Supplemental Treatments for Timber Bridge Components

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Abstract

A series of joint treatments on southern pine, red oak, and yellow-poplar were evaluated. These included treatments applied in holes that were subsequently capped, treatments applied to bolt holes and/or bolts, treatments applied to felt pads located between wooden members, and treatments applied directly to the surfaces of the joints. Water-soluble diffusible systems applied in holes adjacent to joints generally performed more poorly than expected because of the lack of rainfall during the exposure period. The notable exception was a copper-borate paste applied directly to the joint area. Application of a solvent-borne copper naphthenate with or without a water repellent to felt pads was also very effective. Water repellent alone and fumigant treatments gave unsatisfactory performance over the long term.

To simulate hazards encountered by piling, kiln-dried untreated southern pine pole stubs that received various supplemental treatments were placed in the field for 41 months. Upon groundline evaluation of these test specimens, it was noted that seven preservatives or combinations of preservatives looked very favorable. The following treatments yielded sound stubs with no evidence of decay or insect attack: (1) copper-borate paste applied to the surface at and below groundline; (2) copper-borate paste applied to the surface at and below groundline plus boron rods inserted into holes near groundline; (3) copper-borate paste applied to the surface at and below groundline plus fumigant inserted into holes near groundline; (4) pentachlorophenol grease applied to the surface at and below groundline; (5) fluoride paste applied to the surface at and below groundline; (6) fluoride paste applied to the surface at and below groundline plus boron rods inserted into holes near groundline; and (7) fluoride paste applied to the surface at and below groundline plus fumigant inserted into holes near groundline.

All structures require periodic inspection and maintenance to assure a long service life. Highway bridges are no exception, whether they are constructed of wood, concrete, steel, or a combination of materials. Bridges are subjected to a variety of biological and physical agents of deterioration. To minimize the probability of premature failures, inspection and maintenance procedures should be developed for all types of bridges. These procedures should then be documented in manuals and applied by trained personnel to all bridges in a highway system (county, state, or federal) on a regular basis. To prepare such guidelines for wooden bridges, comparisons of alternative maintenance treatments and delivery systems must be evaluated, as was done in this research. By using wood species representative of various groups (e.g., pine, dense hardwood, medium-dense hardwood), the test results from this study can be extrapolated to other species within each group. This approach assures that the research results can be applied across broad geographic regions rather than being regionalized. Within geographic areas, the data derived from this approach will provide a basis for choosing which local wood species could or should be used and how bridges fabricated from them should be inspected and maintained.

Structures constructed with treated wood require periodic inspections and maintenance treatments to continue to perform as designed. With treated wood, one must be aware that untreated heartwood is present within treated

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products, and that protection of the material from biological deterioration can be affected by exposing this untreated material inside of the treated zone to wetting at joints, fastener connections, and materials cut to length at the construction site.

Loss (depletion) of preservative in the treated zone due to leaching or volatilization also affects the durability of treated wood products. For instance, inspections of timber bridges in rural Mississippi conducted by the authors indicated that many bridge support piles were decaying at groundline while others remained sound after 25 years in service with no supplemental preservative treatment (Baileys et al. 1992, Quintana 1994, Daniels et al. 1995). Cores removed from inspected piles were assayed for creosote retention. It was found that nearly all decayed piles had a creosote retention of 5 lb/ft^3 or less, indicating that the initial treatment was not adequate or that excessive loss of preservative via leaching and/or volatilization had occurred. These results indicate that it is important to assay treated wood components for preservative retention during periodic bridge inspections to identify those components requiring immediate supplemental treatments. Bridge inspections should be conducted, and supplemental or maintenance treatments for treated wood should be applied, where the probability of exposure of untreated wood inside the treated zone to biological deterioration agents (or where depletion of preservative within the treated zone) would be expected to be the greatest. These areas of concern with timber bridges would be (1) joints, (2) fastening points, (3) checks and splits, especially on the upper faces of horizontal timbers, and (4) the groundline and tops of piles. Deterioration from metal fastener interaction with wood is an additional concern. An extensive review of the literature related to timber bridges is available (Ritter 1990) and will not be repeated here. For the interested reader, extensive reviews of remedial treatments for wood and wooden structures and components can be found in the literature (Amburgey and Barnes 1997, Barnes 2007). These reviews cover remedial systems and preservatives, modes of action, and other technical aspects of remedial treatments.

