inches (10 cm) in each direction (Figure 2). The 4-inch (10 cm) distance cores were analogous to positions 5 and 6 in Figure 2. Tangential direction cores were taken 3 inches (7.6 cm) (positions 3 and 4) from the rod hole (Figure 2). Additional sampling points were added at 80 and 130 weeks for the crosstie sampling. At these time periods, we sampled longitudinally from the rod hole at 4 and 6 inches (10, 15 cm) in each direction (Figure 2). The 6-inch (15 cm) distance cores were positions 1 and 2. The 4-inch (10 cm) distance cores were positions 5 and 6. Tangential direction cores for crossties at 80 and 130 weeks were taken at 1 ½ inches (3.8 cm) (positions 7 and 8) and 3 inches (7.6 cm) (positions 3 and 4) from the rod hole (Figure 2).

All dried cores were sprayed with curcumin indicator, allowed to dry for five minutes, then sprayed with salicylic acid indicator to observe boron penetration as per AWPA Standard A78-16 (AWPA, 2021). The cores were then sectioned into inner 3-inch (7.6 cm) and outer 3-inch (7.6 cm) sections that were ground in a Wiley mill to pass a 20-mesh screen (Arthur H. Thomas Co. Philadelphia, USA). Ground inner and outer samples were sent to Oregon State University, where they were processed and analyzed for boron via the Azomethine-H method as described in AWPA Standard A65-21 (AWPA, 2021). In an earlier paper (Mankowski, et al., 2019), we had dissimilar values compared to this analysis as we had not compensated for the difference between wood species density in the boron calculations. Our earlier study also gave boron in PCF B_2O_3 not PCF BAE as we show here.

RESULTS AND DISCUSSION

Rod condition at 11 weeks:

Rod holes in both bridge timbers and crossties were either filled with water and we could not detect the presence of a rod or they were empty indicating the borate rods had completely dissolved within 11 weeks after application.

Moisture Content - Bridge Timbers:

Figure 3 shows the average moisture content for red and white oak bridge timbers 6, 15, 30, 50, 80, and 130 weeks after treatment. Red and white oak had mean moisture contents of 71.0% and 62.8%, respectively, six weeks after treatment. Moisture levels remained above 54% for both species for the test duration. These elevated moisture levels for all periods sampled indicate that conditions were suitable for boron diffusion. It is unknown whether the rods dissolved at all during the creosote treatment process; however, diffusion should have begun almost immediately since initial moisture contents of the timbers were above 60% in both species. Many rod holes inspected 11 weeks after treatment contained water, which most likely further aided in boron diffusion.

