FORMOSAN AND NATIVE SUBTERRANEAN TERMITE ATTACK OF PRESSURE-TREATED SPF WOOD SPECIES EXPOSED IN LOUISIANA

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ABSTRACT

This study evaluated the relative ability of three types of wood preservatives to inhibit attack by Formosan subterranean termites (FST) (*Coptotermes formosanus* Shiraki) and native subterranean termites (*Reticulitermes* spp.). The study also evaluated the roles of preservative retention and penetration in preventing termite damage. Sections of boards from six wood species within the Spruce–Pine–Fir species group were pressure-treated with one of four concentrations of a borax–copper (BC) preservative composed of 93% borax (sodium tetraborate decahydrate) and 7% technical copper hydroxide or one concentration of disodium octaborate tetrahydrate (DOT) or chromated copper arsenate (CCA). Specimens were cut after treatment, exposing untreated end-grain in specimens not completely penetrated by preservative. The specimens were exposed above-ground, protected from the weather, at a site with populations of both native and FST near Lake Charles, Louisiana. Specimens were rated for extent of termite attack after 6, 12, and 24 months of exposure. Attack by FST was more severe than that by native termites for all preservative treatments, although this difference was less obvious at higher preservative retentions. For all treatments, termites preferred to attack the center of the end-grain of the specimens where preservative was either absent or at a lower concentration. However, CCA, which had the lowest overall penetration, was more effective than either borate preservative in preventing attack, whereas some DOT- and BC-treated specimens suffered attack even with what appeared to be complete boron penetration. These results indicate that the efficacy of shell treatments in preventing termite attack is a function of the type of preservative. The BC wood preservative protected wood from both native and Formosan termite attack at B_2O_3 concentrations equivalent to or lower than that of DOT treatments.

Keywords: Borates, CCA, Formosan subterranean termites, Louisiana, native subterranean termites, penetration, retention, shell treatment, SPF.

INTRODUCTION

The introduction and spread of Formosan subterranean termites (*Coptotermes formosanus* Shiraki) (FST) in the southern United States have increased the need for preservative treatments to protect wood products from termite attack (Shupe and Dunn 2000). Of particular concern is the protection of framing lumber used in residential and commercial structures. Because of their large colony sizes and aggressive foraging patterns, FST are considered to be a greater threat to wooden structures than the native (*Reticulitermes* spp.) termites (Shupe and Dunn 2000). The FST are also thought to be somewhat more resistant to some types of wood preservatives, although this has been difficult to quantify. The preservative most commonly used for treatment of framing lumber is disodium octaborate tetrahydrate (DOT). Numerous researchers have evaluated the efficacy of DOT in protecting wood from termite attack (Drysdale 1994; Grace and Yamamoto 1994a; Grace et al. 1992; Preston et al. 1996; Preston et al. 1986). On the basis of these studies, borates have been standardized for interior treatments at retentions of 2.8 kg/m^3 for areas with native subterranean termites and 4.5 kg/m^3 (as B_2O_3) for areas with FST (AWPA 2003). Less information is available on the concentrations of other types of borate systems, such as those based on borax, needed to prevent attack by FST. On a weight basis, borax converts to the equivalent of 37% B_2O_3, whereas DOT converts to the equivalent of 67% B_2O_3. However, whether B_2O_3 equivalents are an appropriate measure of the termiticidal properties of a borate compound is unclear. The solution chemistry of borates is complex (Eisler 1990) and multiple boron species likely exist within the treated wood.