The main objective of the tests outlined in this report was to evaluate the effectiveness of alternative supplemental treatments and delivery systems applied at the areas of concern (e.g., joints between members and the groundline area of piles). Performance, distribution, ease of application, and fate of candidate preservatives were the criteria for judging candidate systems. The integration of proven methodologies into a practical, cost-effective maintenance scheme aimed at extending the service life of timber bridges was a secondary objective.

Experimental Procedures

This research included the evaluation of fumigants and delivery methodologies using some systems that are not currently listed as hazardous use. To obtain meaningful data in a reasonable time frame, the supplemental treatments were applied to untreated, rather than treated, wood. In practice, these treatments would be applied to treated construction materials to protect untreated wood inside of the treated zone or to supplement the initial preservative treatments. The post-rail (P-R) test units were exposed to natural inoculum at the Dorman Lake test facility located near the Mississippi State University campus in Starkville.

Test site description

The field test site is located 10 miles south of the Mississippi State University campus in Oktibbeha County, Mississippi. The test site encompasses approximately 20 acres of mixed pine–hardwood forest land on clay–loam soil and receives direct to dappled sunlight. The test site is well established, having been in use for over 50 years. This site is located in American Wood Protection Association (née American Wood-Preservers' Association) Hazard Zone 4 (AWPA 2000).

Joints (P-R units)

Three types of supplemental treatments for joints were evaluated: (1) fumigants; (2) liquid, solid, and paste diffusible preservatives; and (3) liquid water-repellent preservative formulations. In addition, alternative methods of applying treatments were evaluated.

Wood materials.—Since alternative remedial treatments may prove more effective on different wood species, all tests were conducted using untreated southern pine (treatable softwood), southern red oak (dense ring-porous hardwood), and yellow-poplar (medium dense diffuse-porous hardwood). These species/materials represent the diversity covered by the species under evaluation as bridge timbers. As such, they were chosen to act as model systems. Results from these species should be directly applicable to species of similar densities.

Each P-R unit was constructed from untreated nominal 4 by 4 stock. The upright portion of the joint measured 1.5 feet, and the arm, attached at 45°, measured 1.0 foot. Exposed ends of both the upright portions and the arms of all joints were sealed with SEALTITE 60 (ISK Biocides) sealer.[1]

Supplemental treatments.—P-R units were constructed (1) with and without porous pads (felt) placed between the joining timbers (Fig. 1; Amburgey et al. 2007, 2009; Amburgey and Sanders 2008; Sanders and Amburgey 2009); (2) with holes bored adjacent to joints to serve as fumigant or preservative reservoirs; or (3) wood-to-wood joints alone. These configurations tested the efficacy of pads or capped holes as reservoirs for supplemental treatment chemicals. Treatments consisted of injecting or applying a fumigant (WoodFume, Osmose Co.), solvent-borne preservative (copper naphthenate), water-repellent preservative (copper naphthenate plus paraffin), diffusible borate rods (Impel rods, Viance Corp.), waterborne borate preservative (BoraCare, Nisus Corp.), and copper-borate paste (CuRap 20, ISK Biocides). The focus was on the use of candidate systems with lower environmental impact. Test units were placed on specially designed test fences at the Dorman Lake test site (Fig. 2).

The study design is shown in Table 1. Five replications per treatment combination were exposed. Untreated test units without felt pads at joints served as controls.

All holes drilled in P-R units for treatment of joints were 0.8 inch in diameter. Holes for Impel borate rods and CuRap 20 paste were 2 inches deep and at 90° to the surface. Holes for WoodFume were 1.5 inches deep and at 45° to the surface.

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[1] The mention of trade names is for the convenience of the reader only and does not constitute endorsement by Mississippi State University over similar products equally suitable.

Figure 1.—Application of felt pads between members at joint.

Figure 2.—Post-rail units exposed on vertical test fences at the Dorman Lake test site in American Wood-Preservers' Association Hazard Zone 4 (units on right have preservative paste applied to the joint [circle]).

Table 1.—Treatment combinations per species for the study on supplemental treatment of joints.