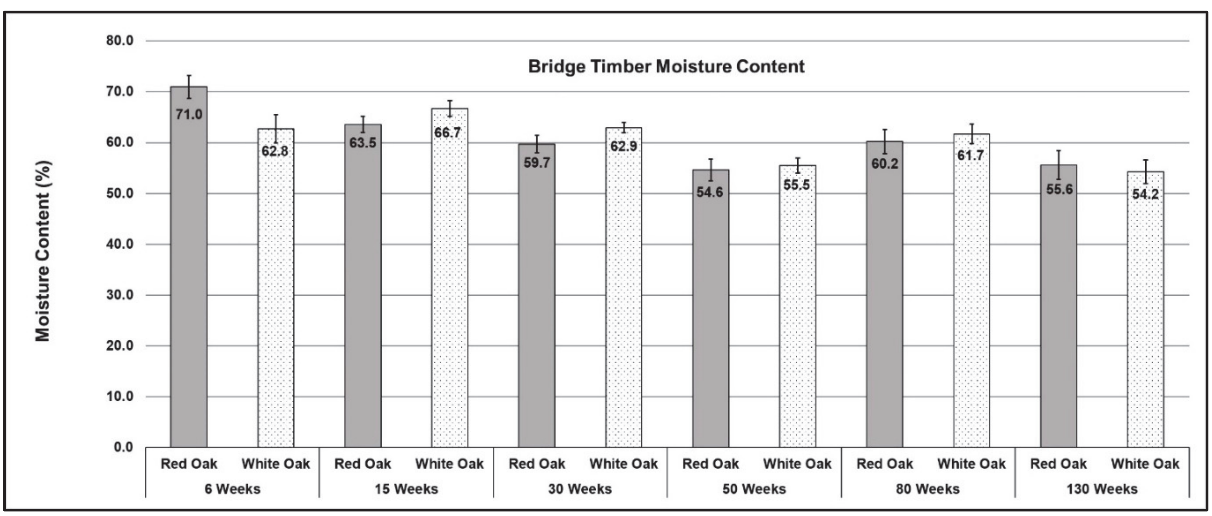

Figure 3. Average moisture contents of red oak and white oak bridge timbers as measured on increment cores removed 6, 15, 30, 50, 80, and 130 weeks after treatment with borate rods and creosote. Timbers were treated green with high initial moisture content.

Moisture Content - Crossties:

Figure 4 shows the average moisture content for red and white oak crossties at 6, 50, 80, and 130 weeks after treatment. Red and white oak had mean moisture contents of 82.2% and 84.0%, respectively, six weeks after treatment. Moisture levels for red and white oak remained above 63.9% and 58.3%, respectively, for the entire test. As with the bridge timbers, moisture levels remained suitable for boron diffusion throughout the test period. The elevated moisture levels provide excellent conditions for boron movement, but they also provide ideal conditions for fungal growth and illustrate the potential long-term benefits of placing boron into the non-creosoted portions of the timbers.

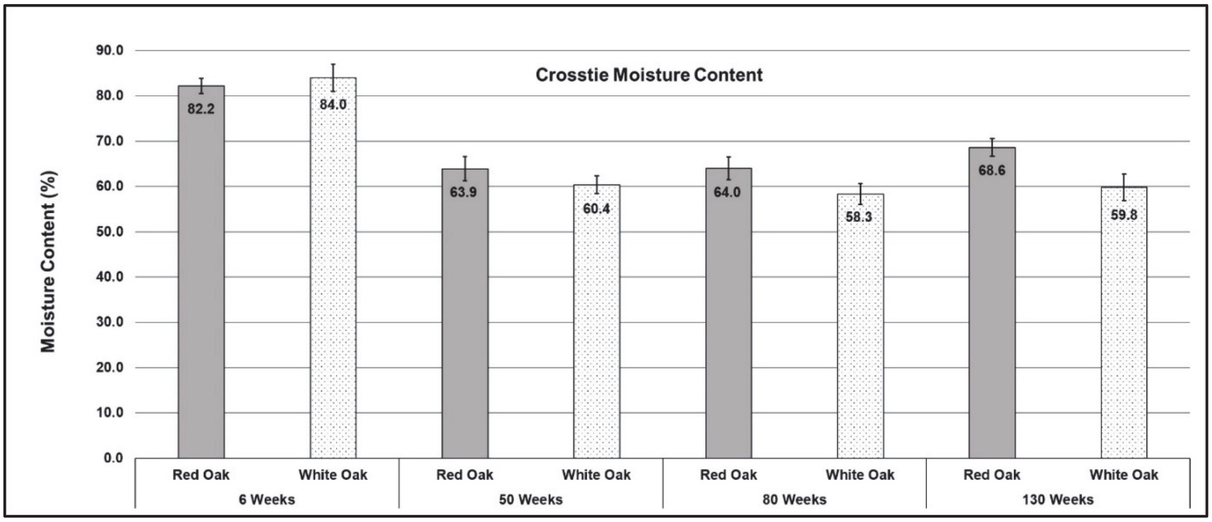

Figure 4. Average moisture contents of red oak and white oak crossties as measured on increment cores removed 6, 50, 80, and 130 weeks after treatment with borate rods and creosote. Timbers were treated green with high initial moisture content.