Previous researchers have also reported that wood treated to relatively high DOT retentions may sustain some attack or "browsing" by FST (Grace et al. 1992; Grace et al. 2001; Grace and Yamamoto 1994a; Preston et al. 1996). Some feeding may occur because borates are not termite repellants, and the toxic effects are not immediate (Grace et al. 1992). However, Grace and Yamamoto (1994b) have also attributed this attack to localized variations in DOT retention within the wood substrate. This latter finding raises the concern that framing lumber not completely penetrated with preservative may be vulnerable to FST attack. Whereas much of the framing lumber used in the southern United States is southern pine, a species group with easily treated sapwood, a substantial portion of the framing market is supplied from the Spruce–Pine–Fir (SPF) species group. (When considered in its broadest terms, the SPF species group includes subalpine fir, balsam fir, jack pine, lodgepole pine, red pine, black spruce, Engelmann spruce, red spruce, Sitka spruce, and white spruce.) The SPF species are generally considered to be difficult to treat (refractory) or variable in their treatability (Gjovik and Schumann 1992; Richards and Inwards 1989; Smith 1986). Recent studies have found that DOT penetration in these species is greater than that experienced with CCA (Baker et al. 2001; Lebow et al. 2005), and that treatability with a borax-based preservative is intermediate between CCA and DOT (Lebow et al. 2005). Current treatment standards, however, require preservative penetration of only 10 mm in SPF species (AWPA 2003), and researchers are concerned that construction activities will create breaks in the treated shell and expose the untreated core to termite attack. Experience has shown that shell treatments are effective in preventing rapid fungal degradation of treated wood exposed above ground (Choi et al. 2004; Morris et al. 2004; Smith et al. 1998); however, less evidence exists of the efficacy of such treatments in preventing termite damage. Morris et al. (2003) and Grace et al. (2001) evaluated the performance of DOT and CCA shell treatments of western hemlock *(Tsuga heterophylla* Raf. Sarg.) and Pacific silver fir (*Abies amabilis* Dougl. ex Forbes) against *Reticulitermes flavipes* (Kollar) and *C. formosanus* termites and found that protection was generally good. Peters and Creffield (2003, 2004) also concluded that shell treatments of deltamethrin and permethrin were effective in preventing attack by the Australian termites *Coptotermes acinaciformis* (Froggatt) and *Schedorhinotermes seclusus* (Hill). In contrast, a subsequent study reported that *Coptotermes acinaciformis* (Froggatt) readily attacks the exposed end-grain of wood protected only by a shell treatment of permethrin (Lenz et al. 2004).

In this study, we exposed specimens of SPF species with shell treatments of three types of wood preservatives to attack by both native and FST at a Louisiana test site. The results of this study reveal the relative tolerance of FST and native termites to three types of wood preservatives and demonstrate the roles of preservative retention and penetration in preventing termite attack. The specimens exposed in this study are a subset of the samples generated in an earlier study of the treatability of SPF lumber with CCA and borate preservatives (Lebow et al. 2005).

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* (L.) Mill), Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), Sitka spruce (*P. sitchensis* (Bong.) Carr.), red spruce (*P. rubens* Sarg.), white spruce (*P. glauca* (Moench) Voss), and lodgepole pine (*Pinus contorta* Dougl. ex Loud.). With the assistance of the Western Wood Products Association and the Northeastern Lumber Manufacturers Association, packets of 38-mm by 89-mm by 2.4-m-long boards of each species were obtained from mills in the northeastern, midwestern, and northwestern United States. From these packets, boards were selected that would allow removal of defect-free samples, yielding a total of 34 boards of each species. The relative content of heartwood and sapwood was ignored in this selection process. Six 305-mm-long specimens were cut from each board and conditioned to a constant weight in a room maintained at 23°C 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

1. Borax–copper (BC) (trade name Cu-Bor, Copper Care Wood Preservatives, Inc., Co-

lumbus, Nebraska) is used commercially as a paste for remedial treatment of utility poles and other large wooden members. Although it does have a U.S. Environmental Protection Agency (EPA) label for pressure and treatment, this use remains largely experimental. Borax–copper with an active composition of 7.2% technical copper hydroxide and 92.8% sodium tetraborate decahydrate (10 mole borax) formulation was evaluated with treatment solutions containing 0.49%, 0.78%, 1.39%, and 2.34% active ingredients. These solution concentrations resulted in average retentions of 0.60, 1.20, 2.40, and 3.53 kg/m^3. The EPA label for pressure treatment with this preservative calls for retentions ranging from 1.48 to 2.96 kg/m^3.

