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Efficacy of a Borax–Copper Preservative in Exposed Applications

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Abstract

This study evaluated the ability of pressure treatments with a borax–copper (BC) preservative to protect wood exposed above ground or in contact with the ground. Stake testing indicated that the 2.3% and 4.7% BC concentrations were fairly effective in preventing decay in Wisconsin but were not effective in protecting stakes exposed in Mississippi. The 1.4% and 2.3% BC concentrations effectively protected decking specimens exposed for 5 years at the Wisconsin test site. Assay of stakes at the Wisconsin site indicated that over 90% of boron in the below-ground portion of the stakes was lost within the first year, leaving copper as the sole biocide. Assay of the decking specimens after 4 years of exposure indicated that between 30% and 45% of copper and 80% and 95% of boron was lost from the BC-treated decking specimens. These copper losses were greater than those found with the laboratory simulated rainfall study, which indicated that 5% to 6% of copper was lost from the 1.4% and 2.3% BC treatments after the equivalent of 1 year of rainfall. Boron losses of 45% to 55% were noted with 1 year's equivalent of simulated rainfall. This series of studies indicates that the efficacy of BC as a pressure-treatment preservative in exposed applications is a function of copper retention.

Keywords: Borax–copper, pressure-treated wood, above-ground, ground-contact, durability, leaching

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Introduction

Societal perceptions of the level of acceptable risk associated with wood preservatives continue to evolve. Chromated copper arsenate (CCA-C) was the dominant preservative treatment for over three decades, but recently its use has been limited in favor of arsenic- and chromium-free alternatives. The primary active ingredient in these alternative preservatives is copper, which presents minimal mammalian health concerns. Although effective, these high-copper preservatives have disadvantages that have limited their ready acceptance. The first of these is higher cost, which has lessened the cost advantage that treated wood has enjoyed in comparison to non-wood building materials. Concerns have also arisen over leaching of copper, corrosiveness to metal fasteners, and mold growth (Kamdem 2008, Schultz and Nicholas 2008). Copper leaching and toxicity is of particular concern in aquatic applications such as boardwalks and bridges. Various organic formulations have also been proposed, but these formulations have drawbacks as well. Another alternative type of preservative is borates. Borates have relatively low toxicity to humans and the environment and are effective in preventing attack by decay fungi and termites (Manning 2008). Unfortunately, borates are not chemically bound to the wood, and thus can be leached out of the wood in some types of applications. This disadvantage can be partially overcome by selection of appropriate end-use applications and the incorporation of a less-leachable co-biocide. This paper discusses an evaluation of the potential end-uses of a preservative that contains both borate (40% sodium tetraborate decahydrate) and low levels (3.1%) of copper hydroxide.

Borax–copper (BC) preservative is currently in commercial use as a concentrated paste for remedial treatment to protect the ground-line area of utility poles. To minimize boron losses in remedial ground-line treatments, impermeable sheets are used to cover the preservative paste and inhibit leaching of boron away from the pole. The preservative then gradually diffuses from the paste and into the wood. Previous research indicates that these ground-line treatments can be effective. In 1993, unseasoned pine posts were treated with ground-line BC bandages and installed at the Forest Products Laboratory (FPL) test site in southern Mississippi (Abbott and others 2001).

After 10 years, the remedially treated posts were generally sound at the ground line, although most suffered top decay (Crawford and others 2005). The average borax retention was 24.2, 15.8, and 10.6 kg/m^3 after 3.5, 6.5, and 10 years, respectively. The average copper hydroxide retention in the sampled increments was 3.7, 4.2, and 3.5 kg/m^3 after 3.5, 6.5, and 10 years, respectively. Although retentions varied among posts, in most cases, the borax retentions were still above the threshold needed to prevent attack by decay fungi even 10 years after treatment. A subsequent inspection of the posts after 15 years of exposure found that the ground-line area of posts protected with the BC bandages remained sound.

The performance of BC as a ground-line treatment does not necessarily ensure its performance as a pressure-treatment preservative. Research by Lebow and others (2005a) has demonstrated that the preservative can be diluted in water and will successfully penetrate the wood during pressure treatment, indicating that BC is adaptable to pressure treatment. Because BC is diluted for pressure treatment, the concentration of BC in the wood (retention) needed to provide protection against decay and termite attack must also be evaluated. The approximate retention of BC necessary to protect wood against a range of decay fungi has been determined through laboratory soil block tests (Woodward and others 2002), and efficacy against termites has been established through protected above-ground field tests in Hawaii and Louisiana (Lebow and others 2005b, 2006).

However, other aspects of adapting BC to use as a pressure-treatment preservative, particularly for wood exposed outdoors, have not been fully evaluated. Permanence of the boron and copper in the treated wood is a concern because pressure-treated applications typically do not include a bandage, wrap, or similar mechanism to prevent the borax from leaching out of the wood during service. Efficacy, which is a function of permanence, must also be evaluated in outdoor

Table 1. Borate and copper concentrations in treatment solutions

Treatment solution	Borax (%)	B_2O_3[a] (%)	Cu as $Cu(OH)_2$[b] (%)	Cu as CuO[c] (%)
0.9% BC[d]	0.86	0.29	0.07	0.06
1.4% BC	1.3	0.47	0.10	0.08
2.3% BC	2.2	0.80	0.14	0.11
4.7% BC	4.4	1.60	0.28	0.22
1.1% DOT[e]	—	0.74	—	—
1% CCA-C[f]	—	—	—	0.18

[a] Boric oxide.
[b] Copper(II) hydroxide.
[c] Copper(II) oxide.
[d] Borax–copper.
[e] Disodium octaborate tetrahydrate.
[f] Chromated copper arsenate.