Boron Indicator:

Boron was well distributed longitudinally from the treatment holes, particularly near the rod hole. The inner core sections were generally stained a darker red, suggesting higher boron levels in the inner part of the timber at longitudinal sample points. We observed very little staining in cores removed from the tangential positions, suggesting reduced boron movement. This was particularly true for core positions 3 and 4 (3 inches (7.6 cm)) (Figure 2) from the bore hole. More intense curcumin staining was observed in the outer longitudinal positions (1 and 2) compared to the mid-way positions (5 and 6). This may have been from overlapping boron fronts from the adjacent rods in the timber or crosstie.

Boron Analysis - Red Oak Bridge Timbers:

Analytical results for boron levels in the core samples removed 15, 30, 50, 80, and 130 weeks after treatment are shown in Figure 5. In an earlier paper (Mankowski, et al., 2019), we had dissimilar values compared to this analysis as we had not compensated for the difference between wood species density in the boron calculations. Our earlier study also gave boron in PCF B_2O_3 not PCF BAE as we show here. The boron levels from all inner and outer cores (n=60) are shown in the far-left columns of the chart. The horizontal dotted line marks the target treatment level for the boron, 0.10 PCF BAE, that was calculated based on rod number and timber volume. Boron levels were also compared for the inner and outer core sections, all longitudinal or tangential samples, and the average of samples taken at each sampling point away from the rod hole (Figure 2). Boron levels were higher in the inner core and longitudinal sampling points compared to the outer core sections and tangential sampling points. These results agree with previous studies showing that boron generally diffuses faster longitudinally versus tangentially (Highley and Ferge, 1995; DeGroot, et al., 2000).

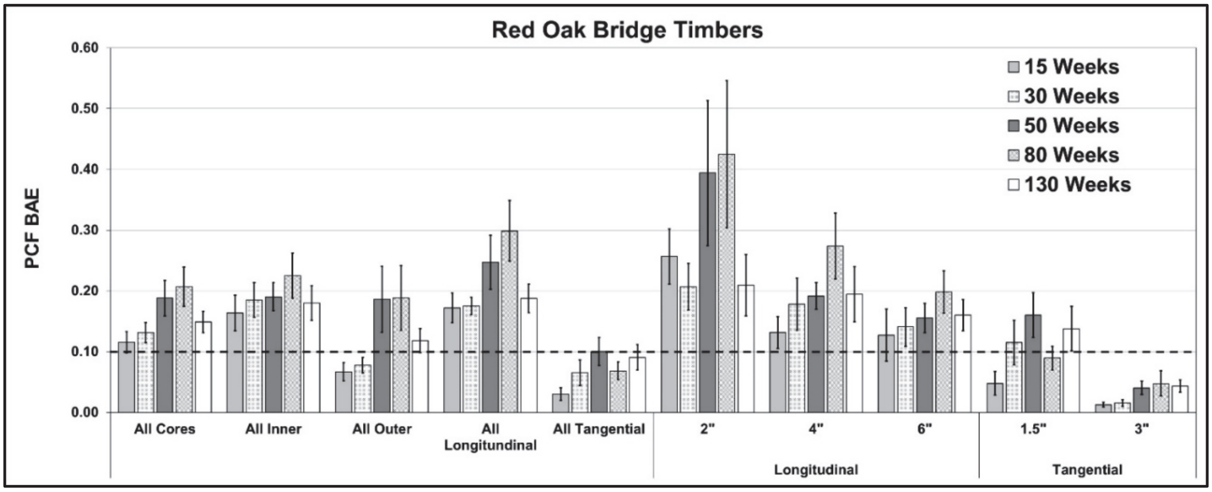

Figure 5. Boron (PCF BAE) levels in increment cores taken at various points away from borate rods inserted in red oak bridge timbers that were then treated with creosote and sampled 15, 30, 50, 80, and 130 weeks after treatment. The horizontal dotted line signifies the target treatment level for boron (0.10 PCF BAE).