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, resulting in an average retention of 6.1 kg/m^3. This compares to the AWPA specified retentions of 4.01kg/m^3 for wood used aboveground and 6.4 kg/m^3 for wood used in contact with the ground (AWPA 2003).
3. Disodium octaborate tetrahydrate (DOT), considered 100% DOT active. This formulation was evaluated with a 1.86% solution concentration resulting in an average of retention of 4.19 kg/m^3. This compares to the AWPA specified retention of 4.5 kg/m^3 for wood exposed to attack by *C. formosanus* (AWPA 2003).

Treatment groups

The study used 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. The large number of specimens was used to satisfy the requirements for the treatability evaluation. For the termite evaluation discussed in this paper, a subset of 10 replicates was randomly selected from each treatment group.

Treatment conditions

All treatments were conducted using a full-cell pressure process. The vacuum was maintained at −75 kPa for 30 min; pressure was maintained at 1.03 MPa for 5 h. To improve preservative penetration, the DOT solution and all BC solutions were heated to 66°C, and this temperature was maintained throughout the pressure period. 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-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-long section was then cut from each specimen, oven-dried, and used to determine boron penetration after diffusion. In this paper, only the boron penetration after diffusion is reported, as it best reflects

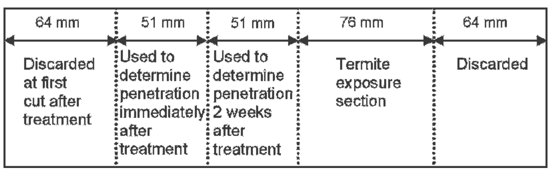

FIG. 1. Pattern of cutting 305-mm-long samples after treatment to determine penetration and obtain specimens for subsequent termite evaluations.

the extent of penetration at the time of termite exposure. For further details on initial penetration and the extent of penetration increase during the diffusion period, see Lebow et al., 2005. For the 10 samples selected from each treatment group for termite exposure, another 76-mm-long section was cut from the samples. This section was removed at a distance of 64 mm from the end of the specimen (Fig. 1), allowing for exposure of untreated end-grain.

Preservative penetration

After drying, the 51-mm-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 C31–02 (AWPA 2003). We evaluated penetration of both copper and boron for the BC treatments, evaluated only copper for the CCA treatment, and only boron for the DOT treatment. 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 in accordance with 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 of preservative penetration (AWPA 2003).

Termite exposure

Installation.—The exposure test was conducted at a site within Sam Houston Jones State Park near Lake Charles, Louisiana. Untreated stakes were first placed within the park and used to locate areas with FST activity. On the basis of the results of this preliminary evaluation, an area inaccessible to the public was selected within a fenced deer pasture because the attack on the untreated stakes suggested high FST activity. In June 2002, the 360 specimens (10 replicates of each wood species–preservative solution combination) were randomly assigned to positions in rows with 305-mm spacing between specimens. The presence of fencing and wetland areas dictated that the samples be placed in two "subplots" separated by several meters of low ground.

The specimens were exposed using a slight modification of a technique previously described and used by Amburgey et al. (1993). In this method, the test specimen is supported approximately 100 mm above the ground by an untreated southern pine sapwood "feeder stake" that is driven 70–90 mm into the ground (Fig. 2). Holes drilled in the feeder stake provide a direct route from the soil through the feeder stake to the test specimen. An advantage of this method is that the feeder stake serves as an untreated control for each specimen as well as a larger volume of wood for collecting and identifying the type of termite associated with that specimen. The test specimen was placed in the bait stake with one of the cross-sections oriented