Configuration	Treatment[a]
Felt pads	Solvent-borne copper naphthenate, water repellent, water-repellent preservative, none
Wood-to-wood	Waterborne borate, copper-borate paste, none
Holes	Fumigant, waterborne borate, borate rod, copper-borate paste, none

[a] Five replications per combination.

All bolts used to fasten the two components of the P-R units together were 0.3-inch-diameter by 7-inch-long bolts with heat shrink tubing (Grainger 3KH59) applied to their shanks to prevent iron degradation and fastened with wing-nuts to facilitate disassembly at inspections. Holes measuring 0.375 inch were predrilled for these bolts. The test units were fastened to a fence using 0.5-inch galvanized carriage bolts either with or without tubing on their shanks to permit direct contact between the bolts and the wood. These bolts were used to test procedures for mediating iron deterioration at fastener points. Iron degradation of wood within holes containing fasteners resembles decay by brown-rot decay fungi and frequently is confused with fungal decay. The iron-mediated deterioration results in instability at fastening points due to increase in the diameters of the bolt holes and a gradual decrease in diameters of the bolt shanks. In this study, remediation of iron deterioration at fastening points was evaluated by (1) using bolts with or without heat-shrink tubing applied to their shanks (physical barrier between iron and wood), (2) dip treating bolts, with and without heat-shrink tubing, in BoraCare (1:1 in water) prior to using the fasteners, or (3) applying BoraCare (1:1) to the walls of the holes for the bolts fastening the units to the fence prior to inserting the fasteners.

All holes for treatment of the P-R units were plugged with Caplug L-11 plugs. All boron rods used in this part of the study were 0.5 inch in diameter by 1.5 inches long. BoraCare solution used for treatment was a 1:1 mixture (1:1 by volume with water) with approximately 6 mL applied per hole. The copper naphthenate solution used was mixed at an 8:1 (1% Cu by weight) ratio (mineral spirits:copper naphthenate). The water-repellent solution contained 1 quart of mineral spirits and 23 g of paraffin wax.

Evaluation.—P-R units were disassembled after 12, 25, and 44 months of exposure and the wood at the joint area and bolt shanks/holes inspected for signs of deterioration. The condition of the joint area was rated from 0 to 5 according to the AWPA (2000) Standard E9–97 scale: 0 = sound; 1 = signs of slight surface decay (trace); 2 = small zones of obvious decay (90% sound); 3 = extensive decay (70% sound); 4 = in danger of complete failure and loss of integrity (40% sound); 5 = failure (as a component in service, the wood will have to be replaced).

Piling

The primary areas of deterioration in thick-sapwood pile species such as southern pine are at the groundline where piles are joined with other timbers or at the upper ends where nontreated heartwood is exposed. Since problems with joints are addressed in the P-R studies, these tests deal with the groundline area of southern pine piles and poles.

Wood species.—Kiln-dried, untreated southern pine poles (6 to 10 inches in diameter) were obtained and cut into 5-foot stubs for use in this test. Stubs were set 1.5 feet in the ground.

Supplemental treatments.—Groundline treatments consisted of fumigants, borate rods, fluoride rods, borate- and fluoride-based paste, and pentachlorophenol grease used either alone or in combination (Table 2).

Table 2.—Treatments used in the pile study.

Treatment	Brand
Fumigant (FA)	WoodFume[a]
Borate rod (BR)	Impel[b]
Copper borate paste (BP)	CuRap 20[c]
BP+BR	
BP+FA	
Penta grease (PG)	
Untreated	
Fluoride paste (FP)	COP-R-PLASTIC[a]
FP+BR	
FP+FA	
Fluoride rods (FR)	FLURODS[a]

[a] Osmose Co.
[b] System Three Resins, Inc.
[c] ISK Biocides.

Treatment of piles (pole stubs).—The fluoride paste was troweled on the surfaces of the pole stubs from 6 inches above the groundline to the lower end (24 in.) and held in place by a polyethylene film stapled over it. The copper-borate paste was applied as ready-to-use bandages that contained the paste and a polyethylene film. In both instances, the film barrier kept the paste from diffusing into the soil surrounding the stubs.