Boron Analysis - White Oak Bridge Timbers:

Analytical results for boron levels in the core samples 15, 30, 50, 80, and 130 weeks after treatment are shown in Figure 6. The horizontal dotted line marks the selected target boron treatment level, 0.10 PCF BAE. This was used to calculate the number and size of rods needed based on timber volume. Boron levels from all inner and outer cores (n=60) are shown in the far-left columns of the chart. Results were similar to red oak, except less boron was detected tangentially after 30 weeks in white oak compared to red oak. This is consistent with the major differences in permeability between the two species. Siau (1984) reported longitudinal gas permeabilities for red and white oak as 10^{2} and 10^{-2} Darcy's, respectively, a thousand-fold difference. Tangential permeabilities would be much lower in the range of 10^{-4} and 10^{-6} Darcy's for the same species. The extent of longitudinal boron diffusion in white oak in this study was greater than that reported in previous studies (Morrell, et al., 1992; Highley and Ferge, 1995; Mankowski, et al., 2019; 2020), perhaps because of the higher moisture contents observed in this study. It is also possible that the elevated temperatures used during pressure-treatment aided boron diffusion as suggested by Lloyd, et al. (2015).

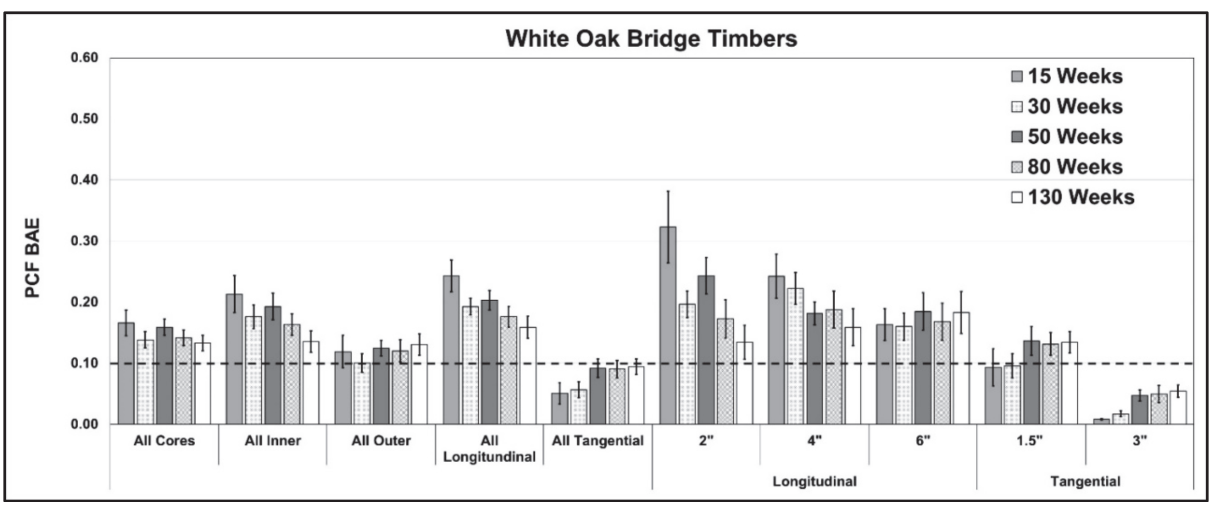

Figure 6. Boron (PCF BAE) levels in increment cores taken at various points away from borate rods inserted in white oak bridge timbers that were then treated with creosote and sampled 15, 30, 50, 80, and 130 weeks after treatment. The horizontal dotted line signifies the target treatment level for boron (0.10 PCF BAE).