Table 2. Average borate and copper retentions in treated stakes

Treatment solution	B_2O_3[a] (kg/m^3)		CuO[b] (kg/m^3)	
	By uptake	By assay	By uptake	By assay
0.9% BC[c]	1.76	2.00	0.27	0.20
1.4% BC	2.69	2.86	0.42	0.43
2.3% BC	4.72	4.35	0.74	0.71
4.7% BC	9.54	8.89	1.49	1.51
1.1% DOT[d]	3.95	4.35	—	—
1% CCA-C[e]	—	—	1.18	1.10

[a] Boric oxide.
[b] Copper(II) oxide.
[c] Borax–copper.
[d] Disodium octaborate tetrahydrate.
[e] Chromated copper arsenate.

exposures. We expect that the type of outdoor exposure (above-ground versus ground-contact) will affect both efficacy and permanence.

This paper discusses research conducted to evaluate the permanence and efficacy of BC in pressure-treated wood exposed outdoors. Permanence was evaluated in stakes placed in ground contact and in decking exposed to natural weathering or simulated rainfall. Efficacy was evaluated in stakes placed in test sites in Wisconsin and Mississippi and in decking specimens exposed in Wisconsin.

Materials and Methods

Efficacy and Permanence in Ground-Contact Applications

Stake Preparation and Treatment

Forty stakes (19 by 19 by 457 mm) per treatment group were cut from clear Southern Pine sapwood and conditioned to constant weight in a room maintained at 74 °F (23 °C) and 65% relative humidity. An additional 25 longer specimens (19 by 19 by 610 mm) were also prepared for each treatment group. The 65 stakes per treatment group were combined and treated with one of the following solutions:

- Borax–copper (BC) (trade name Cu-Bor, Copper Care Wood Preservatives, Inc., Columbus, Nebraska) with an actives composition of 7.2% technical copper hydroxide and 92.8% sodium tetraborate decahydrate (10-mole borax). This formulation was evaluated with treatment solutions containing 0.93%, 1.40%, 2.34%, and 4.66% actives (Table 1).
- Disodium octaborate tetrahydrate (DOT), considered 100% DOT active ingredients. This formulation was evaluated with a 1.1% solution concentration.
- Chromated copper arsenate Type C (CCA-C), with an actives composition of 47.5% chromium (CrO_3 basis), 34.0% arsenic (As_2O_5 basis), and 18.5% copper (CuO basis). This formulation was evaluated with a 1.0% solution concentration.

The 2.3% and 4.7% BC treatments were conducted with heated solutions (approximately 50 °C) to increase solubility, while the remaining BC treatments and the DOT and CCA treatments were conducted at ambient temperature. All treatments were conducted using a full-cell pressure process. The initial vacuum was maintained at –75 kPa for 30 min; the pressure was maintained at 1.03 MPa for 1 h. Each stake was weighed before and after treatment to determine solution uptake and allow calculation of uptake retention (Table 2).

Following treatment, the stakes were stacked in plastic bags for one week, and then allowed to air-dry under room conditions. Twenty of the shorter (457-mm) stakes treated with each solution were assigned to the exposure plot in Mississippi, and the remaining 20 were designated for exposure in Wisconsin. Sections (152 mm) were cut from the longer specimens for assay of original treatment retention (Table 2), and the remaining 457-mm-long sections were placed into the Wisconsin site for leaching evaluation. Twenty untreated stakes were also installed in each test plot.

Stake Installation and Inspection

The Mississippi plot is located in a forested area within Harrison Experimental Forest (approximately 15 miles north of Gulfport–Biloxi). The location is within the American Wood Protection Association (AWPA) Deterioration Zone 5, which is considered a severe deterioration hazard (AWPA 2007). Although native subterranean termites are active at this site, the presence or activity of Formosan subterranean termites has not yet been reported. The Wisconsin plot is located in grassy field a few miles west of Madison, Wisconsin. The location is within AWPA Deterioration Zone 2 (moderate deterioration hazard). Because of the cold climate, the Wisconsin site is outside the current range of termite activity, and stakes at this location are typically rated only for decay. At each location, the stakes were placed in rows with

Table 3. Rating criteria for stakes and decking

Rating	Stake rating criteria	Decking rating criteria
10	No evidence of decay; one or two termite nibbles allowed	Completely sound, appearance unchanged from installation
9	Trace of decay or slight termite feeding: up to 3% of cross section	UV color change (graying) but no evidence of microbial growth on upper surface
8	Decay or termite attack from 3% to 10% of cross section	UV color change or darkening due to mildew and moisture, but no evidence of decay
7	Decay or termite attack from 10% to 30% of cross section	Darkening and additional symptoms that lead to suspicion of decay
6	Decay or termite attack from 30% to 50% of cross section	Fruiting bodies of decay fungi present; may have slight softening
4	Decay or termite attack from 50% to 75% of cross section	Fruiting bodies and obvious softening
0	Failure	Breaks easily along or across the grain

305-mm spacing between stakes within each row and 915 mm between rows. The stakes were placed at randomly assigned locations within the rows and were buried vertically to one-half their length. An iron rod was used to create holes for stake placement. The stakes were installed in either October 2001 (Wisconsin) or January 2002 (Mississippi) and inspected on the corresponding months at 1, 2, 3, 4, and 5 years after installation. At each inspection, the stakes were scraped lightly to remove soil and given a visual rating for decay or termite attack or both, according to the 10, 9, 8, 7, 6, 4, 0 scale (Table 3) as described in AWPA Standard E7 (AWPA 2007). For purposes of this study, we calculated average ratings for the Mississippi stakes using the lower of two ratings (decay or termite) for each stake. Typically the lowest rating was associated with decay, but several stakes in the untreated, DOT, 0.9% BC, and 1.4% BC treatment groups were most severely attacked by termites.

Treatment Efficacy Comparisons in Stakes

Treatment comparisons were based on cumulative logit models of repeated, ordinal ratings following methods outlined in Molenberghs and Verbeke (2005). Separate models were fit to the minimum ratings for Mississippi and the decay ratings for Wisconsin. Contrasts were constructed for pairwise treatment comparisons within each of these models.

