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August 22, 2000

James Gauntt
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Dear Jim:

Enclosed is a pre-proposal entitled, "TREATMENT OF CROSSTIES REMOVED FROM TRACK TO PREVENT THE SPREAD OF THE FORMOSAN SUBTERRANEAN TERMITE". If you have any questions, please feel free to contact me.

Sincerely,

Terry L. Amburgey
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TLA/nkb

Enclosure

Forest and Wildlife Research Center
Mississippi Forest Products Laboratory

RESEARCH PRE-PROPOSAL

TREATMENT OF CROSSTIES REMOVED FROM TRACK TO PREVENT THE SPREAD OF THE FORMOSAN SUBTERRANEAN TERMITE

Submitted to:

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Documentation: Letter from Terry Amburgey to Gauntt dated June 14, 2000.

Submitted by:

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August 22, 2000

TREATMENT OF CROSSTIES REMOVED FROM TRACK TO PREVENT THE SPREAD OF THE FORMOSAN SUBTERRANEAN TERMITE

Evidence indicates that at least one source of movement of formosan subterranean termites (*Coptotermes formosanus)* from areas of infestation to non-infested regions is via used crossties (Forschler *et al.*, 2000). This being the case, it is imperative that both railroads operating in regions known to be infested by *C. formosanus* and tie producers supplying ties to those regions develop strategies for dealing with this problem before state/federal regulations dictate how they will do business. Regions of immediate concern are the southern third of Louisiana, Mississippi, Alabama, and all of Florida. Other regions likely will be added to this list.

Borates are known to have both insecticidal and fungicidal properties as well as having the capacity to diffuse through non-seasoned wood. This was the basis for an earlier study that I did in cooperation with the Railway Tie Association. In that study, ties were dip-treated with borates prior to being placed in an air-drying facility to protect them from insect and fungal deterioration during storage and to protect the centers of ties after subsequent treatment with creosote. This technology should be used to protect ties being placed in *C. formosanus* - prone regions.

Fumigation has been used to treat a variety of products to control insect infestations. This technology could be used to eliminate the possibility of transporting *C. formosanus* in used ties to other regions of the country.

STUDY PLAN

A. New crossties

New crossties should be treated with borates, seasoned, re-treated with creosote, and placed in-line in regions such as southern Louisiana. Permanent test sites should be established and monitored for *C. formosanus* activity annually for a minimum of five years. Untreated wood stakes could be placed adjacent to the test ties to "bait"
C. formosanus. Each site should be established as follows:

a. 10 borate-creosote treated white oak
b. 10 creosote treated white oak

c. 10 borate treated white oak
d. 10 borate-creosote treated red oak
e. 10 creosote treated red oak
f. 10 borate treated red oak
g. 10 borate-creosote treated gum
h. 10 creosote treated gum
i. 10 borate treated gum

Two untreated southern pine stakes will be driven between the ties after every third tie. These will be monitored annually for *C. formosanus* activity. If stakes become colonized, ties adjacent to them will be removed from track after two years and sectioned to determine if they have become colonized. If no stakes become colonized, the fifth tie in each treatment group will be removed and sectioned to determine possible interior deterioration. The remaining ties will continue to be monitored annually.

B. Borate-treated ties in line

Records will be searched to determine if anyone has borate-treated ties in line in regions known to be infested by *C. formosanus*. If such ties are found, permanent test sites should be established to include both the borate treated ties and adjacent ties treated with only creosote . Two borate-treated and two creosote-treated ties should be removed, sectioned, and examined for internal deterioration at year one. Untreated southern pine stakes should be driven between both borate-treated and creosote-treated ties and monitored annually for *C. formosanus* activity. Continued monitoring and/or tie removal will be as discussed under "new ties."

C. Stake test

Stakes (approximately 2 x 4 x 18-inches) of white oak, red oak, and gum will be pressure treated with creosote, borate, or borate followed by creosote. Untreated stakes of all three species groups will serve as controls. Following treatment, the stakes will be exposed horizontally at a test site known to be infested with *C. formosanus*. The stakes will be monitored annually for five years to determine extent of colonization by *C. formosanus*.

D. Used crossties

Ties removed from track in regions known to be infested with *C. formosanus* will be examined for signs of active infestation. Infested ties will be accumulated at one location, tarped, and fumigated. Terminix has agreed to cooperate with this project and to do the necessary fumigations. Fred Strickland, Director of Technical/Training Division for Terminix has given verbal approval for their cooperation. Douglas Webb will be in charge of all fumigation activities.

Following fumigation, representative ties will be sectioned and examined for live *C. formosanus*.

Cost

If RTA is interested in any or all of the studies described, a detailed budget will be furnished.

Literature Cited

Forschler, B.T., J. Harron, & T.M. Jenkins. 2000. Case histories involving attempts at identifying infestations, determining the source and controlling the formosan subterranean termite in Atlanta, Georgia, USA. International Research Group on Wood Preservation, paper IRG/WP 00-10342. 11pp.