All holes drilled in pole stubs for treatment were 0.8125 inch in diameter. Holes for borate and fluoride rods and fumigant were 3.5 inches deep and at 45° to the surface. All boron rods used in this part of the study were 0.5 inch in diameter by 2 inches long. All fluoride rods used in this part of the study were 0.5 inch in diameter by 3 inches long. Holes were placed at three points around the circumference of the pole stubs approximately 4 to 6 inches above the groundline. Holes for treatment in the pole stubs were plugged with Caplug L-11 plugs. Pole stubs had a ProTop (Bayne Co., Spokane, WA) cap placed on the top to protect the end grain from rain wetting (Fig. 3).

Evaluation.—All stubs were installed on a 10-acre test site adjacent to the Forest Products Laboratory in Starkville, Mississippi. At the conclusion of the first year, a representative pole stub from each treatment group was removed from the test and visually examined, and a cross section was cut from each at groundline. These samples were inspected for biodeterioration. All other pole stubs were inspected in place for decay and insect damage after excavating 6 to 8 inches of soil from their perimeters. At the conclusion of the second year, all the remaining pole stubs were removed from test and visually evaluated for decay and/or insect damage, then reinserted into their holes. All pole stubs were removed and the test completed at the 41-month inspection. The 0 to 5 rating scale described previously was used for all visual inspections.

Results and Discussion

P-R units

The group average condition for the P-R units after the 12-, 25-, and 44-month inspections is given in Table 3. Typical performance is shown in Figures 4 and 5. Ratings for treatments applied to holes are compared with untreated P-R units in Figure 6. For yellow-poplar, no treatment applied in holes was considered effective, with an average rating across all treatments of 2.85 after 44 months of exposure. Across all species, the waterborne borate (average = 1.27) and boron rod (1.33) treatments were shown to be most effective. The waterborne borate was the most effective treatment applied to holes for red oak. It was also the most effective treatment for southern pine. Fumigant treatment was not long-lived on any species, as is clear from the 44-month ratings. This likely was due to the short lengths of the P-R members, which permitted loss of fumigant. Work with refractory pole species indicates a longer-lived effectiveness for fumigants (Morrell et al. 2004).

The copper-borate paste applied in holes near the joint was effective on red oak but, surprisingly, yielded poor results for pine. The reason for this anomaly may be the lack of rainfall during the study period. Diffusion treatments require free water, as is clear from the articles in two international proceedings dealing with diffusible preserva-

Figure 3.—Installation of caps and pole stubs in the test plot.

tive systems (Hamel 1990, Forest Products Society 1997). The average annual rainfall during the exposure period was 1,336 mm compared with the average for the 4 years after the exposure period of 1,543 mm. Two of the years during the exposure period were extremely dry compared with the norm, with average rates less than 1,270 mm/y. Treatments were most effective on red oak followed by southern pine (0.65 vs. 1.65 average rating). Fumigant treatments looked promising during the first 2 years of exposure, but performance decreased after 3.5 years, suggesting that fumigants, if not influenced by the short test unit lengths, would need to be renewed on a 2- to 3-year cycle.

A comparison of systems applied to felt pads (Fig. 7) included a water repellent and a 1 percent copper naphthenate solution with and without water repellent. The copper naphthenate treatments with or without water

Table 3.—Average index of condition for post-rail units by species and treatment for three exposure periods.

