# TREATABILITY OF SPF FRAMING LUMBER WITH CCA AND BORATE PRESERVATIVES

*Stan Lebow*†
Research Wood Scientist

*Cherilyn Hatfield*
Statistician
USDA Forest Service
Forest Products Laboratory[1]
One Gifford Pinchot Drive
Madison, WI 53726

and

*William Abbott*
President
Pole Maintenance Company
Columbus, NB

(Received January 2005)

ABSTRACT

There is increasing interest in preservative pressure-treatment of framing lumber to prevent attack by decay fungi and insects. However, the Spruce–Pine–Fir species group that is often used in framing construction can be difficult to penetrate with preservatives. We compared solution uptake and penetration of boron and copper from a borax–copper (BC) preservative to that of boron in a disodium octaborate tetrahydrate (DOT) treatment and copper in a chromated copper arsenate (CCA) treatment. For all wood species, average solution uptake was consistently greater with the DOT solution than with the BC or CCA solution. Average boron penetration with DOT was also greater than that for any BC solution. Immediately after treatment, boron penetration with DOT exceeded 10 mm in at least 80% of specimens, indicating that the treatment could meet American Wood Preservers' Association (AWPA, 2003) penetration standards. Following a 2-week diffusion period, boron in BC treatments also met or exceeded AWPA standards in most cases. Copper penetration was much lower than boron penetration and did not meet AWPA standards in any species. Collapse was noted in some specimens treated with heated BC and DOT solutions.

*Keywords:* Spruce–Pine–Fir, treatability, preservative, boron, copper, DOT, CCA.

## INTRODUCTION

The spread of the Formosan subterranean termite in the southern United States has increased the need to find safe and effective ways to protect wooden construction materials (Shupe and Dunn 2000). One option for the protection of framing lumber is pressure treatment with a preservative prior to construction. However, it is difficult to treat some wood species, even under pressure. In these species, only a shell of preservative treatment often surrounds a core of untreated wood. Experience has shown that these shell treatments are effective in preventing rapid fungal degrade of treated wood exposed above ground (Choi et al. 2004; Morris et al. 2004; Smith et al. 1998), but there is much less evidence of the efficacy of such treatments in pre-

† Member of SWST.
[1] The Forest Products Laboratory is maintained in cooperation with the University of Wisconsin. This article was written and prepared by U.S. Government employees on official time, and it is therefore in the public domain and not subject to copyright. The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

venting termite damage. Morris et al. (2003) and Grace et al. (2001) evaluated the performance of shell treatments of western hemlock *(Tsuga heterophylla*) and Pacific silver fir (*Abies amabilis*) against *Reticulitermes flavipes* and *Coptotermes formosanus* termites and found that protection was generally good. However, there is still concern that construction activities will create breaks in the treated shell and expose the untreated core to termite attack.

While much lumber used in the southern United States is southern pine, a species group that is easily treated, a substantial portion of the framing market is supplied by the Spruce–Pine–Fir (SPF) group, a diverse grouping that is sometimes further subdivided into SPF–West and SFP–South. When considered in its broadest terms, the SFP species group includes subalpine fir, balsam fir, jack pine, lodgepole pine, black spruce, Engelmann spruce, red spruce, Sitka spruce, and white spruce. These species are generally considered to be difficult to treat (refractory) or variable in their treatability with chromated copper arsenate (CCA) (Gjovik and Schumann 1992; Richards and Inwards 1989; Smith 1986). For most types of wood preservatives, refractory species need to be incised before treatment to improve the depth and uniformity of preservative penetration (AWPA Standard C2–02, AWPA 2003). An exception to this incising requirement is treatment of SPF with the borate preservative disodium octaborate tetrahydrate (DOT) (AWPA Standard C31–02, AWPA 2003). This exception is based on studies conducted in Canada that concluded that adequate penetration could be achieved with use of a heated DOT solution (Baker et al. 2001). The potential ability of borate preservatives to penetrate and protect refractory species is particularly notable in regards to framing lumber. Borate preservatives are well-suited for treatment of framing lumber because they are odorless and have relatively low human toxicity. The major drawback of borate preservatives, their leachability, is also much less of a concern in an indoor application.

We sought to further investigate the use of borates for treatment of SPF framing lumber by evaluating a borax-based preservative currently used for remedial treatment of the groundline area of utility poles. Borax (sodium tetraborate decahydrate) is a form of borate that may be less expensive to manufacture than DOT, but it also has lower water solubility. The effect of lower solubility on the ability of borate to penetrate refractory species warrants further investigation. The borax preservative selected also contains a small amount of copper as a co-biocide to provide further protection against attack by termites, decay, and mold fungi. Again, however, the ability of the copper in this formulation to penetrate refractory SPF species is unknown.

In this study, we compared the penetration of boron and copper from the borax-based preservative to that of boron in a DOT treatment and copper in a CCA treatment. A subset of the treated samples is undergoing exposure to native subterranean termites and Formosan subterranean termites in Louisiana. The outcome of that termite evaluation will be presented in a subsequent publication.