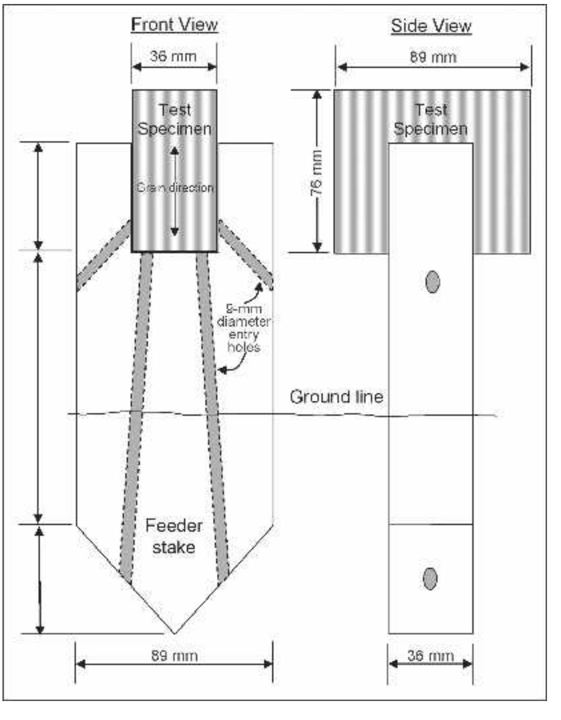

FIG. 2. Test units used to expose specimens to termite attack. Units were covered with capped PVC pipe (not shown) to provide protection from the weather.

down. This presents a severe test of the shell treatment because the holes drilled into the feeder stake lead directly to the center of the specimen cross-section. For protection from the weather, each feeder stake–specimen test unit is enclosed within a section of capped PVC pipe.

Inspection and ratings.—The specimens were placed at the site in June 2002 and subsequently rated after 6, 12, and 24 months of exposure. At each inspection, the feeder stakes were first examined for evidence of termite attack. If the feeder stake showed evidence of termite activity, the specimen was given a visual rating for termite attack based on a 10, 9, 8, 7, 6, 4, 0 rating system (Table 1). If the feeder stake was not attacked, that specimen was considered "not tested." We identified the type of termite attack (FST or native) on the basis of the appearance of soldiers, ratio of soldiers to workers, and appearance of the attacked wood. In 23 of the 360 specimens, we were not able to determine the type of termite attacking a specimen, and the rating for those specimens was recorded as "unknown." At each inspection, feeder stakes suffering more than slight attack were replaced. In this report, only the 24-month ratings are presented, as they represent the cumulative damage to each test specimen.

Statistical analysis of extent of termite attack

A statistical analysis was conducted on the 24-month data to better determine if the type of treatment solution or type of termite affected the severity of termite attack. Specimens for which the type of attack was not determined were not included in the analysis. For the purposes of this evaluation, the results for individual wood species were combined within each treatment group. A statistical analysis of variance was conducted using the SAS GLM (SAS Institute, Inc., Cary, North Carolina) procedure in conjunction with a Tukey studentized range test on average ratings for termite attack. Table 2 shows the results of the Tukey mean separations for each type of treatment solution and type of termite. In this table, preservatives solutions having common letters represent groups in which the average termite ratings are not statistically different at the 0.05 level.

TABLE 1. *Rating system for severity of termite attack.*

Rating	Description of condition
10	Sound; one to two small nibbles permitted
9	Slight evidence of feeding to 3% of cross section
8	Attack from 3% to 10% of cross section
7	Attack from 10% to 30% of cross section
6	Attack from 30% to 50% of cross section
4	Attack from 50% to 75% of cross section
0	Failure

RESULTS

Preservative treatment

The four BC treatment solution concentrations evaluated in this study resulted in average retentions that ranged from 0.60 to 3.53 kg/m^3 (Table 2). Retention was fairly uniform between species with the exception of the relatively low retention in red spruce treated with the highest BC solution concentration. The average DOT retention for specimens of all species (4.19 kg/m^3) was slightly below that specified by AWPA standards (4.5 kg/m^3) for treatment of wood exposed to attack by FST (AWPA 2003). Only the average retention of Sitka spruce specimens met or exceeded the AWPA requirement. Retention of CCA in the specimens was well above the 4.0 kg/m^3 specified for protection of wood against FST attack (AWPA 2003). Preservative penetration in the samples varied greatly by preservative formulation and preservative component. The greatest penetration was achieved with the boron in the DOT treatments (Table 2), whereas penetration of copper in the BC treatments was limited to a few millimeters (Table 2). Boron penetration in the BC treatments was not as great as that in the DOT treatments but still generally exceeded the minimum penetration of 10 mm required for these species in AWPA standards (AWPA 2003). Boron penetration was lowest for the lowest BC treatment solution concentration. Average copper penetration with the CCA treatments exceeded 10 mm in Engelmann