Permanence of BC in Stakes

Additional stakes were installed at the Wisconsin site to evaluate preservative permanence. At annual inspections, five stakes of each treatment group were removed and returned to the laboratory for analysis. Long sections (5-cm) of each stake were removed from 5 cm below and above the ground line. These sections were then milled and digested for analysis of preservative content. Concentrations of boron, copper, chromium, and arsenic (as appropriate) were determined by inductively coupled plasma atomic emission spectrometry (ICP-AES). The preservative content in the exposed stakes was compared with that in the section removed from the stake prior to installation.

Efficacy and Permanence in Above-Ground Applications

Preparation of Decking Specimens

Decking specimens were prepared from 38- by 140-mm Southern Pine sapwood lumber. Twenty-four 3.66-m-long boards were each cut to obtain three, 0.91-m-long specimens that were free of large knots or other serious defects. The resulting 72 specimens were conditioned to constant weight in a room maintained at 74 °F (23 °C) and 65% relative humidity assigned to one of six treatment groups:

- 0.93%, 1.40%, or 2.34% BC solution (see Table 1 for borate and copper concentrations)
- 1.4% BC plus 10% sodium silicate (This combination was included to evaluate whether the inclusion of sodium silicate would impart water repellency, potentially minimizing checking and/or slowing the leaching of borate from the wood.)
- 1% CCA-C
- Untreated

The 2.3% BC treatment was conducted with a solution heated to approximately 50 °C, whereas the remaining BC treatments and the CCA treatments were conducted at ambient temperature. All treatments were conducted using a full-cell pressure process. The initial vacuum was maintained at –75 kPa for 30 min; the pressure was maintained at 1.03 MPa for 1 h. Each specimen was weighed before and after treatment to determine solution uptake and allow calculation of uptake retention (Table 4). We noted that the sodium silicate interfered with solution uptake, causing a lower preservative retention in the 1.4% BC plus sodium silicate specimens. The treated specimens were allowed to air-dry, and then an assay sample was obtained by drilling a 9.5-mm-diameter bit to a depth of 15 mm into the narrow face of each specimen and collecting the shavings. These holes were then filled with silicone caulk. The two sets of shavings from each specimen were combined to obtain a single composite sample. The shavings were then digested and analyzed for preservative components by ICP-AES (Table 4).

Table 4. Average borate and copper retentions in decking specimens

Treatment solution	B_2O_3 [a] (kg/m^3)		CuO [b] (kg/m^3)		Na_2SiO_3 [c] (kg/m^3)
	By uptake	By assay	By uptake	By assay	By uptake
0.9% BC[d]	1.61	1.37	0.33	0.21	—
1.4% BC	2.58	2.38	0.44	0.37	—
1.4% BC + 10% Na_2SiO_3	1.39	1.30	0.24	0.17	29.64
2.3% BC	4.19	4.27	0.58	0.69	—
1% CCA-C[e]	—	—	1.08	1.06	—

[a] Boric oxide.
[b] Copper(II) oxide.
[c] Sodium silicate (SS).
[d] Borax–copper.
[e] Chromated copper arsenate.

Decking Installation and Inspection

The decking specimens were placed at the FPL test site west of Madison, Wisconsin. Racks were constructed so that the specimens could be installed horizontally (pith side down), with a single fastener drilled through the center of the specimen 152 mm from each end. The specimens were placed on the rack in October 2001, and inspected at 1, 2, 3, 4, and 5 years after installation. At each inspection, the specimens were removed from the rack and given a rating based on a 10, 9, 8, 7, 6, 4, 0 scale (Table 3).

Permanence of Preservative in Outdoor Decking Specimens

Permanence was evaluated 4 years after installation. Using the same methodology used prior to installation, an assay sample was obtained by drilling a 9.5-mm-diameter bit to a depth of 15 mm into the narrow face of each specimen and collecting the shavings. This assay sample was removed from within 50 mm of the pre-installation assay location. As before, the shavings from each specimen were digested and analyzed for preservative components by ICP-AES. The percentage of each preservative component leached from the specimens after 4 years was calculated by comparison to the original assay.

Above-Ground Permanence—Laboratory Simulated Rainfall

Specimen Preparation

Five end-matched Southern Pine sapwood specimens (38 by 140 by 254 mm) were cut from each of five longer boards and conditioned to ambient room conditions (6% to 9% moisture content). The resulting 24 specimens were end-sealed with a neoprene rubber coating to prevent end-grain penetration during treatment or losses from the end-grain during leaching. Five treatment solutions were evaluated in this leaching study:

- 1.40% or 2.34% BC solution (see Table 1 for borate and copper concentrations)
- 1.4% BC plus 10% sodium silicate
- 1.1% DOT
- 1% CCA-C

The 2.3% BC treatment was conducted with a solution heated to approximately 50 °C, while the remaining BC treatments and the CCA treatments were conducted at ambient temperatures. All treatments were conducted using a full-cell pressure process. The initial vacuum was maintained at –75 kPa for 30 min; the pressure was maintained at 1.03 MPa for 1 h. As we observed with the decking exposure specimens, the sodium silicate interfered with solution uptake and caused a lower preservative retention in the 1.4% BC plus sodium silicate specimens. Each specimen was weighed before and after treatment to determine solution uptake and allow calculation of uptake retention (Table 5). Following treatment, the specimens were wrapped in plastic for one week and then allowed to equilibrate at ambient conditions (6% to 9% equilibrium moisture content) prior to leaching.