Repeated exposure of borate-treated Douglas-fir lumber to Formosan subterranean termites in an accelerated field test

J. Kenneth Grace
Robin T. Yamamoto

Abstract

Douglas-fir boards (ca. 74.5 g) pressure treated with disodium octaborate tetrahydrate (DOT) to retentions of 0 (controls), 0.88, 1.23, 1.60, or 2.10 percent (weight/weight) DOT were sequentially exposed to four active field colonies of Formosan subterranean termites, *Coptotermes formosanus* Shiraki (Isoptera: Rhinotermitidae), in an aboveground field test. Samples were placed in contact with each colony for 10 weeks, with ovendry weight losses determined between exposures, for a total termite exposure period of 40 weeks. Feeding activity differed among termite colonies. The two lower borate retentions (0.88% and 1.23% DOT) were virtually equal in efficacy, with mean wood weight losses during each individual 10-week exposure ranging from 1.2 to 4.6 percent. Feeding was negligible on wood treated to the two higher borate retentions. Mean wood weight losses from termite feeding during each 10-week period ranged from 0.7 to 1.3 percent with an initial retention of 1.60 percent DOT, and 0.3 to 0.9 percent with 2.10 percent DOT. Total cumulative wood weight losses over the 40-week exposure were: 10.2 percent (0.88% DOT), 8.7 percent (1.23% DOT), 3.6 percent (1.60% DOT), and 2.4 percent (2.10% DOT). Under conditions of high termite hazard, wood treatment to retentions greater than 1 percent DOT can be expected to provide protection from serious structural damage, although minor feeding may still occur. Treatment to higher retentions can be expected to progressively minimize the possibility of minor cosmetic damage.

Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) lumber, pressure treated with various wood preservatives, is used extensively in building construction in western North America and Hawaii (9). In Hawaii, termites (Isoptera) are generally more destructive than decay fungi to wood in service, and the most destructive termite species is the Formosan subterranean termite, *Coptotermes formosanus* Shiraki (Family Rhinotermitidae). Recently, disodium octaborate tetrahydrate (DOT, as TIM-BOR®) has become available in Hawaii as a pressure treatment for Douglas-fir (1). Lumber stamped with the HI-BOR® quality mark has a minimum retention of 1.1 percent DOT (1.32% boric acid equivalent (BAE)) by weight in an 0.6-inch assay zone (4).

A previous 23-week field test established that a cross-sectional retention of 0.85 percent DOT (1.02% BAE) was sufficient to restrict wood weight loss from termite feeding to less than 3 percent of the initial weight (3). These results raised the question of whether this very minor feeding could be further minimized by treatment to even higher DOT retentions; that is, whether any retention of DOT was sufficient to guarantee that minor cosmetic damage would not occur. We also wished to determine whether repeated termite invasions over the life of a structure and attempts to feed on the treated wood by different Formosan subterranean termite colonies could lead to greater cumulative damage to the wood.

In the present study, Douglas-fir lumber pressure-treated to cross-sectional retentions from 0.88 to 2.10 percent DOT (1.06% to 2.52% BAE) was exposed

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Forest Prod. J. 44(1):65-67.

TABLE 1. — *Weight losses of borate-treated Douglas-fir boards (ca. 74.5 g) during each sequential 10-week exposure to four Formosan subterranean termite field colonies.*

DOT	BAE	Wood weight losses during each 10-week termite exposure[a]							
		1st		2nd		3rd		4th	
(%)	(%)	(g)	(%)	(g)	(%)	(g)	(%)	(g)	(%)
2.10	2.52	0.7 ± 0.2 A	0.9 ± 0.2	0.4 ± 0.3 A	0.6 ± 0.4	0.3 ± 0.2 A	0.4 ± 0.3	0.5 ± 0.2 A	0.7 ± 0.3
1.60	1.92	0.6 ± 0.1 A	0.7 ± 0.1	0.7 ± 0.5 AB	0.8 ± 0.5	0.8 ± 0.4 AB	0.9 ± 0.5	1.0 ± 0.4 A	1.3 ± 0.5
1.23	1.48	1.3 ± 0.7 A	2.0 ± 1.0	0.7 ± 0.2 AB	1.2 ± 0.4	2.7 ± 2.1 B	4.4 ± 3.4	0.9 ± 0.8 A	1.5 ± 1.3
0.88	1.06	1.6 ± 1.2 A	2.0 ± 1.4	1.0 ± 0.5 AB	1.2 ± 0.5	2.5 ± 2.2 AB	3.1 ± 2.7	3.4 ± 1.2 AB	4.6 ± 1.7
0	0	10.9 ± 4.3 B	15.1 ± 5.9	1.1 ± 0.4 B	1.6 ± 0.5	1.0 ± 1.0 AB	1.3 ± 1.4	10.1 ± 10.4 B	14.1 ± 14.7

[a] Each mean (±SD) represents four boards pressure impregnated with disodium octaborate tetrahydrate (DOT) (expressed as cross-sectional weight/weight percent DOT or boric acid equivalents (BAE)). New control boards were used during each exposure. Means within a column followed by the same capital letter are not significantly different (ANOVA, Duncan's Multiple-Range Test, $p = 0.05$).