TABLE 2. *Average specimen preservative retention, penetration, and termite attack ratings after 24 months of exposure.*

					Number of specimens attacked by each type of termite and corresponding ratings after 24-month exposure					
			Penetration (mm)		Formosan			Native		
Preservative	Wood species	Retention (kg/m^3 total oxides)	Cu	B	Reps	Average[a]	Min	Reps	Average[a]	Min
BC 0.49%	Balsam fir	0.60	1.2	12.0	4	8.0	7	6	9.2	8
	Engel. spruce	0.60	1.3	11.5	3	3.7	0	7	7.4	0
	Lodge. pine	0.62	1.5	20.4	5	7.4	7	4	9.3	8
	Red spruce	0.59	1.7	17.6	7	5.1	0	3	8.0	7
	Sitka spruce	0.60	1.1	19.8	8	5.6	0	2	8.5	8
	White spruce	0.59	1.3	13.7	7	4.4	0	2	9.5	9
	All species	**0.60**	**1.3**	**15.8**	**34**	**5.7 C**	**0**	**24**	**8.5 B**	**0**
BC 0.78%	Balsam fir	1.20	1.1	24.1	4	7.8	6	5	8.6	8
	Engel. spruce	1.19	5.7	23.1	6	6.8	6	2	9.3	9
	Lodge. pine	1.20	1.7	21.7	2	7.5	7	8	9.0	8
	Red spruce	1.17	1.1	16.3	4	4.3	0	3	9.3	9
	Sitka spruce	1.22	1.4	23.4	5	5.8	0	5	8.2	7
	White spruce	1.19	1.1	18.0	5	7.6	7	5	8.2	7
	All species	**1.20**	**1.9**	**21.2**	**26**	**6.6 BC**	**0**	**29**	**8.7 B**	**7**
BC 1.39%	Balsam fir	2.40	1.1	30.6	5	8.2	8	5	9.4	0
	Engel. spruce	2.38	1.1	25.0	3	7.3	6	6	8.3	8
	Lodge. pine	2.43	3.5	24.2	4	7.3	6	6	9.2	8
	Red spruce	2.38	1.1	28.0	5	7.4	6	4	8.5	8
	Sitka spruce	2.40	1.1	29.1	5	7.2	7	4	8.8	8
	White spruce	2.39	1.1	26.0	6	7.0	6	4	8.5	8
	All species	**2.40**	**1.5**	**27.2**	**28**	**7.4 B**	**6**	**29**	**8.8 B**	**8**
BC 2.34%	Balsam fir	3.70	1.3	30.4	5	8.6	7	5	9.2	8
	Engel. spruce	3.76	5.1	27.7	5	6.8	6	4	9.0	8
	Lodge. pine	3.76	4.1	25.7	4	8.8	8	5	8.8	8
	Red spruce	2.85	1.2	18.7	4	7.0	7	6	8.8	8
	Sitka spruce	3.28	1.1	28.4	2	7.5	7	5	9.0	8
	White spruce	3.76	1.6	27.1	2	8.5	8	7	8.7	8
	All species	**3.53**	**2.4**	**26.6**	**22**	**7.8 AB**	**7**	**34**	**8.9 AB**	**8**
DOT 1.86%	Balsam fir	4.31	—	42.0	5	8.4	8	4	9.8	9
	Engel. spruce	4.00	—	38.8	3	6.7	6	5	9.2	8
	Lodge. pine	3.97	—	30.6	3	7.3	7	7	9.3	8
	Red spruce	4.02	—	40.1	2	7.5	7	7	9.4	8
	Sitka spruce	4.61	—	42.0	2	7.0	7	7	8.9	8
	White spruce	4.16	—	39.2	5	8.0	8	5	9.2	8
	All species	**4.19**	**—**	**38.9**	**20**	**7.7 B**	**6**	**35**	**9.3 AB**	**8**
CCA 1.14%	Balsam fir	6.16	6.9	—	4	9.5	8	5	9.6	9
	Engel. spruce	6.38	19.2	—	6	9.5	9	4	10.0	10
	Lodge. pine	6.39	16.3	—	7	9.3	9	3	10.0	10
	Red spruce	5.26	6.9	—	5	8.4	7	4	9.5	9
	Sitka spruce	6.42	7.7	—	5	9.0	8	4	10.0	10
	White spruce	6.29	7.1	—	5	9.2	9	4	9.0	8
	All species	**6.13**	**11.0**	**—**	**32**	**9.2 A**	**7**	**24**	**9.7 A**	**8**