Species	Treatment[a]	Location	Index of condition for 3 exposure periods[b] 12 mo	25 mo	44 mo
Red oak	Untreated	—	0.2 (0.4)	0.8 (0.8)	1.0 (0.7)
	CuNap	Felt	0.0	0.2 (0.4)	0.2 (0.4)
	CuNap+WR	Felt	0.0	0.0	0.0
	Untreated	Felt	0.0	2.0 (1.2)	2.0 (1.2)
	WR	Felt	0.4 (0.5)	1.6 (0.9)	2.8 (0.8)
	BoraCare	Hole	0.0	0.0	0.2 (0.4)
	Boron rods	Hole	0.2 (0.4)	0.4 (0.5)	0.6 (0.5)
	CuRap	Hole	0.0	0.4 (0.5)	0.4 (0.5)
	Woodfume	Hole	0.4 (0.5)	0.6 (0.5)	1.4 (0.9)
	BoraCare	Wood–wood	0.0	0.4 (0.5)	0.8 (1.1)
	CuRap	Wood–wood	0.0	0.0	0.0
Southern pine	Untreated	—	0.2 (0.4)	2.6 (0.9)	2.6 (0.9)
	CuNap	Felt	0.0	0.0	1.0 (1.2)
	CuNap+WR	Felt	0.0	0.0	0.4 (0.5)
	Untreated	Felt	0.0	1.6 (1.5)	2.8 (1.6)
	WR	Felt	0.0	4.0 (1.0)	4.0 (1.0)
	BoraCare	Hole	0.4 (0.5)	0.8 (0.8)	0.8 (0.8)
	Boron rods	Hole	0.0	0.4 (0.9)	1.2 (1.1)
	CuRap	Hole	0.4 (0.5)	2.2 (1.6)	3.0 (1.2)
	Woodfume	Hole	0.0	0.0	1.6 (1.5)
	BoraCare	Wood–wood	0.0	0.0	0.8 (0.8)
	CuRap	Wood–wood	0.0	0.0	0.0
Yellow-poplar	Untreated	—	0.2 (0.4)	1.4 (1.3)	2.2 (0.8)
	CuNap	Felt	0.0	0.0	0.8
	CuNap+WR	Felt	0.0	0.0	0.8
	Untreated	Felt	1.2 (0.8)	3.0 (1.5)	3.6 (1.6)
	WR	Felt	0.8 (0.4)	3.6 (0.5)	3.8 (0.4)
	BoraCare	Hole	0.4 (0.5)	2.8 (0.8)	2.8 (0.8)
	Boron rods	Hole	0.6 (0.9)	2.0 (1.2)	2.2 (0.8)
	CuRap	Hole	1.2 (0.4)	2.4 (0.9)	2.6 (0.5)
	Woodfume	Hole	1.0 (0.7)	3.4 (0.9)	3.8 (0.4)
	BoraCare	Wood–wood	0.0	1.8 (1.3)	2.8 (0.8)
	CuRap	Wood–wood	0.0	0.0	0.0

[a] CuNap = copper naphthenate; WR = water repellent.

[b] 0 = no decay; 5 = failure. Each value is the average (standard deviation).

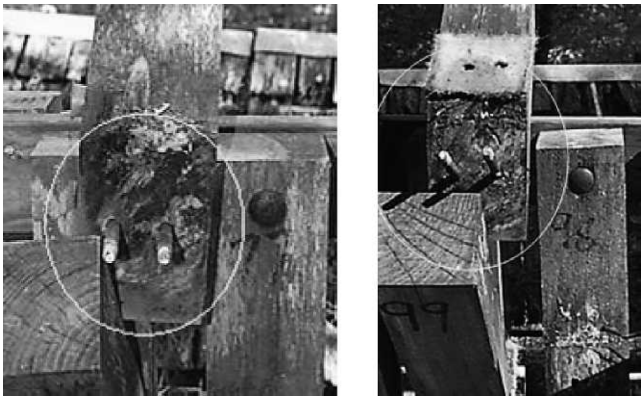

Figure 4.—Extensive decay (left) and insect damage (right) in yellow-poplar test units with water repellent–treated pads in the joints after 2 years of exposure.

repellent were by far the most effective treatments for all species. The addition of a water repellent alone generally decreased performance compared with controls since they provided no biocide to prevent decay and no water repellency to the wood.

In joints constructed without felt pads, the copper-borate paste troweled into the joints was completely effective for all wood species (Fig. 8). Recall that copper-borate paste performance when applied to holes was rather poor. This seems to indicate that there was not enough moisture to move the copper-borate paste into the joints from the adjoining holes; whereas, movement did occur when the copper-borate paste was applied directly to the joint. In practice, the copper-borate paste could be applied to joints using a modified grease gun. Results indicate that this procedure would significantly decrease decay at joints if it was a part of a regular maintenance program. The waterborne borate system was effective in southern pine and red oak but ineffective with yellow-poplar.

Figure 5.—Post-rail units exhibiting poor (left) and excellent (right) performance after 44 months of exposure.