Boron Analysis - Red Oak Crossties:

Analytical results for boron levels in the core samples 50, 80, and 130 weeks after treatment are shown in Figure 7. Boron levels from all inner and outer cores (n=60) are shown in the far-left columns of the chart. The horizontal dotted line marks the target treatment level for boron, 0.10 PCF BAE, that was calculated based on rod number and timber volume. Comparisons were also made between boron levels for the inner and outer cores sections, all longitudinal or tangential samples, and the average of samples taken at each sampling point away from the rod hole (Figure 2). As with the bridge timbers, boron levels were higher in the inner core and longitudinal sampling points compared to the outer core sections and tangential sampling points, respectively. These results are supported by previous studies that have documented boron generally diffuses faster longitudinally versus tangentially (Highley and Ferge, 1995; DeGroot, et al., 2000).

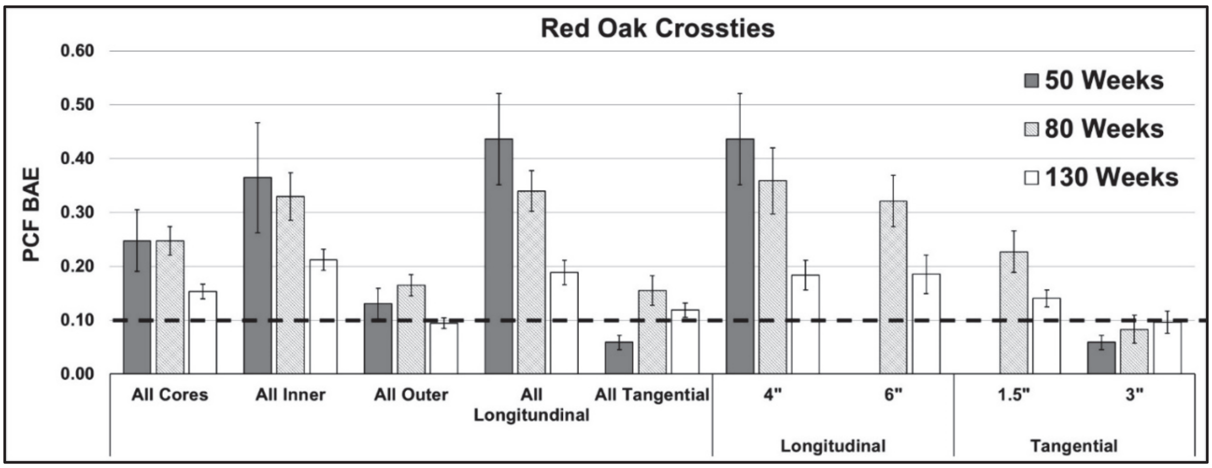

Figure 7. Boron (PCF BAE) levels in increment cores taken at various points away from borate rods inserted in red oak crossties that were then treated with creosote and sampled 50, 80, and 130 weeks after treatment. The horizontal dotted line signifies the target treatment level for boron (0.10 PCF BAE).

Boron Analysis - White Oak Crossties:

Analytical results for boron levels in the core samples removed 50, 80, and 130 weeks after treatment are shown in Figure 8. Boron levels from all inner and outer cores (n=60) are shown in the far-left columns of the chart. Results were similar to red oak crossties, except less boron diffused tangentially after 30 weeks in white oak compared to red oak. Previous studies have indicated that longitudinal boron diffusion in white oak is usually lower than was observed in this study (Morrell, et al. 1992; Highley and Ferge, 1995, Mankowski, et al., 2019; 2020). This may in part be due to the high moisture contents found over the entire course of the study. Lloyd, et al. (2015) observed that elevated temperatures used during pressure-treatment aided boron diffusion. This could potentially be happening in the case of our study as well.