[a] Within each column of average termite ratings, means that share common letters are not statistically different (alpha = 0.05). Mean separations apply only to averages that combine all wood species.

spruce and lodgepole pine but was much lower in the other species. The retention and penetration results presented in this study are limited to the subset of specimens exposed to termite attack. A more thorough discussion of the treatability of these preservative–wood species combinations can be found in Lebow et al. (2005).

Termite resistance

For all species considered, the type of termite attack experienced by the specimen–feeder stake assemblies was largely a function of location within the plot. Assemblies exposed in the northern area of the plot were more likely to be attacked by FST, whereas those in the southern part of the plot were more likely to be attacked by native termites. Because the test specimens were assigned locations randomly throughout the entire plot, the two types of termite attack were not evenly distributed across the treatment groups. For example, in some treatment groups as few as 2 of 10 replicates were attacked by FST, while the other 8 replicates were attacked by native termites, or vice versa (Table 2). Because of the limited number of replicates for some treatment group–type-of-termite combinations, statistical analysis was not practical at the treatment group–wood species level. Trends do become apparent, however, when comparing the averages for combined wood species for each treatment group. One trend is that average and minimum ratings for specimens attacked by FST are lower (greater feeding) than those for specimens attacked by native subterranean termites (Table 2). This trend was most apparent for the DOT treatment and the lower retentions of BC treatments, where it was statistically significant with over 99% probability. Although less obvious for CCA, the difference between FST and native ratings was still significant at the 98% confidence level.

In comparing preservative formulations, it is apparent that the CCA-treated wood was most resistant to attack by both FST and native termites. In the case of specimens attacked by FST, ratings of CCA-treated specimens were significantly higher than all other treatments except the highest concentration of BC (2.34%). There was no significant difference between the DOT ratings and the ratings of the specimens treated with the three highest BC concentrations. Specimens treated with the two lowest retentions of the BC treatments were the least resistant to termite attack, whereas the two highest BC retentions performed similarly to the DOT treatment. In the case of attack by native termites, we found no significant difference between the ratings for specimens treated with CCA, DOT, or the highest BC retention. There was also no significant difference between the ratings for DOT and any of the BC treatments.

Preservative retention appeared to be more of a factor in prevention of FST attack than in prevention of native termite attack. A slight positive correlation was noted between retention and FST attack rating for all treatments, but there appeared to be little correlation between BC and DOT retentions and the extent of termite attack by native termites (Fig. 3). The exception to this trend was the CCA treatments, where native and Formosan termites responded similarly to varying retentions. Somewhat surprisingly, even less correlation was observed between extent of pre-