## MATERIALS AND METHODS

### *Specimen preparation*

The SPF species evaluated in this study are all members of the SPF–South subgrouping. They included balsam fir (*Abies balsamea*), Engelmann spruce (*Picea engelmannii*), Sitka spruce (*Picea sitchensis*), red spruce (*Picea rubens*), white spruce (*Picea glauca*), and lodgepole pine (*Pinus contorta*). With the assistance of the Western Wood Products Association and Northeastern Lumber Manufacturers Association, thirty-four 38-mm by 89-mm by 2.4-m-long (1.5-in. by 3.5-in. by 8-ft-long) boards of each species were obtained from mills in the northeastern, midwestern, and northwestern United States. Six 305-mm- (12-in.-) long specimens were cut from each board and conditioned to constant weight in a room maintained at 23°C (74°F) and 65% relative humidity. The end grain of each specimen was then sealed with a neoprene rubber coating to limit end-grain penetration.

### *Preservative formulations*

Treatability was assessed with three types of preservative formulations:

1. Borax–copper (BC) (trade name Cu-Bor) with an active composition of 7.2% copper hydroxide and 92.8% sodium tetraborate decahydrate (10 mole borax). This formulation was evaluated with treatment solutions containing 0.39%, 0.78%, 1.39%, and 2.34% active ingredients.
2. Chromated copper arsenate Type C (CCA-C) with an active composition of 47.5% $CrO_3$, 18.5% CuO, and 34.0% $As_2O_5$. This formulation was evaluated with a treatment solution containing 1.14% active ingredients.
3. Disodium octaborate tetrahydrate (DOT), considered 100% DOT active. This formulation was evaluated with a 1.86% solution concentration.

### *Treatment groups*

The study utilized six treatment groups: one each for CCA and DOT, plus four BC solution concentrations. To minimize the effects of between-board variations, end-matched specimens cut from each board of each wood species were randomly assigned to one of the six treatment groups. The 6 wood species and 34 replicate boards for each wood species yielded a total of 204 specimens for each type of treatment. Because the treatment cylinder was not large enough to contain all the specimens, each treatment was applied using two charges, each containing 102 specimens.

### *Treatment conditions*

All treatments were conducted using a full-cell pressure process. The vacuum was maintained at −75 kPa (25 inHg) for 30 min; pressure was maintained at 1.03 MPa (150 lb/in.$^2$) for 5 h. To improve preservative penetration, the DOT solution and all BC solutions were heated to 66°C (150°F), and this temperature was maintained throughout the pressure period. Specimens from one charge of the 2.34% BC solution were discarded because the temperature controller failed and the solution temperature approached 93°C (200°F). Most specimens in this charge collapsed, making it difficult to quantify or compare preservative penetration. Thus, data for only one charge of the 2.34% BC solution are presented here. Because heat can cause sludging of CCA solution, the CCA treatments were conducted at room temperature.

All specimens were weighed before and after treatment to determine solution uptake. After treatment, a 51-mm- (2-in.-) long section was cut from each specimen and oven-dried (Fig. 1). This section was subsequently used to determine preservative penetration immediately after treatment. The boron in the BC and DOT formulations does not fix in the wood, and additional diffusion penetration can occur after treatment. To evaluate this additional penetration, the remaining portions of the specimens were stacked and covered in plastic for 2 weeks at room temperature to allow diffusion. Another 51-mm- (2-in.-) long section was then cut from each specimen, oven-dried, and used to determine boron penetration after diffusion. Finally, a 76-mm- (3-in.-) long section was cut from a subset of the specimens and reserved for termite evaluation.

### *Preservative penetration*

After drying, the 51-mm- (2-in.-) long sections cut from each specimen were again cut to reveal a fresh cross-section and sprayed with either copper or boron indicator stain. The chrome azurol–S copper indicator and curcumin–salicylic acid boron indicator solutions were prepared in accordance with AWPA Standard

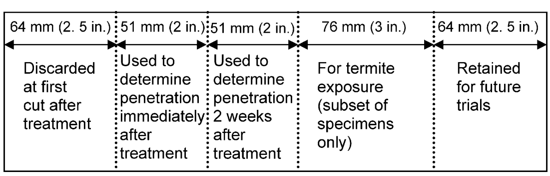


FIG. 1. Pattern for cutting 305-mm- (12-in.-) long specimens after treatment to determine penetration and obtain sections for termite evaluations.

C31–02 (AWPA 2003). Penetration of both copper and boron were evaluated for the BC treatments, while only copper or boron was evaluated for the CCA and DOT treatments, respectively. Penetration measurements similar to those determined commercially (by removal of increment cores) were obtained by measuring penetration at the midpoint of both narrow faces of each specimen (AWPA Standard M2–01, AWPA 2003). For the species evaluated in this study, AWPA standards C2–02 and A3–00 require that 80% of boards sampled in a charge have at least 10 mm (0.4 in.) of preservative penetration (AWPA 2003).