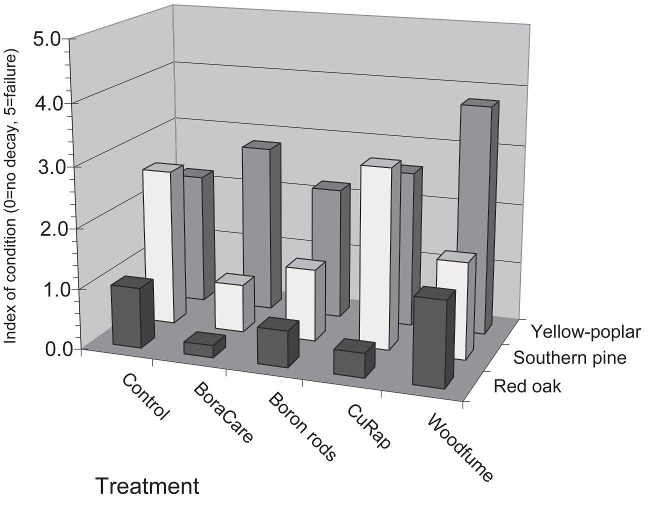

Figure 6.—Comparison of effectiveness of treatments applied to holes adjacent to joints in post-rail test units after 44 months of exposure.

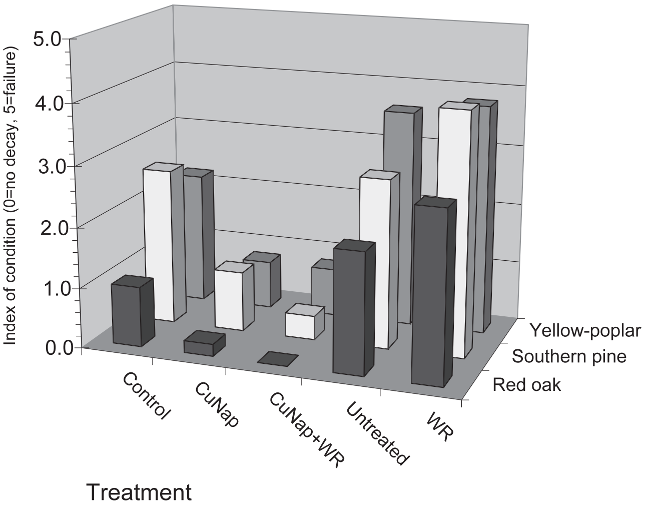

Figure 7.—Comparison of performance ratings for treatments applied to felt pads at joints in post-rail (P-R) test units after 44 months of exposure. Controls are untreated P-R units with no felt pad at the joint. Untreated refers to nontreated felt pads at joints in P-R units. CuNap = copper naphthenate; WR = water repellent.

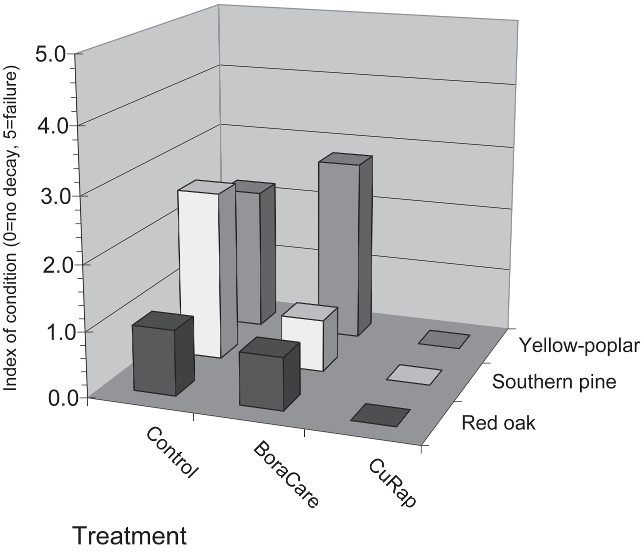

Figure 8.—Comparison of treatments applied directly to the wood–wood joints in post-rail test units after 44 months of exposure.

Iron deterioration at fastener points did not occur in units whose bolt shanks were fitted with heat-shrink tubing, but the unprotected bolt heads and nuts corroded in those exposed in oak test units. The shanks of bolts not protected with heat-shrink tubing had corrosion, especially those in oak test units. Corrosion was significantly less in bolts without heat-shrink tubing that had been dipped in BoraCare prior to use and/or the bolt holes had been treated with BoraCare (Fig. 9). These procedures should be considered when specifying fasteners for bridges and other exposed framing, especially when the structures involved are near salt water.