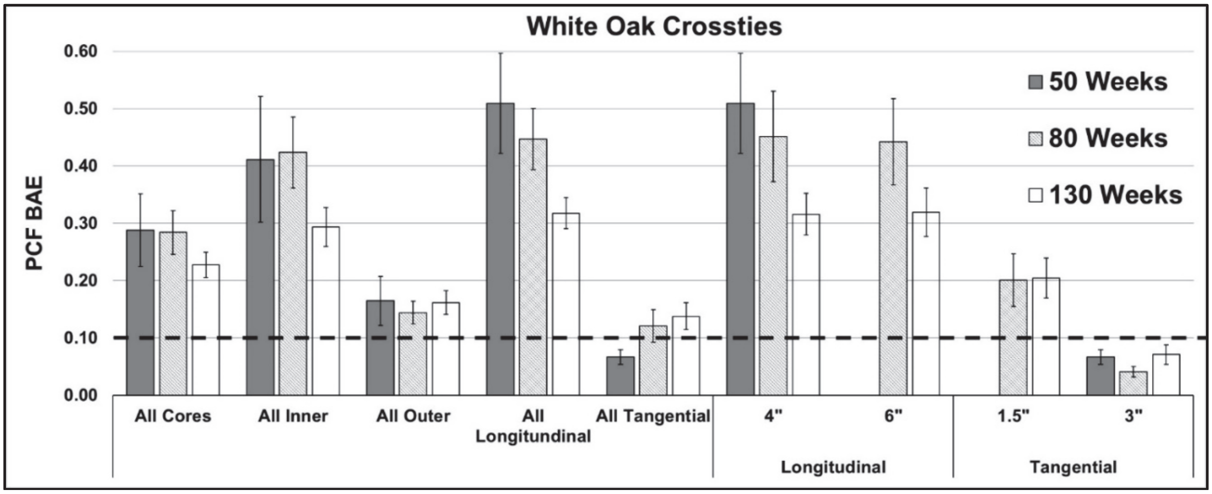

Figure 8. Boron (PCF BAE) levels in increment cores taken at various points away from borate rods inserted in white oak crossties that were then treated with creosote and sampled 50, 80, and 130 weeks after treatment. The horizontal dotted line signifies the target treatment level for boron (0.10 PCF BAE).

CONCLUSIONS

The relatively fast, non-destructive, cruciform sampling pattern was useful for determining qualitative and quantitative boron diffusion and minimized destruction of the entire timbers creating an opportunity for more assessments over time. Passive dual treatment with fused borate rods achieved the target boron loading in the materials tested, but levels were lower in the outer and tangential locations away from where borate rods were placed. Substantial longitudinal diffusion was observed for white oak, which suggests that treatment of low permeability hardwoods may be possible. The moisture content of both red and white oak timbers and crossties remained well above the 30% level needed for boron diffusion even 130 weeks after treatment. As the fused boron rods dissolved, boron moved more longitudinally vs tangentially, which was expected given the higher longitudinal permeability of these species. Boron levels longitudinally from the rod application points decreased in some samples 130 weeks after treatment, suggesting that boron was either redistributing in the wood or being absorbed into the creosote. Of note is that the boron measured tangentially from the treatment sites remained the same or increased slightly after 130 weeks, indicating some continued boron diffusion in this direction.

The lack of boron in the outer, tangential direction from the boron rods suggests that rod installation patterns and dosages may need to be modified to achieve more uniform boron diffusion. It must also be noted that the sampling points represent only a small fraction of the volume of these large timbers. To examine potential boron loss from the timber or crosstie, we plan to analyze soil from under the samples and compare it to soil several meters away.

ACKNOWLEDGEMENTS

The authors would like to thank Shawn Cooper of the FPL in Starkville, MS for assisting with the experimental setup, Chance Parker of the Harrison Experimental Forest for assistance with equipment, and Mike Sanders of Mississippi State University for advisement and assistance with equipment.