### *Statistical analysis of penetration*

A statistical analysis was conducted to better determine if type of treatment solution or wood species affects the percentage of specimens in each charge with penetration equaling or exceeding 10 mm (0.4 in.). For the purposes of this evaluation, the results of the two charges for each treatment group were combined. A statistical analysis of variance was conducted using the SAS™ GLM procedure, in conjunction with a Tukey studentized range test, on the percentage of specimens with penetration ≥10 mm (≥0.4 in.). Tables 2 and 3 show the results of the Tukey tests by species and preservative, respectively. Data on preservatives or species followed by common letters represent groups in which the percentage of specimens with ≥10-mm penetration is not different at the 0.05 level of significance.

## RESULTS

### *Uptake of preservative solution*

The amount of preservative solution retained by specimens after treatment is one indicator of treatability. In this study, solution uptake was assessed by weighing each specimen before and after treatment and comparing the amount of weight gain. For all wood species, average uptake was consistently greater with the DOT solution than with the BC and CCA solutions (Table 1, Fig. 2). There was little overall difference in uptake between the CCA and BC solutions, except that uptake appeared to be least for the most concentrated BC solution (2.34%). Sitka spruce appeared to be the species in which uptake was most sensitive to type of treatment solution. Red spruce appeared to have consistently lower uptake than did the other wood species, while lodgepole pine exhibited the greatest variability in uptake. For commercial treaters, variability in uptake may be as great a concern as amount of uptake because the variability makes it difficult to optimize treating parameters to minimize treatment time and chemical consumption.

### *Copper penetration*

Achieving adequate penetration is the greatest challenge in treating refractory species. For CCA and other copper-based treatments, preservative penetration is typically evaluated on the basis of copper penetration. In this study, average copper penetration of all wood species was at least twice as great for CCA as for the BC

TABLE 1. *Summary of average uptake and penetration for wood preservative/wood species combinations*[a].

| | Solution uptake (kg/m$^3$) | | | Initial penetration (mm) by preservative component | | | | Specimens (%) with ≥10 mm penetration by preservative component | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Species | CCA | BC | DOT | CCA Cu | BC Cu | BC B | DOT B | CCA Cu | BC Cu | BC B | DOT B |
| Balsam fir | 418 | 386 | 596 | 5 | 1 | 18 | 41 | 6 | 0 | 54 | 100 |
| Engel. spruce | 406 | 385 | 582 | 10 | 2 | 17 | 39 | 29 | 2 | 33 | 97 |
| Lodgepole pine | 383 | 386 | 471 | 11 | 3 | 17 | 23 | 41 | 3 | 49 | 82 |
| Red spruce | 313 | 325 | 491 | 5 | 2 | 14 | 34 | 15 | 0 | 54 | 100 |
| Sitka spruce | 496 | 392 | 558 | 9 | 1 | 21 | 41 | 32 | 0 | 68 | 100 |
| White spruce | 402 | 412 | 574 | 5 | 1 | 18 | 37 | 9 | 0 | 55 | 97 |

[a] Replicate charges of CCA and DOT and all BC formulations were combined.