Piling

Very little decay activity was noted in pole stubs after 9 months of exposure (Table 4). At 22 months there was a sharp increase in the number of pole stubs colonized by decay fungi. No insect damage was noted in any of the test specimens. Each pile was rated individually and group averages were calculated for each treatment group for the three exposure periods (Table 4). Figure 10 shows a typical failed pole. Pole stubs treated with in-place treatments containing pastes or grease, alone or in combination with other treatments, remained sound after 41 months of exposure. These results can be seen in Figure 11 and illustrate the effectiveness of pentachlorophenol grease and boron- or fluoride-containing paste systems. Figure 12 shows typical performance of boron and fluoride rods after 22 months in service. Except for the fumigant–boron rod treatment combination, these treatments performed no better than the untreated controls (Table 4). As with the P-R study, the short length of the pole stubs likely was responsible for the loss of fumigant used to treat them.

Table 4.—Index of condition for timber piles after three exposure periods.

Treatment	Index of condition for 3 exposure periods[a] 9 mo[b]	22 mo[c]	41 mo[c]
Untreated	0.0	3.5 (1.3)	3.8 (1.3)
Fumigant (FA)	0.0	2.0 (0.8)	3.5 (1.0)
Borate rod (BR)	0.0	2.3 (1.0)	3.8 (0.5)
Copper borate paste (BP)	0.0	0.0	0.0
BP+BR	0.0	0.0	0.0
BP+FA	0.0	0.0	0.0
Penta grease (PG)	0.0	0.0	0.0
Fluoride paste (FP)	0.0	0.0	0.0
FP+BR	0.0	0.0	0.0
FP+FA	0.0	0.0	0.0
FA+BR	0.0	1.5 (1.7)	1.5 (1.7)
Fluoride rod	0.0	3.3 (1.0)	3.8 (0.5)

[a] 0 = no decay; 5 = failure.

[b] Each value is the average (standard deviation) of five replicates.

[c] Each value is the average (standard deviation) of four replicates.

Summary and Conclusions

Joints

Treatments applied directly to the joint area or to felt pads in southern pine and red oak generally out-performed water-soluble, diffusible systems in this study. It should be

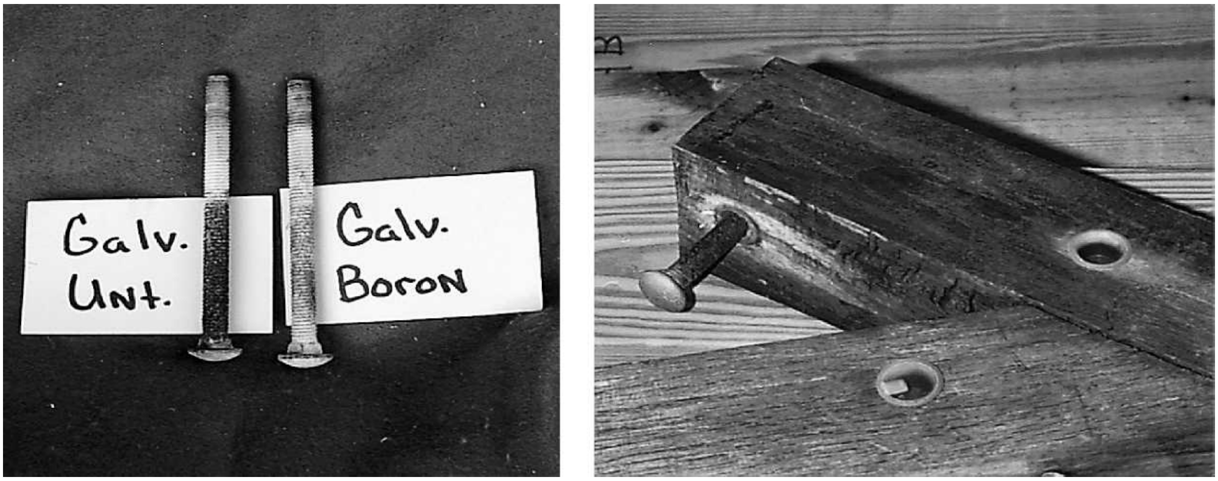

Figure 9.—Corrosion of galvanized bolts was much less in those that had been dipped in BoraCare (1:1) prior to use (left) and a corroded galvanized fastener in an oak test unit (right) after 44 months of exposure.