Simulated Rainfall

A simulated rainfall apparatus was used to spray deionized water onto the wide faces of the specimens. Ten air-atomizing, wide-angle, round spray nozzles were supported on a 1.2- by 2.4-m wire at a height of 1 m above the specimens. Each nozzle was supplied with air and water through a flexible hose. The rate of rainfall was controlled by adjusting the ratio of air:water pressure supplied to the nozzles. Air pressure was regulated at 345 kPa and water pressure at 221 kPa. This pressure combination produced a spray of fine droplets at a simulated rainfall rate of 3.0 mm/h. Specimens were laid horizontally, with the wide face turned up, in trays 280 mm long by 150 mm wide by 114 mm deep; the specimens were supported 20 mm above the bottom of the trays so that they did not contact standing water. Hoses attached to the bottom of the trays drained water run-off into

Table 5. Average initial borate and copper retentions in simulated rainfall leaching specimens

Treatment solution	B_2O_3 [a] (kg/m^3)	CuO[b] (kg/m^3)	Na_sSiO_3[c] (kg/m^3)
1.4% BC[d]	3.03	0.47	—
1.4% BC + 10% Na_4SiO_4	1.13	0.18	23.67
2.3% BC	4.95	0.77	—
1.1% DOT[e]	4.80	—	—
1% CCA-C[f]	—	1.15	—

[a] Boric oxide.
[b] Copper(II) oxide.
[c] Sodium silicate (SS).
[d] Borax–copper.
[e] Disodium octaborate tetrahydrate.
[f] Chromated copper arsenate.

19-L low-density polyethylene collection containers below the platform. A more detailed explanation of the simulated rainfall apparatus can be found in Lebow and others (2003). The specimens were sprayed for 10.5 h/day for 4 days per week (Monday through Thursday) for a total 42 h per week. Between rainfall events, the specimens were left within their trays and allowed to air-dry, but the enclosure surrounding the specimens minimized air flow. The water was not re-used or re-circulated. This pattern was repeated for 6 weeks, producing an average of 756 mm of rainfall. All water draining off the specimens during the course of a week was collected, weighed, acidified with nitric acid, and subsampled for analysis by ICP-AES. The percentage of each preservative component leached was calculated by comparing the mass of preservative in the leachate to that originally present in the specimens.

Results and Discussion

Durability of Stakes in Ground Contact

Placement of wood in direct contact with soil is a severe test of a preservative, and ground contact exposure in southern Mississippi presents particularly harsh conditions. As expected, deterioration of stakes was much more rapid in Mississippi than Wisconsin (Figs. 1 to 3). All but one untreated stake failed within 2 years in Mississippi, whereas two untreated stakes remained after 5 years in Wisconsin (Fig. 3). With the exception of the CCA-C treatment, deterioration of treated stakes was also much more rapid in Mississippi. The average rating of the DOT-treated stakes was less than 4.0 after 1 year in Mississippi, but remained slightly above 4.0 after 5 years in Wisconsin. The pattern of degrade is also dissimilar between the two sites, at least for the least durable treatments. Stakes in Wisconsin tended to decline gradually over the first 4 years and then suffered a greater drop in the fifth year, whereas average ratings in Mississippi tended to drop rapidly for the first 3 to 4 years, with somewhat less dramatic decreases in the fifth year. However, the trend in Mississippi is somewhat misleading because a high proportion of stakes in each group had failed by the fifth year.

The benefit of adding even low levels of copper can be seen by comparing the performance of the DOT-treated stakes

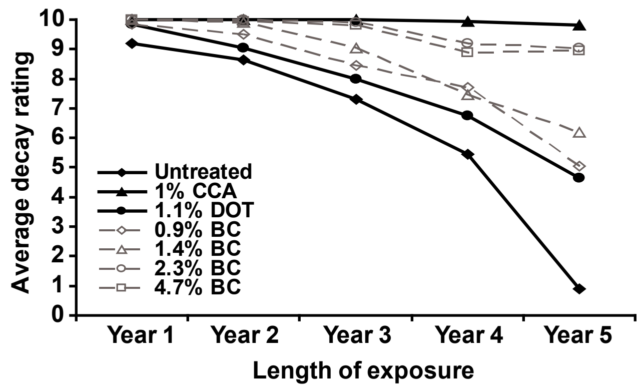

Figure 1—Average decay ratings for stakes exposed in Wisconsin. CCA is chromated copper arsenate; DOT is disodium octaborate tetrahydrate; and BC is borax–copper. See Table 3 for rating criteria.

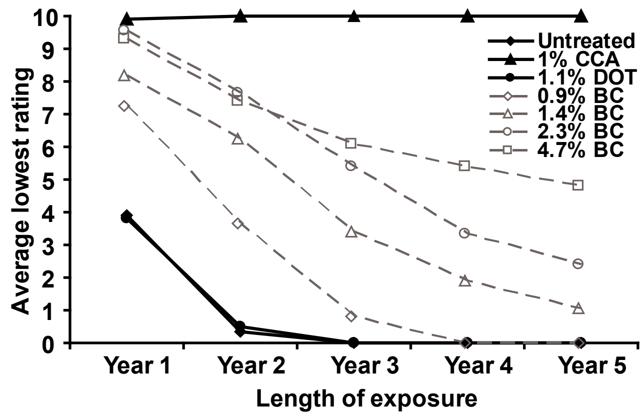

Figure 2—Average ratings for stakes exposed in Mississippi. For each stake and time point, the lower of the decay and termite rating was used to calculate the average. CCA is chromated copper arsenate; DOT is disodium octaborate tetrahydrate; and BC is borax–copper. See Table 3 for rating criteria.

with the stakes treated with 0.9% and 1.4% BC. These two lower BC-treatment stakes contained less boron than the DOT treatment, but the stakes were more durable in Mississippi, and the 1.4% BC stakes more durable in Wisconsin. At the two higher BC solution concentrations, the amount of copper in the treated stakes is similar to that of the CCA treatment (Table 2). The average ratings of the 2.3% and 4.7% BC groups in Wisconsin remained high even after 5 years. Because approximately 90% of the borate, but only 10% to 20% of the copper, had been leached from these stakes within 3 years (Table 6), this finding suggests that these copper concentrations can be fairly effective in northern climates. Although copper did provide benefit in Mississippi, even stakes with the highest BC retention were severely degraded, with over 40% of the stakes failing within 5 years.