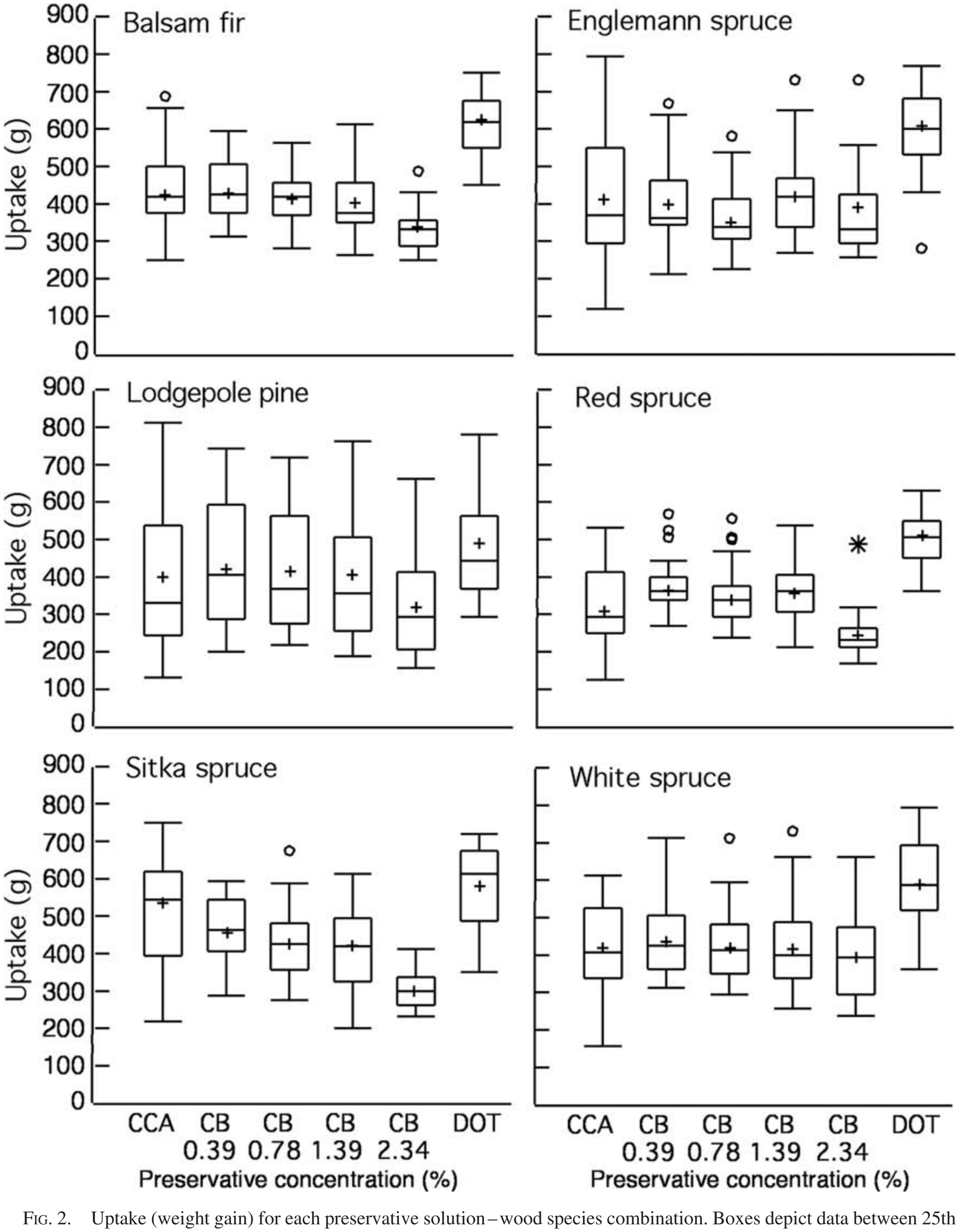


FIG. 2. Uptake (weight gain) for each preservative solution – wood species combination. Boxes depict data between 25th (Q1) and 75th (Q3) percentiles and represent interquartile range (IQR). Horizontal line across box indicates median; plus sign indicates mean. Lower whisker extending from bottom of box indicates data represented by Q1 − (1.5IQR); higher whisker extending from top of box is represented by Q3 + (1.5IQR). Any data beyond these limits are plotted by a circle unless it exceeds either Q1 − (3IQR) or Q3 + (3.0IQR). In this case, data are plotted by an asterisk.

solutions (Table 1). The strength of the BC solution had little consistent effect on copper penetration (Table 2). Although average CCA copper penetration exceeded 10 mm in Engelmann spruce and lodgepole pine (Table 2), this average was skewed upwards by the relatively low proportion of specimens with excellent penetration. Even with the CCA solution, copper penetration did not meet the 10-mm minimum required by AWPA Standards C2–02 and C31–02 (AWPA 2003) (Table 3). Lodgepole pine appeared to have the greatest proportion of specimens meeting the copper penetration standard for CCA; this difference was statistically significant in comparison to penetration in balsam fir and white spruce. Sitka spruce and Engelmann spruce were intermediate in their consistency for achieving 10 mm of penetration. No statistical difference was observed between species for any of the BC formulations, although lodgepole pine tended to have the highest proportion of cores with penetration exceeding 10 mm (Table 3).

### *Boron penetration*

*Penetration immediately after treatment.*— For all species, penetration of boron was much greater than that of copper; this was particularly true for specimens treated with DOT (Table 1). Immediately after treatment, average boron penetration for DOT-treated specimens exceeded 25 mm (1 in.) for all species except lodgepole pine (Table 3, Fig. 3). Lodgepole pine also exhibited the greatest variability in penetration (Fig. 3). Average boron penetration with the DOT solution was greater than that with any BC solution, and the percentage of specimens with at least 10-mm penetration was often statistically greater for DOT. Boron penetration with the DOT treatment exceeded 10 mm in at least 80% of the specimens, indicating that the treatment could meet AWPA penetration standards. There was little difference in boron penetration among the BC solutions, although average penetration tended to be greatest with the 1.39% BC solution and lowest with the 2.34% solution (Table 2). There were also no strong species effects with the BC solutions, although Sitka spruce appeared to be slightly more treatable than the other species (Table 3). The percentage of Sitka spruce specimens with a penetration of at least 10 mm was significantly greater than that of Engelmann spruce for the 0.39% and 0.78% BC