REFERENCES

1. Amburgey, T.L. and Sanders, M.G. 2009. Tie dual treatments with TimBor and creosote or copper naphthenate 20 years of exposure in AWPA Hazard Zone 4. Crossties Magazine, pp.20-22.
2. American Wood Protection Association. 2021. A78-16 Standard Method to Determine the Penetration of Boron Containing Preservatives and Fire Retardants. AWPA Book of Standards. American Wood Protection Association. Birmingham, Alabama. p. 299.
3. American Wood Protection Association. 2021. A65-21 Standard Method to Determine the Amount of Boron in Treated Wood Using Azomethine-H or Carminic Acid. AWPA Book of Standards. American Wood Protection Association. Birmingham, Alabama. pp. 283-284.
4. Cabrera, Y. and J.J. Morrell. 2007. The effect of wood moisture content and rod dosage on movement of boron through Douglas-fir heartwood. International Research Group on Wood Protection Document No IRG/WP/07-40431. Stockholm, Sweden.

5. De Groot, R.C., Felton, C.C. and Crawford, D.M. 2000. Distribution of borates around point source injections in wood members exposed outside. (Research note FPL; RN-0275). 5 p.
6. Edlund, M.L., Henningssson, B., Kaarik, A., Dicker, P.E. 1983. A chemical and mycological evaluation of fused borate rods and a borate/glycol solution for remedial treatment of window joinery. International Research Group on Wood Preservation. Document No. IRG/WP/83-3225. Stockholm, Sweden.
7. Highley T.L. and Ferge, L. 1995. Movement of boron from fused rods implanted in southern pine, Douglas-fir, red oak, and white oak timbers. International Research Group on Wood Preservation. Document No. IRG/WP/95-30061. Stockholm, Sweden.
8. Kim, J.W., and Lloyd, J.D. 2017. Borate and copper naphthenate dual treatment of bridge timbers-borate movement over time. International Research Group on Wood Preservation. Document No. IRG/WP/17-40795. Stockholm, Sweden.
9. Lloyd, J.D., Chambers T, Kim, J.W. 2015. The cost effective extension of bridge tie service life –effectively applying borate during Boulton conditioning and treatment with copper naphthenate. Proceedings of the 111th Annual Meeting of the American Wood Protection Association. 111:155.
10. Kitchens, S.C. and Amburgey, T.L. 2015. Oil-borne encapsulation treatments combined with borate treated non-seasoned crossties. Proceedings of the 111th Annual Meeting of the American Wood Protection Association 111:140-146.
11. Mankowski, M.E., Kirker, G., Lebow, S., Renfroe, J., Morrell, J.J. 2019. The use of boron rods as a boron source for dual treated timber. Proceedings of the 115th Annual Meeting of the American Wood Protection Association. 115:44-50.
12. Mankowski, M.E., Konkler, M., Bell, C., Kirker, G., Morrell, J.J., Renfroe, J. 2020. Using boron rods as a source for dual treatment. CROSSTIES. May/June 2020. 2 p.
13. Morrell, J.J. and Schneider, P.F. 1995. Performance of boron and fluoride based rods as remedial treatments in Douglas-fir poles. In: Proceedings, International research group on wood preservation. International Research Group on Wood Preservation. Document No. IRG/WP/95-30070. Stockholm, Sweden.
14. Morrell, J.J., Sexton, C.M. and Archer, K. 1992. Diffusion of boron from fused borate rods through selected woods. Forest Products Journal, 42 (7/8).
15. Siau, J.F. 1984. Transport processes in wood. Springer Series in Wood Science, Springer-Verlag, Berlin. Page 104
16. Smith, D. N. and Williams, A. I. 1969. Wood preservation by the boron diffusion process--the effect of moisture content on diffusion time. J. of the Inst. of Wood Sci. 22(4): 3-10.

PROCEEDINGS

One Hundred Seventeenth Annual Meeting

of the

AMERICAN
WOOD PROTECTION
ASSOCIATION

Omni Nashville Hotel
Nashville, Tennessee
July 27-29, 2021

VOLUME 117

AMERICAN WOOD PROTECTION ASSOCIATION
P.O. BOX 361784 • BIRMINGHAM, ALABAMA 35236-1784 • USA

ISSN 0066-1198

Colin McCown, *Editor*
Jeff Schofield, *Assistant Editor*