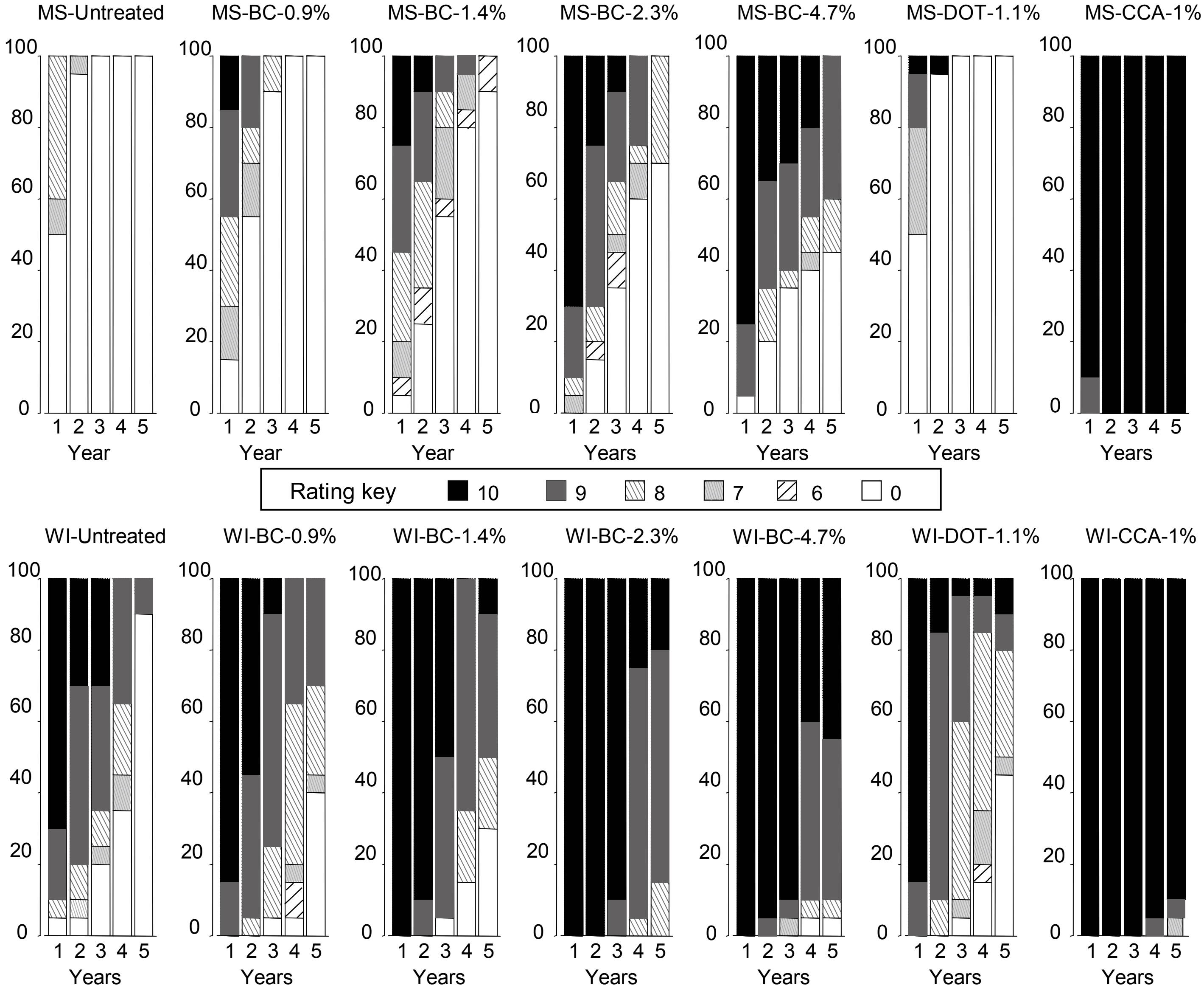

Figure 3—Percentage of stakes in each rating category. CCA is chromated copper arsenate; DOT is disodium octaborate tetrahydrate; and BC is borax–copper. See Table 3 for rating criteria.

The poor performance of copper retentions equivalent to CCA in Mississippi may result from a combination of factors. Certainly the warmer, wetter climate would be expected to result in more rapid deterioration, and it is possible that the ratings in Wisconsin will be similar to those in Mississippi within a few years. It is also true that the Mississippi site has a substantial termite population, whereas the Wisconsin site does not have any termites. However, most of the damage to the 2.3% and 4.7% BC-treated stakes was caused by decay. A third factor that may have led to the failure of the higher copper retentions in Mississippi is the presence of copper-tolerant fungi at that site. Assuming that the boron leached out of the stakes (Table 6), they would have been vulnerable to attack by copper-tolerant fungi.

The yellow mycelium of a fungus (possibly *Antrodia* spp.) that has previously been observed to attack copper-treated stakes was seen on some of the BC-treated stakes. The role of copper-tolerant fungi may be further supported by comparison of the performance of the Mississippi stakes with a separate evaluation conducted with diffusion-treated stakes exposed in Hilo, Hawaii (Copper Care Wood Preservatives, Inc. 2007). At the Hilo site, copper–borax-treated stakes continue to perform well after 4 years of exposure. Because the decay hazard in Hilo is at least as severe as that in Mississippi, this finding suggests that some factor other than climate is contributing to the failure of the stakes in Mississippi. Some of the stakes at the Wisconsin site were also attacked by rodents, which seemed to prefer the BC treatment.