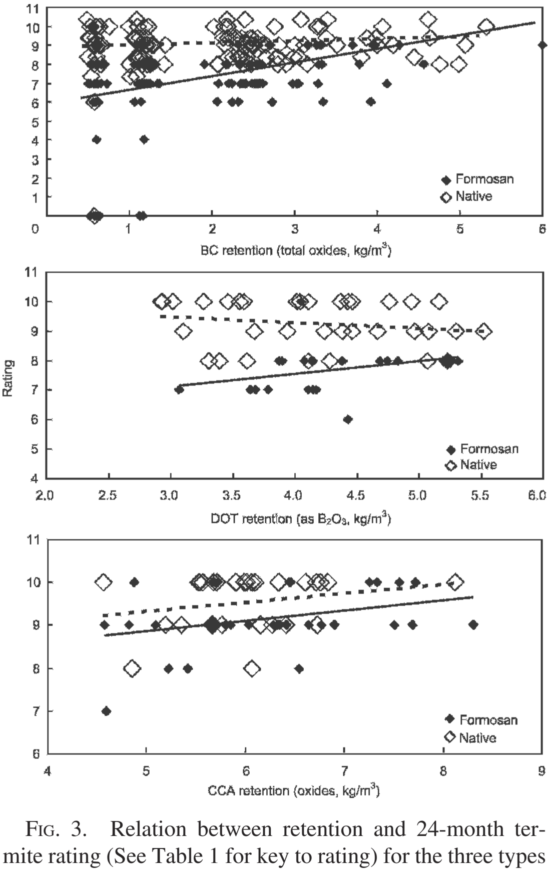

FIG. 3. Relation between retention and 24-month termite rating (See Table 1 for key to rating) for the three types of preservatives and two types of termites. Wood species have been combined.

servative penetration and termite rating for any of the preservatives (Fig. 4). None of the CCA specimens with over 17-mm penetration was rated lower than a 9 for termite attack. Most of the DOT-treated specimens were completely penetrated, and those that were not penetrated were located in the area of the plot attacked by native termites.

DISCUSSION

The results of this study support previous reports (Grace 1997; Green et al. 2000a, b) that the extent of FST attack is greater than that of native termites, and FST are more capable of damaging preservative-treated wood. In the past, these comparisons have been based on samples exposed in laboratories or in widely separated geographic locations where differences in climate and environmental conditions could be expected to influence severity of attack. In this study, we are able to directly compare the extent of native and FST attack on matched samples exposed in the same field conditions. The FST damage was more rapid and more severe than native termite attack. Although these differences were greatest in the untreated feeder stakes and for the lower BC retentions, some difference was also evident with higher BC concentrations and with the DOT treatment. These findings indicate that preservatives effective in preventing FST damage will be at least as effective in preventing damage by native termites.

With the exception of the DOT treatments, most of the specimens exposed in this study were not completely penetrated with preservatives. This was particularly the case for the CCA treatment. With all treatments, both native and Formosan termites preferred to attack the specimens through the poorly treated end-grain at the center of the specimen. This pattern of attack suggests that the shell treatment was a key factor in determining presence and extent of termite attack. This explanation, however, conflicts with the lack of correlation observed between preservative penetration and extent of termite attack (Fig. 4). One explanation for this lack of correlation is that the boron indicator used to assess penetration only detects the presence of boron above the detection limit. It does not quantify the amount of boron, and likely a gradient of boron concentration developed across the cross-section, with lower concentrations in the interior of the specimens. This hypothesis is in agreement with the research of Grace and Yamamoto (1994b), who attributed attack of DOT-treated specimens to localized variations in preservative retention within the wood substrate. Some attack of specimens treated with higher borate concentrations may have also occurred because borates do not repel termites, and toxicity after ingestion is delayed (Grace et al. 1992). Attacks of borate shell treatments in this study were generally more rapid and severe than reported by Grace et al. (2001) and Morris et al. (2003). This is prob-