TABLE 2. *Preservative penetration by wood species.*[a]

| Preservative and element | Balsam-fir | | Engel. spruce | | Lodgepole pine | | Red spruce | | Sitka spruce | | White spruce | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | % pass | Mean | % pass | Mean | % pass | Mean | % pass | Mean | % pass | Mean | % pass |
| Copper | | | | | | | | | | | | |
| CCA | 4.7 | 6 A | 10.2 | 29 A | 10.7 | 41 A | 4.7 | 15 A | 9.2 | 32 A | 4.7 | 9 A |
| BC 0.39% | 1.4 | 0 A | 1.4 | 0 B | 1.3 | 0 B | 1.3 | 0 B | 1.0 | 0 B | 1.4 | 0 A |
| BC 0.78% | 1.1 | 0 A | 2.3 | 3 B | 2.4 | 6 B | 1.0 | 0 B | 1.2 | 0 B | 1.1 | 0 A |
| BC 1.39% | 1.2 | 0 A | 1.1 | 0 B | 3.4 | 6 B | 1.2 | 0 B | 1.1 | 0 B | 1.2 | 0 A |
| BC 2.34% | 1.3 | 0 A | 4.8 | 12 AB | 2.9 | 0 B | 1.2 | 0 B | 1.0 | 0 B | 1.4 | 0 A |
| Boron, initial | | | | | | | | | | | | |
| DOT | 41.1 | 100 A | 38.7 | 97 A | 22.6 | 82 A | 33.8 | 100 A | 41.2 | 100 A | 37.5 | 97 A |
| BC 0.39% | 16.7 | 56 B | 17.0 | 41 CD | 16.0 | 50 A | 15.4 | 74 AB | 21.3 | 82 AB | 16.5 | 62 B |
| BC 0.78% | 16.8 | 56 B | 11.4 | 21 D | 17.9 | 53 A | 13.7 | 50 BC | 23.1 | 76 AB | 15.5 | 53 B |
| BC 1.39% | 22.8 | 74 AB | 23.0 | 76 AB | 18.9 | 62 A | 16.3 | 74 AB | 22.6 | 79 AB | 20.4 | 74 AB |
| BC 2.34% | 17.0 | 59 B | 18.0 | 53 BC | 14.7 | 59 A | 9.6 | 35 C | 15.7 | 71 B | 18.4 | 65 B |
| Boron, 2 wk | | | | | | | | | | | | |
| DOT | 41.3 | 100 A | 39.8 | 97 A | 27.1 | 100 A | 35.2 | 100 A | 42.0 | 100 A | 38.3 | 100 A |
| BC 0.39% | 24.4 | 94 A | 21.2 | 71 A | 23.5 | 85 A | 20.3 | 94 AB | 29.3 | 94 A | 24.3 | 91 A |
| BC 0.78% | 24.0 | 82 A | 20.8 | 85 A | 23.9 | 82 A | 18.5 | 82 AB | 28.9 | 88 A | 21.5 | 97 A |
| BC 1.39% | 26.1 | 91 A | 23.9 | 82 A | 23.6 | 91 A | 22.5 | 82 AB | 28.4 | 97 A | 24.5 | 94 A |
| BC 2.34% | 23.6 | 94 A | 24.6 | 82 A | 24.7 | 88 A | 14.7 | 71 B | 28.9 | 100 A | 27.7 | 94 A |

[a] Mean penetration (mm) and percentage of specimens with penetration passing AWPA standards (≥10 mm). Data with common letters represent groups in which the percentage of specimens with ≥10 mm penetration are not statistically different at 0.05 level of significance.

TABLE 3. *Preservative penetration by preservative component*[a].