Table 6. Percentage copper or boron remaining in above and below-ground portions of stakes after each year of exposure

Formulation and element	Relation to ground line	1 year Average	1 year Standard deviation	2 years Average	2 years Standard deviation	3 years Average	3 years Standard deviation	4 years Average	4 years Standard deviation	5 years Average	5 years Standard deviation
0.9% BC[a]	Above	96.9	14.7	108.8	29.0	96.7	14.2	41.0	24.0	53.7	14.8
Copper	Below	70.4	7.6	86.1	25.3	68.5	24.9	53.0	63.2	64.5	13.2
1.4% BC	Above	89.5	18.8	98.6	14.5	90.6	10.5	135.5	35.9	95.8	11.3
Copper	Below	61.2	13.1	82.1	9.4	61.5	8.5	53.8	6.3	80.2	8.3
2.3% BC	Above	102.7	9.4	115.0	15.6	97.8	11.3	98.7	4.9	88.0	19.0
Copper	Below	71.3	16.5	91.0	4.4	80.9	8.5	58.2	31.9	74.2	23.0
4.7% BC	Above	96.7	12.4	91.9	5.3	88.6	7.9	63.2	29.5	95.0	18.7
Copper	Below	82.4	18.6	86.6	8.7	88.1	12.6	50.5	10.6	82.5	12.6
1% CCA[b]	Above	96.2	23.5	109.5	4.4	102.0	12.0	92.8	7.6	99.6	12.1
Copper	Below	75.1	13.6	97.3	7.7	84.9	6.1	81.0	11.7	80.7	9.7
0.9% BC	Above	39.4	9.2	10.7	3.7	12.7	22.0	1.8	0.9	0.1	0.0
Boron	Below	1.4	0.3	0.4	0.1	3.2	2.7	1.5	0.5	0.1	0.0
1.4% BC	Above	27.1	5.4	8.1	4.7	3.6	1.0	2.3	1.6	0.7	0.6
Boron	Below	1.1	0.2	2.0	3.1	2.8	1.5	0.7	0.2	0.5	0.4
2.3% BC	Above	35.7	4.3	11.0	3.3	17.2	12.8	2.8	1.0	0.2	0.4
Boron	Below	1.1	0.2	0.1	0.1	1.0	1.0	0.5	0.4	0.0	0.0
4.7% BC	Above	31.2	7.3	9.6	6.5	4.7	2.3	2.3	1.0	0.1	0.1
Boron	Below	0.8	0.2	4.1	7.8	2.8	5.1	0.2	0.0	0.0	0.0
1.1% DOT[c]	Above	23.7	15.5	5.7	3.6	11.6	11.1	1.3	0.5	0.1	0.1
Boron	Below	4.9	9.7	3.7	6.9	4.9	10.0	0.5	0.1	0.0	0.0

[a] Borax-copper.
[b] Chromated copper arsenate.

The average ratings of the relatively small (19- by 19-mm) stakes used in this study do not adequately represent the distribution of ratings, and this was especially true at the Mississippi site. As can be seen in Figure 3, the stake ratings in Mississippi typically drop from 10, 9, or 8 directly to 0, with very few stakes receiving ratings of 7, 6, or 4. Even in Wisconsin where degradation is more gradual, ratings below 7 are uncommon. As a result, the ratings tend to a bimodal distribution, and presentation of only the average ratings may not provide a complete picture of the distribution of ratings for the stakes' condition. The stakes treated with 4.7% BC and exposed in Mississippi provide an example. After 2 years of exposure, the average rating for the stakes was 7.4, but four of the stakes had already failed and the remainder were rated as either 8, 9, or 10. After 5 years, the average rating was 4.9, with all the stakes rated as either 0, 8, or 9.

Permanence of Preservative in Stakes

Considerable variability was observed in losses of preservative, especially copper, from the stakes exposed at the Wisconsin test site (Table 6). Although analysis of the treated wood before and after exposure is often the only practical method of assessing leaching for wood exposed outdoors, this approach suffers from increased variability because of differences in distribution of preservative within the wood and variability in conducting wood assays. The effect of this variability is proportionally greater for the least leachable preservative components and for components present at low concentrations. In the present study, it is difficult to draw strong conclusions about the permanence of copper in the stakes. Below-ground losses of copper from the BC treatments appear to be greater than those for CCA-treated stakes in most cases, although this trend is not always clear. Preservative losses are typically greater below ground because the lower portions of the stakes have more wetting, as well as exposure to inorganic and organic soil components that may solubilize preservative components such as copper. Average copper losses in this study did tend to be greater below ground for stakes treated with CCA and the higher retentions of BC, but this was not always the case for stakes treated with 0.9% BC.

Depletion of boron from the below-ground portion of the stakes was very rapid, with average losses over 90% within the first year (Table 6). Loss of boron from the above-ground portion of the stakes was slower but exceeded 90% for all treatments within 4 years. Although depletion was not evaluated in the Mississippi stakes, boron losses at that site likely were at least as rapid. These results indicate that durability of the BC-treated stakes is almost entirely attributable to copper, and as discussed above, the stakes would be vulnerable to attack by the copper-tolerant fungi present at the Mississippi test site. The rapid loss of boron also explains why the DOT-treated stakes performed so similarly to the untreated controls at the Mississippi site.

Note that the small size of these test stakes (relative to the lumber and timbers used in construction) greatly accelerates leaching when it is expressed on the basis of percentage depleted.

Durability of Decking Specimens

Above-ground exposures are a less severe biodeterioration hazard than ground-contact exposures. After 5 years at the Wisconsin test site, none of the decking specimens has completely failed, although most of the untreated specimens are obviously decayed.

Many specimens exhibited graying caused by UV surface degradation, which lowered their rating to 9 within the first year. All the specimens eventually weathered to gray, but it took several years for the CCA-treated and 2.3% BC-treated specimens to discolor. The specimens treated with 1.4% BC plus sodium silicate weathered to a lighter gray color than the other specimens. After the second year, many of the untreated specimens were darkened by the growth of mold and mildew, which further degraded their appearance.