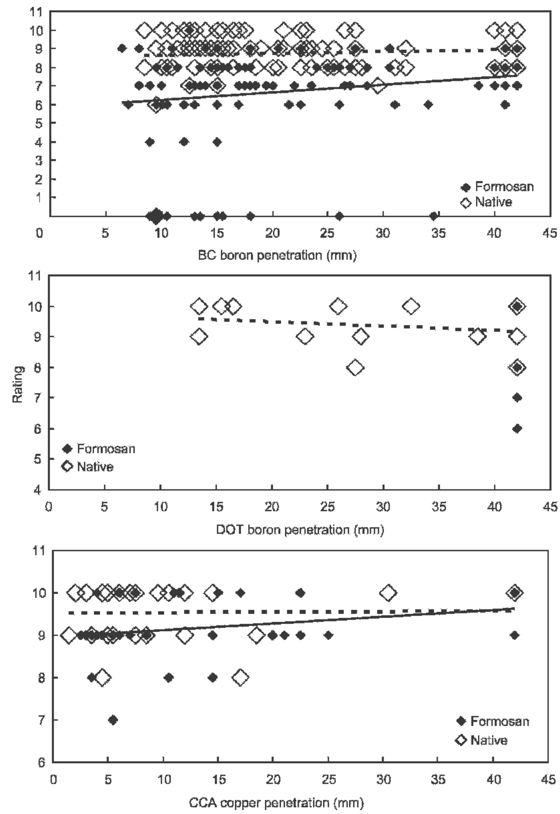

FIG. 4. Relation between penetration and 24-month termite rating (See Table 1 for key to rating) for the three types of preservatives and two types of termites. Wood species have been combined.

ably attributed to differences in test design and location. The data also suggest that the efficacy of a shell treatment is preservative-dependent, as the CCA-treated specimens had the lowest penetration but highest termite ratings (least attack). Possibly some component of the CCA treatment is volatilizing and deterring termite attack, but previous studies have not indicated that CCA is a termite repellent (Grace 1998; Grace and Yamamoto 1994a). The average CCA retention in these specimens was greater than that specified for protection against FST attack (AWPA 2003). However, even in specimens with lower retentions, little termite attack was noted. The interaction between preservative formulation and shell treatment efficacy has become more relevant as the development of alternatives to CCA continues. Treatment with CCA can no longer be used in many applications where FST attack is a concern, and the efficacy of the alternatives is less understood. Achieving adequate penetration during treatment should remain a priority, as should the avoidance of construction practices that breach the treated shell.

The two highest retention BC treatments appeared to be at least as effective in preventing FST as DOT, even though the BC retentions were lower. Possibly the synergism between copper and boron, or the formation of a copper–boron complex, increased the efficacy of this preservative against termites. Previous work has also suggested that the combinations of copper and boron are more effective than boron alone (Amburgey and Freeman 1993). However, the poor penetration of copper in the BC-treated specimens in this study would have limited copper's contribution to very near the surface of the wood. An alternative explanation is that the form of boron applied (borax versus DOT) affected the efficacy of the boron, or the amine component of BC had some inhibitory effect.

At the lowest BC retention, the severity of both FST and native termite attack appeared to be greater for the four species of spruce evaluated than for either balsam-fir or lodgepole pine (Table 2). Various authors have reported that native and FST termite feeding and severity of attack vary greatly with wood species, with the differences attributed to factors such as extractive content, density, or wood anatomy (Arango et al. 2004; Morales-Ramos and Rojas 2001; Kard and Mallette 1997). It is not clear how these factors may have influenced termites to attack spruce wood more heavily than balsam-fir, although it is possible that the balsam-fir specimens contained more heartwood or a higher concentration of undesirable extractives. The species differences observed in this study do not appear to be a function of their respective treatability, but these differences did become less apparent at higher BC retentions or with the CCA or DOT treatments. This suggests that differences among these species will not be a major concern for commercial treatments.

CONCLUSIONS

The results of this study indicate that a BC wood preservative can protect wood from both native and Formosan termite attack at B_2O_3 concentrations equivalent to or lower than that of DOT treatments. Possibly, low levels of copper in the BC preservative may have provided improved protection of the wood surface, or the form of borate may have influenced its efficacy. Attack by Formosan termites was more severe than that of native termites for all preservatives and wood species, even under identical site conditions. For all treatments, termites preferred to attack the center of the end-grain of the specimens where preservative was either absent or at a lower concentration. The CCA, which had the lowest overall penetration, was more effective than either borate preservative in preventing attack, whereas some DOT- and BC-treated specimens suffered attack even with what appeared to be complete boron penetration. These results indicate that the efficacy of shell treatments in preventing termite attack is a function of the type of preservative as well as the depth of penetration. The termites appeared to prefer feeding on the spruce wood species in comparison to balsam-fir or lodgepole pine, but this trend became less evident at higher preservative concentrations.

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