| Wood species and element | CCA | | BC 0.39% | | BC 0.78% | | BC 1.39% | | BC 2.34% | | DOT | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | % pass | Mean | % pass | Mean | % pass | Mean | % pass | Mean | % pass | Mean | % pass |
| Copper | | | | | | | | | | | | |
| Balsam-fir | 4.7 | 6 B | 1.4 | 0 A | 1.1 | 0 A | 1.2 | 0 A | 1.3 | 0 A | — | — |
| Engel. spruce | 10.2 | 29 AB | 1.4 | 0 A | 2.3 | 3 A | 1.1 | 0 A | 4.8 | 0 A | — | — |
| Lodgepole pine | 10.7 | 41 A | 1.3 | 0 A | 2.4 | 6 A | 3.4 | 6 A | 2.9 | 12 A | — | — |
| Red spruce | 4.7 | 15 AB | 1.3 | 0 A | 1.0 | 0 A | 1.1 | 0 A | 1.2 | 0 A | — | — |
| Sitka spruce | 9.2 | 32 AB | 1.0 | 0 A | 1.2 | 0 A | 1.1 | 0 A | 1.0 | 0 A | — | — |
| White spruce | 4.7 | 9 B | 1.4 | 0 A | 1.1 | 0 A | 1.2 | 0 A | 1.4 | 0 A | — | — |
| Boron, initial | | | | | | | | | | | | |
| Balsam-fir | — | — | 16.7 | 56 AB | 16.8 | 56 A | 22.8 | 74 A | 17.0 | 59 A | 41.2 | 100 A |
| Engel. spruce | — | — | 17.0 | 41 B | 11.4 | 21 B | 23.0 | 76 A | 18.0 | 53 A | 38.7 | 97 A |
| Lodgepole pine | — | — | 16.0 | 50 AB | 17.9 | 53 AB | 18.9 | 62 A | 14.7 | 59 A | 22.6 | 82 B |
| Red spruce | — | — | 15.4 | 74 AB | 13.7 | 50 AB | 16.3 | 74 A | 9.6 | 35 A | 33.8 | 100 A |
| Sitka spruce | — | — | 21.3 | 82 A | 23.1 | 76 A | 22.6 | 79 A | 15.7 | 71 A | 41.2 | 100 A |
| White spruce | — | — | 16.5 | 62 AB | 15.5 | 53 AB | 20.4 | 74 A | 18.4 | 65 A | 37.5 | 97 A |
| Boron, 2 wk | | | | | | | | | | | | |
| Balsam-fir | — | — | 24.4 | 94 A | 24.0 | 82 A | 26.1 | 91 A | 23.6 | 94 A | 41.3 | 100 A |
| Engel. spruce | — | — | 21.2 | 71 B | 20.8 | 85 A | 23.9 | 82 A | 24.6 | 82 A | 39.8 | 97 A |
| Lodgepole pine | — | — | 23.5 | 85 AB | 23.9 | 82 A | 23.6 | 91 A | 24.7 | 88 A | 27.1 | 100 A |
| Red spruce | — | — | 20.3 | 94 A | 18.5 | 82 A | 22.5 | 82 A | 14.7 | 71 A | 35.2 | 100 A |
| Sitka spruce | — | — | 29.3 | 94 A | 28.9 | 88 A | 28.4 | 97 A | 28.9 | 100 A | 42.0 | 100 A |
| White spruce | — | — | 24.3 | 91 AB | 21.5 | 97 A | 24.5 | 94 A | 27.7 | 94 A | 38.3 | 100 A |

[a] Mean penetration (mm) and percentage of specimens with penetration meeting AWPA standards (≥10 mm). Species with common letters represent groups in which percentage of specimens with ≥10 mm penetration are not statistically different at 0.05 level of significance.

solutions. Boron penetration reached 10 mm in over 80% of Sitka spruce specimens treated with 0.39% BC.

*Boron penetration after 2-week diffusion period.*—Boron in the borate solutions evaluated is not fixed within the wood and remains mobile as long as sufficient moisture is present. Although this mobility can be a disadvantage in exposed end-uses, it can be an advantage in improving penetration. In this study, the treated specimens were wet-stacked, in plastic, for 2 weeks following treatment, and boron penetration was then measured and compared to that measured immediately after treatment. An increase in boron penetration was noted for most wood species and treatment solutions (Fig. 3). This increase tended to be greatest for the most concentrated (2.34%) BC solution (Table 3). This finding is not unexpected, as the higher boron concentration on the wood surface would be expected to create a steeper gradient for boron diffusion. Initial penetration also tended to be lower with this concentration, leaving more room for subsequent diffusion. The least improvement occurred with the DOT solution because a high proportion of the specimens had initially been 100% penetrated. The 2-week diffusion period greatly increased the percentage of BC-treated specimens in which boron penetration exceeded 10 mm (Fig. 3). It appears that, in most cases, treatment with these solutions could meet the AWPA standard of 10-mm penetration in at least 80% of the specimens.

## DISCUSSION

The excellent penetration of SPF specimens with the heated DOT solution supports earlier research reported by Baker et al. (2001). Most specimens had 100% penetration after the diffusion period, suggesting that lumber used in construction would be well protected from termite attack even after on-site fabrication. Although boron penetration with the BC solutions was not as great as that found with DOT, borax-based formulations do appear to have the potential to adequately penetrate these species when applied