After 3 years, all the untreated controls were weathered, dark gray, and spotted with mildew. Many appeared to have some softening on the end-grain, and one had a fruiting body identified as *Gleophyllum saepiarium* (a common brown-rot fungus). The appearance of the specimens treated with 0.9% BC was only marginally better than that of the untreated specimens, with some mildew present. However, there was no evidence of decay in any of the treated specimens. Specimens treated with 1.4% and 2.3% BC were visibly brighter than the controls and generally free of mildew. There was little difference in appearance between the 1.4% and 2.3% treatments. The 1.4% BC plus sodium silicate treatment maintained a slightly brighter or more "bleached" appearance than the other treatments. The CCA-treated specimens continued to gray but were otherwise unaffected.

Decay continued to develop in the untreated specimens during the fourth year of exposure, with fruiting bodies evident on seven specimens. Gleophyllum saepiarium remained the most obvious organism, but the fruiting bodies of *Irpex lacteus*, a white-rot fungus, were also frequently observed. None of the preservative-treated specimens exhibited obvious signs of decay, although the appearance of the 0.9% BC treatment appeared slightly darker than the other preservative treatments.

After 5 years, the first signs of decay appeared in treated specimens. Two of the specimens treated with 0.9% BC and one of the specimens treated with 1.4% BC plus 10% sodium silicate had fungal fruiting bodies. During treatment, we noted that the addition of sodium silicate inhibited solution absorption, and the 1.4% BC plus sodium silicate specimens had initial copper and boron retentions slightly below that of the 0.9% BC specimens. The 0.9% BC treatments also tended to be slightly darker in color and sometimes had mildew on the upper surface.

Table 7. Summary of ratings of decking specimens after 5 years of exposure

Treatment solution	Average	Maximum	Minimum
0.9% BC [a]	8.5	9	6
1.4% BC	9.0	9	9
2.3% BC	9.0	9	9
CCA [b]	9.0	9	9
1.4% BC + 10% Na_2SiO_3 [c]	8.7	9	6
Untreated	5.3	7	4

[a] Borax-copper.
[b] Chromated copper arsenate.
[c] Sodium silicate (SS).

None of the specimens treated with either 1.4% or 2.3% BC, or with 1% CCA, showed any sign of decay. They also were a lighter gray and did not have mildew on the upper surface. Many of the specimens (including some of those treated with CCA) did have areas of mildew on the bottom surface. All the specimens developed many small checks as would be expected on the "bark side" of flat-sawn boards. The preservative treatments, including the 1.4% BC plus sodium silicate, did not appear to have an effect on the amount of checking. None of the specimens is exhibiting significant warp, cup, or twist. In general, specimens treated with 1.4% and 2.3% BC appear to be performing well after 5 years of exposure. In contrast to the BC-treated stakes exposed in Wisconsin, no rodent attack was observed on any of the BC-treated decking specimens during the first 5 years. Average, maximum, and minimum ratings after 5 years of exposure are presented in Table 7. Specimens treated with 1.4% and 2.3% BC continue to perform well. The addition of sodium silicate to the 1.4% BC treatment did appear to cause the wood to have a lighter gray color during weathering.

Permanence of Preservative in Outdoor Decking Specimens

Loss of preservative from the outdoor decking specimens was evaluated after 4 years of exposure. Results of this evaluation indicate that between 30% and 45% of copper and 80% to 95% of the boron were lost from the BC-treated decking specimens (Table 8) during 4 years of exposure. Loss of copper from the decking specimens is greater than expected when compared with losses from the 19-mm stakes (Table 6). However, as we observed in evaluating losses from stakes, considerable variability was observed between decking replicates, and this was especially the case for copper losses from the BC treatments. The loss of the majority of boron from the deck boards is expected and is in agreement with losses from the stakes. Boron losses from 1.4% BC treatment with sodium silicate appear to be slightly less than those from the 1.4% BC treatment without sodium silicate, but given the variability, it is unclear that this difference is meaningful. Loss of copper from the CCA-treated specimens appeared to be substantially lower than that from the BC-treated specimens.

Leaching in Simulated Rainfall

Collection and analysis of rainfall run-off from leaching specimens reduces variability and allows for a more controlled comparison of treatments. When evaluated in this manner, approximately 5% to 6% of copper and 45% to 55% of boron appears to be lost from the 1.4% and 2.3% BC treatments after the equivalent of 1 year of rainfall (Fig. 5). The percentage of copper lost from the 1.4% BC treatment with added sodium silicate is lower than for the other BC treatments, but still greater than that from CCA. This test approximates only 1 year of rainfall. If extrapolated out to 4 years of rainfall, the losses of copper estimated from the 1.4% and 2.3% BC treatments would be in the range of 7% to 9%, whereas boron losses would be in the range of 90% to 95%. These copper losses are substantially lower than those obtained by assaying the outdoor decking specimens after 4 years of exposure (Table 8) and would seem to support the relatively low percentage of copper loss values observed for the stakes. The losses of boron in simulated rainfall appear to be in good agreement with those observed for both the stakes and outdoor decking specimens. However, conditions of the simulated rainfall test are artificial and may not incorporate all factors that affect leaching outdoors. For example, the simulated rainfall specimens do not develop the extent of checking that occurs in outdoor exposure. Check development may be expected to expand the available surface area and increase leaching (Lebow and others 2008).

The simulated rainfall leaching does indicate that boron in the BC treatments is at least as leachable as that delivered

Table 8. Average percentage preservative losses from outdoor decking after 4 years of exposure

	Percentage of preservative component leached [a]			
Treatment solution	Arsenic	Chromium	Copper	Boron
0.9% BC [b]	—	—	44.5 (20.4)	94.0 (5.1)
1.4% BC	—	—	37.9 (19.6)	93.6 (4.6)
2.3% BC	—	—	31.6 (14.0)	89.0 (3.9)
CCA [c]	7.6 (4.1)	6.8 (5.5)	5.2 (3.3)	—
1.4% BC + 10% Na_2SiO_3	—	—	33.8 (19.2)	82.8 (8.9)

[a] Values in parenthesis represent one standard deviation from the mean.
[b] Borax-copper.