Figure 10.—Typical failed untreated pole stub after 41 months in service in American Wood-Preservers' Association Hazard Zone 4.

noted, however, that many of these diffusible preservatives did not receive adequate moisture to activate the diffusion process. Also, it is likely that the poor performance of the fumigant was a consequence of the short lengths of the test units. Consequently, direct-application systems are recommended as supplemental treatments for areas with dry climates. Direct application of a copper-borate paste to the joint area was the most effective treatment for all three species.

Piling

Many of the paste and grease preservatives and combinations thereof provided excellent protection against decay. Others would have performed better had there been sufficient moisture for increased diffusion of preservative or, with fumigant, the test units had been longer. Diffusible preservatives require moisture to form a bridge to transport the preservative from a point of high concentration to a point of low concentration. However, the lack of rainfall also indicated that some of the tested preservatives are not appropriate for areas with a drier climate.

Acknowledgments

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Figure 11.—Typical performance of fluoride paste (left) and copper borate paste (right) treatments with no decay after 41 months of exposure in American Wood-Preservers' Association Hazard Zone 4.

Figure 12.—Performance of fluoride (left) and boron (right) rod treatments after 41 months of exposure in American Wood-Preservers' Association Hazard Zone 4.

Literature Cited

Amburgey, T. L. and H. M. Barnes (Eds.). 1997. Proceedings of the Second Southeastern Pole Conference. Proceedings no. 7287. Forest Products Society, Madison, Wisconsin. 158 pp.

Amburgey, T. L., H. M. Barnes, and M. G. Sanders. 2007. Delivery system for supplemental wood preservative systems. US patent 7,195,823.

Amburgey, T. L. and M. G. Sanders. 2008. Protecting wooden doors, windows, and wall framing from decay. Southern Climatic Housing (SCH) Report 11. Forest and Wildlife Research Center, Mississippi State University, Mississippi State. 3 pp.

Amburgey, T. L., M. G. Sanders, and H. M. Barnes. 2009. Supplemental preservative treatments—Joints. *Proc. Am. Wood Prot. Assoc*. 105: 271. (Abstract.)

American Wood-Preservers' Association (AWPA). 2000. Book of Standards. AWPA, Granbury, Texas.

Baileys, R. T., T. L. Amburgey, and H. M. Barnes. 1992. A survey of timber bridges in Oktibbeha County, Mississippi. *Proc. Am. Wood-Preserv. Assoc*. 88:88. (Abstract.)

Barnes, H. M. (Ed.). 2007. Proceedings of the 2007 Southeastern Utility Pole Conference. Proceedings no. 7226. Forest Products Society, Madison, Wisconsin. 235 pp.

Daniels, B., P. H. Short, T. L. Amburgey, H. M. Barnes, V. Culver, and K. Hood. 1995. Modern timber bridges in Mississippi: An examination of critical issues. Mississippi Cooperative Extension Service, Mississippi State University, Mississippi State. 48 pp.

Forest Products Society (Ed.). 1997. Proceedings of the Second International Conference on Wood Protection with Diffusible Preservatives and Pesticides. Proceedings no. 7284. Forest Products Society, Madison, Wisconsin. 188 pp.

Hamel, M. (Ed.). 1990. Proceedings of the First International Conference on Wood Protection with Diffusible Preservatives. Proceedings no. 47355. Forest Products Society, Madison, Wisconsin. 143 pp.

Morrell, J. J., C. Freitag, H. Chen, and C. Love. 2004. 24th Annual Report, Utility Pole Research Cooperative, Oregon State University, Department of Wood Science & Engineering, Corvallis. 133 pp.

Quintana, S. C. 1994. The potential of producing prefabricated, modern timber bridge components in Mississippi. NA-TP-08–94. USDA Forest Service, Timber Bridge Information Center, Morgantown, West Virginia. 53 pp.

Ritter, M. A. 1990. Timber bridges: Design, construction, inspection, and maintenance. Report EM 7700-8. USDA Forest Service, Washington, D.C. 944 pp.

Sanders, M. G. and T. L. Amburgey. 2009. Protecting wooden windows, doors, and adjacent framing. *Proc. Am. Wood Prot. Assoc*. 105: 107–108.