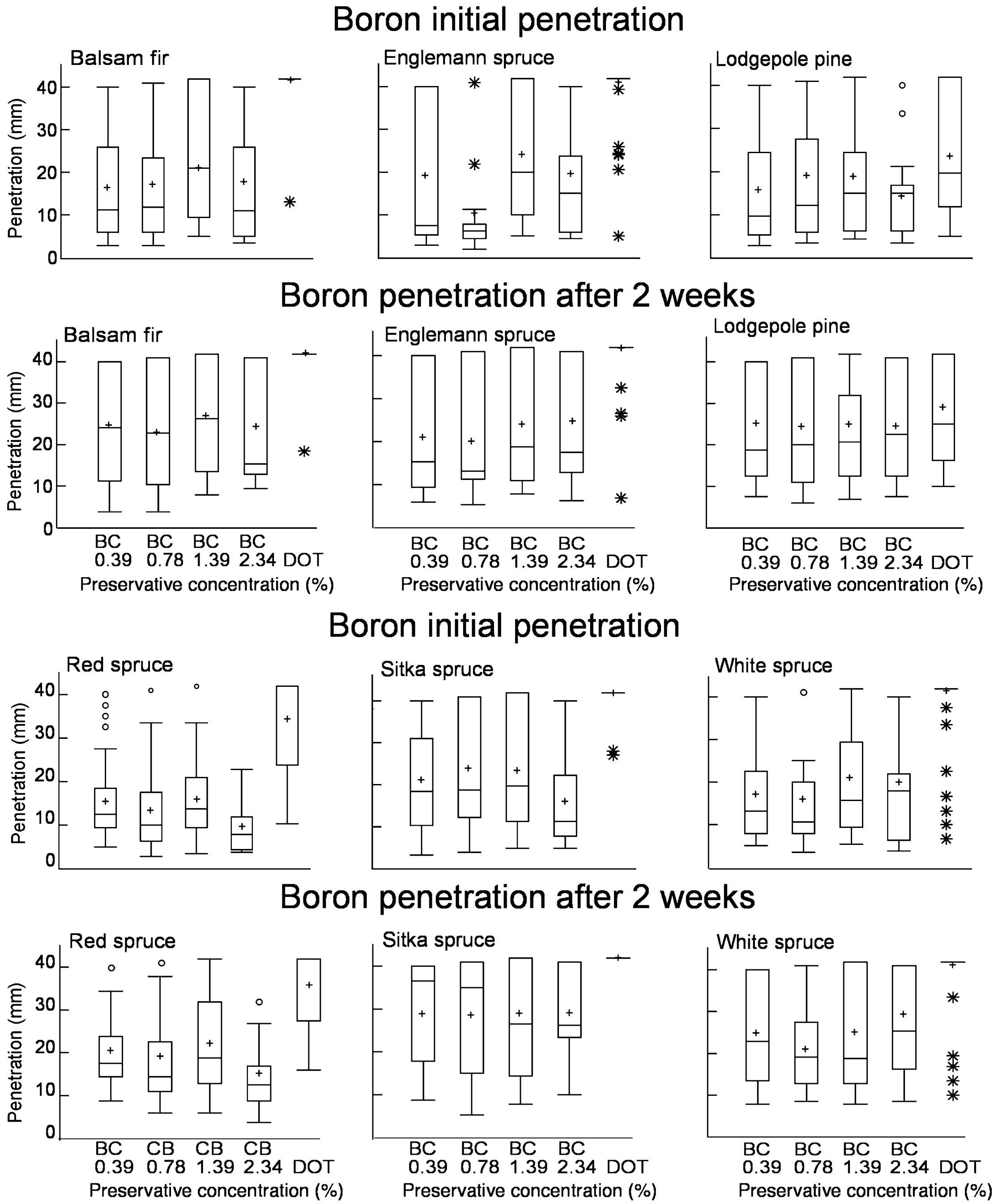


FIG. 3. Boron penetration immediately after treatment and after 2-week diffusion period. See legend to Fig. 2 for explanation of symbols.

in heated solutions and allowed to diffuse after treatment.

It is evident, however, that some care will be needed in applying heat and pressure with these species as collapse was noted in some specimens. In the charge where the temperature controller failed and the solution temperature approached 93°C (200°F), nearly all the specimens exhibited severe collapse. Further consideration of time/temperature limitations in the standards may be warranted. Currently, AWPA standards provide limited guidance on maximum temperature/pressure combinations. Borate treatments have typically been applied under AWPA commodity Standard C31-02, "Lumber used out of contact with the ground and continuously protected from liquid water—treatment by pressure processes" (AWPA 2003). This standard does not provide a temperature limitation for heating in preservative, but it does limit maximum pressure to 1,050 kPa (150 lb/in.$^2$) for treatment of SPF species. The new AWPA processing and treatment standards that have replaced the older commodity standards limit preservative temperatures to 65°C (150°F) for alkali-based formulations and 95°C (200°F) for inorganic boron formulations. Maximum pressure for treatment of SPF species is limited to 1,250 kPa (180 lb/in.$^2$) (AWPA 2003).

In contrast to boron, penetration of copper in these species was poor. This was particularly true for the BC solutions, despite the use of heat. The poor copper penetration with the BC solutions may be a function of the low copper concentration of the solution and the reactivity of copper with the wood substrate. Copper in alkaline treatment solutions reacts rapidly with wood components via ion-exchange or similar reactions (Cooper 1991; Lebow and Morrell 1995; Thomason and Pasek 1997), and it is possible that at low concentrations the bulk of copper was adsorbed from the treating solution in the outer few millimeters of the wood surface. The heated solution may have also increased the rate of these reactions. This phenomenon created a "zonal" treatment in the specimens: boron on the inside surrounded by a thin shell of copper on the surface.