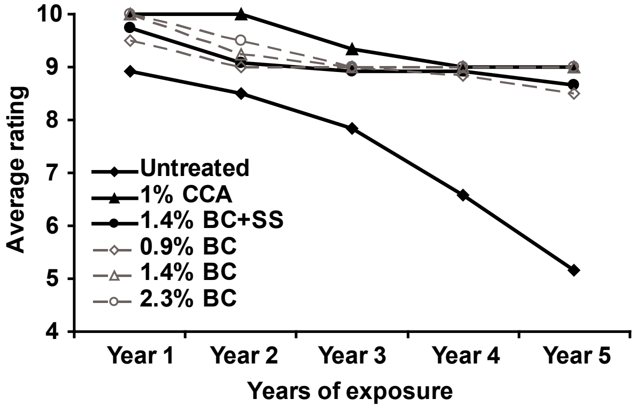

Figure 4—Average ratings of decking specimens during 5 years of exposure in Wisconsin. CCA is chromated copper arsenate; SS is sodium silicate; and BC is borax–copper. See Table 3 for rating criteria.

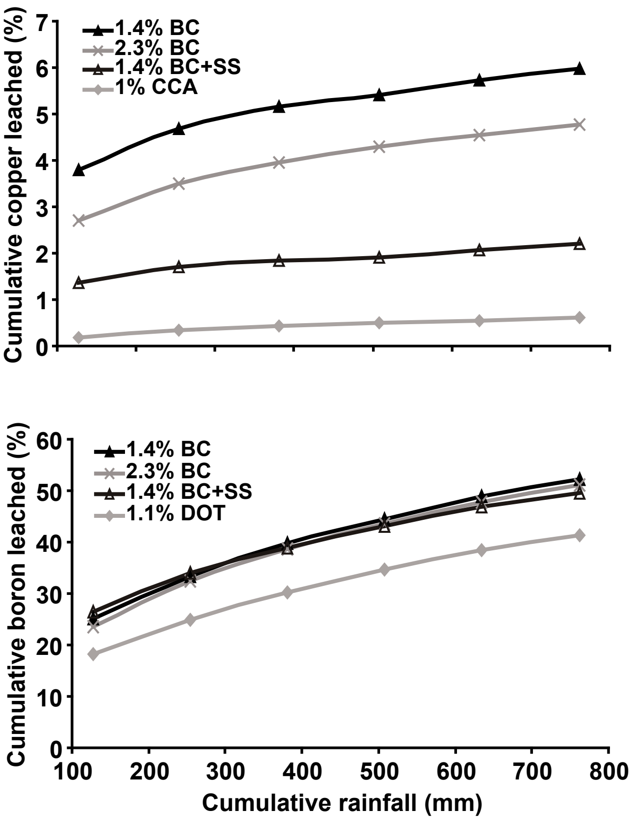

Figure 5—Average cumulative percent losses of copper (top) and boron (bottom) from lumber specimens exposed to simulated rainfall. DOT is disodium octaborate tetrahydrate; CCA is chromated copper arsenate; SS is sodium silicate; and BC is borax–copper.

in the form of DOT. The percentage of boron depletion was very similar for all three BC treatments, indicating that the addition of sodium silicate to the 1.4% BC treatment had little effect on boron loss.

Conclusions

The ability of the BC treatments to protect wood placed in contact with the ground appears to depend on site conditions. The two highest concentrations of BC provided substantial protection against decay for stakes exposed in Wisconsin for 5 years. However, even the highest BC retention did not adequately protect stakes in Mississippi, possibly reflecting the combination of higher decay hazard, termite activity, and the presence of copper-tolerant fungi at the Mississippi location. Assay of stakes at the Wisconsin site indicates that over 90% of boron in the below-ground portion of the stakes was lost within the first year, leaving copper as the sole biocide. Although between 70% and 80% of the copper remained in the below-ground portion of the BC-treated stakes after 5 years of exposure, the stakes would have still been vulnerable to attack by the copper-tolerant fungi present at the Mississippi test site. This study indicates that although pressure treatment with BC can extend the ground-contact durability of wood, caution is warranted when considering the ground contact use of BC in areas with severe deterioration hazards. The affinity of rodents for the BC-treated stakes may also be a concern in some locations.

The two highest BC concentrations evaluated (1.4% and 2.3%) have been effective in protecting decking specimens exposed for 5 years at the Wisconsin test site. The appearance of specimens treated with these formulations is similar to those treated with CCA, and no decay has been observed. The addition of 10% sodium silicate to the 1.4% BC solution caused the wood surface to weather to a lighter gray color, but it did not appear to prevent checking. The sodium silicate interfered with BC solution absorption, causing these specimens to have lower BC retentions. Assay of the decking specimens after 4 years of exposure indicated that between 30% and 45% of copper and 80% to 95% of the boron was lost from the BC-treated decking specimens. These copper losses were greater than expected when compared with losses observed in the 19-mm stakes. Copper losses were also higher than those found in the laboratory leaching study using simulated rainfall. The simulated rainfall study indicates that 5% to 6% of copper is lost from the 1.4% and 2.3% BC treatments after the equivalent of 1 year of rainfall. Extrapolation of those trends results in estimated losses of only 7% to 9% of copper after 4 years. Boron losses of between 45% and 55% were noted with simulated rainfall. The boron leaching trends indicate over 90% depletion within 4 years. Both approaches to evaluating boron loss from above-ground specimens suggest that the majority of boron is lost within the first few years, leaving copper as the sole biocide.

This series of studies indicates that the efficacy of BC as a pressure-treatment preservative in exposed applications is a function of copper retention. The boron is rapidly depleted from the wood, providing little long-term benefit. The BC concentrations evaluated were effective in situations where the relatively low copper retentions were sufficient to protect the wood. The low copper retentions were not effective in ground-contact in Mississippi because of the severe deterioration hazard and the presence of copper-tolerant fungi. The current BC formulation may have potential as a pressure treatment for wood used above-ground, but the value of the borax in the formulation warrants further consideration.

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