Although no wood species was consistently the most or least treatable, Sitka spruce was generally the species with the greatest boron penetration, while red spruce often had the least penetration. However, species treatability can vary by region, drying practices, and other factors, and this study was not designed to provide a comprehensive comparison of species treatability. Relative species treatability did appear to be a function of treatment solution. Lodgepole pine and Engelmann spruce were among the most treatable species with CCA, but ranked towards the bottom in treatability with the borate solutions. Balsam fir, in contrast, treated poorly with CCA but relatively well with the borate solutions. Some lodgepole pine specimens were similar to ponderosa pine in macroscopic appearance but were determined to be lodgepole pine based on their microscopic anatomy. CCA penetration in these specimens was much greater than in lodgepole specimens with a more typical appearance.

## CONCLUSIONS

This study confirms that heated DOT solutions provide excellent penetration in Spruce–Pine–Fir (SPF) species. It indicates that the boron in a borax-based preservative may also provide adequate penetration if allowed time to diffuse into the wood. The partitioning of copper on the surface of specimens treated with the borax–copper (BC) solutions created a layered treatment in these specimens. It is unclear how this will affect preservative performance, but an ongoing termite evaluation with a subset of these specimens should provide some insight in this area. The use of heated preservative solutions can cause collapse in some wood species, as was observed in some specimens in this study. Further work is needed to define combinations of heat and pressure that will provide adequate penetration while minimizing degradation, and further processing limitations may need to be incorporated into standards of the American Wood Preservers' Association.

## ACKNOWLEDGMENTS

The authors would like to thank Kevin Cheung of the Western Wood Products Association for assistance in obtaining the western SPF–South species and the Northeastern Lumber

Manufacturers Association for obtaining the eastern SPF–South species. We would also like to thank cooperating sawmills, which include, but are not limited to, the Stimson Timber Company (Priest River, Idaho), Trask River Lumber Company (Tillamook, Oregon), and Shearer Lumber Products (Grangeville, Idaho).

## REFERENCES


American Wood Preservers Association (AWPA). 2003. Book of standards. American Wood Preservers Association, Selma, AL. Standard A3-00. Standard methods for determining penetration of preservatives and fire retardants. Standard C2-02. Lumber, timbers, bridge ties and mine ties—treatment by pressure processes. Standard C31-02. Lumber used out of contact with the ground and continuously protected from liquid water—treatment by pressure processes. Standard M2-01. Standard for inspection of wood products treated with preservatives. Standard T1-03. Use category system: Processing and treatment standard.

Baker, C., C. Wilson, S. M. McFarling, and P. I. Morris. 2001. Pressure treatment of Canadian SPF with heated borate solutions. *In* Proc. Canadian Wood Preservation Association 21:69–78.

Choi, S., J. N. R Ruddick, and P. Morris. 2004. Chemical redistribution in CCA-treated decking. Forest Prod. J. 54(3):33–37.

Cooper, P. A. 1991. Cation exchange adsorption of copper on wood. Wood Protection 1(1):9–14.

Gjovik, L. R., and D. R. Schumann. 1992. Treatability of native softwood species of the northeastern United States. Res. Pap. FPL-RP-508. USDA, Forest Serv., Forest Prod. Lab., Madison, WI. 20 pp.

Grace, J. K., R. J. Oshiro, T. Byrne, P. I. Morris, and K. Tsunoda. 2001. Performance of borate-treated lumber in a four-year, above-ground termite field test in Hawaii. Int. Res. Group Wood Preserv. IRG/WP 01-30265. Stockholm, Sweden.

Lebow, S. T., and J. J. Morrell. 1995. Interactions of ammoniacal copper zinc arsenate (ACZA) with Douglas-fir. Wood Fiber Sci. 27(2):105–118.

Morris, P. I., J. K. Grace, K. Tsunoda, and A. Byrne. 2003. Performance of borate-treated wood against *Reticulitermes flavipes* in above-ground protected conditions. Int. Res. Group Wood Preserv. IRG/WP 03-30309. Stockholm, Sweden.

———, J. K. Ingram, J. N. R. Ruddick, and S. M. Choi. 2004. Protection of untreated wood by adjacent CCA-treated wood. Forest Prod. J. 54(3):29–32.

Richards, M. J., and R. D. Inwards. 1989. Treatability with CCA and initiation of field performance testing of refractory softwoods. *In* Proc. Canadian Wood Preservation Association. Vancouver, BC. 10:144–178.

Shupe, T. F., and M. A. Dunn. 2000. The Formosan subterranean termite in Louisiana: Implications for the forest products industry. Forest Prod. J. 50(5):10–18.

Smith, W. B. 1986. Treatability of several northeastern species with chromated copper arsenate wood preservative. Forest Prod. J. 36(7/8):63–69.

———, W. S. McNamara, and R. J. Ziobro. 1998. Field performance of CCA-treated timber from the Northeastern U.S. *In* Proc. Am. Wood Preserv. Assoc. 94:117–118.

Thomason, S. A., and E. A. Pasek. 1997. Amine copper reaction with wood components: Acidity versus copper adsorption. Int. Res. Group Wood Preserv. IRG/WP 97-30161. Stockholm, Sweden.