TABLE 2. — *Cumulative weight losses of borate-treated Douglas-fir boards (ca. 74.5 g) during four 10-week exposures to Formosan subterranean termite field colonies.*

DOT	BAE	Cumulative percent wood weight loss[a]				Final wood weight loss
		10 weeks	20 weeks	30 weeks	40 weeks	
(%)	(%)	(%)	(%)	(%)	(%)	(g)
2.10	2.52	0.9 ± 0.2	1.4 ± 0.2	1.8 ± 0.5	2.4 ± 0.8	1.9 ± 0.5 A
1.60	1.92	0.7 ± 0.1	1.5 ± 0.5	2.4 ± 1.0	3.6 ± 0.8	3.1 ± 0.7 AB
1.23	1.48	2.0 ± 1.0	3.1 ± 0.6	7.4 ± 3.0	8.7 ± 2.3	5.6 ± 1.5 B
0.88	1.06	2.0 ± 1.4	3.1 ± 0.8	6.1 ± 3.4	10.2 ± 3.6	8.5 ± 3.1 C

[a] Each mean (±SD) represents four boards pressure-impregnated with disodium octaborate tetrahydrate (DOT) (expressed as the cross-sectional weight/weight percent DOT or boric acid equivalents (BAE)). Means within the last column followed by the same capital letter are not significantly different (ANOVA, Duncan's Multiple-Range Test, $p = 0.05$).

sequentially to three separate *C. formosanus* field colonies, and twice to the first termite colony, for a total of four sequential 10-week field tests. We used a rigorous field test protocol, in which the wood samples were placed directly into active termite feeding sites within traps established to monitor and collect termites from each of these colonies (2,7,8).

Experimental procedure

Douglas-fir heartwood boards (nominal 1 by 4 in. lumber) measuring 8.5 by 8.5 by 1.8 cm (averaging 74.5 g each) were pressure impregnated with DOT (TIM-BOR, United States Borax and Chemical Corporation, Los Angeles, Calif.) by a modified full-cell process (4). DOT retentions were determined by weight gain, and confirmed by ashing selected samples, extracting the residue, and using inductively coupled plasma (ICP) spectroscopy to determine boron in solution (4). Four wood samples each were pressure impregnated to retentions of 0.88, 1.23, 1.60, or 2.10 percent DOT.

Four sequential 10-week aboveground field tests (total 40-week exposure) were conducted using Formosan subterranean termite colonies located on the Manoa campus of the University of Hawaii, and at the Poamoho Experiment Station near Waialua on the island of Oahu, Hawaii. Boards were ovendried (90°C for 72 hr.) before and after each termite exposure to determine weight losses from termite feeding. Each board was placed over the open end of a rectangular box (termite trap) constructed of untreated Douglas-fir and placed on the soil surface, protected by a covered 5-gallon metal can with the bottom removed. This trap design was first described as a means of collecting termites (7), and has been used in field evaluations of ACZA (8) and DOT (3). In all cases, termites had been actively foraging on an untreated wood box placed within each can immediately prior to its replacement with a new box and the test sample.

After three sequential 10-week exposures, each to a different termite colony, the samples were exposed again for 10 weeks to the first colony tested, since this colony was noted to have fed considerably more on the control (untreated) samples than either of the other two termite colonies. Differences in feeding activity among termite colonies have been documented in other studies (6), although the basis for these differences is not understood. The foraging populations of the three colonies were estimated, using a mark-release-recapture method (2), to be approximately 1.0, 1.6, and 2.4 million.

Weight losses of the test samples after each 10-week termite exposure and cumulative weight losses after 40 weeks were subjected to analysis of variance (ANOVA) and means significantly different at the 0.05 level were separated by Duncan's Multiple-Range Test (5).

Results and discussion

At least minor evidence of termite feeding was noted on all test boards, and the degree of cosmetic damage was negatively correlated with DOT retention. With wood treated to the highest retention of 2.10 percent DOT (2.52% BAE), extremely shallow feeding depressions were visible on the wood surface at the end of the 40 weeks of termite exposure. However, weight losses from termite "tasting" at 2.10 percent DOT averaged less than 1 percent of the initial wood weight during each 10-week exposure, for a cumulative weight loss of only 2.4 percent after 40 weeks (Tables 1 and 2).

With wood treated to the lowest preservative retention of 0.88 percent DOT (1.06% BAE), the mean cumulative wood weight loss after 40 weeks of 10.2 percent (Table 2) exceeded the 2.5 percent weight loss recorded in our previous field test with wood treated to a comparable retention (0.85% DOT) after 23 weeks of exposure to a single *C. formosanus* colony (3). These results indicate that increasing damage to DOT-treated wood can occur from repeated exploratory attacks by different termite colonies, although each attack may be of brief duration. However, it must be emphasized that this was an extremely rigorous field test in which wood samples were physically moved from colony to colony. In practice, the likelihood of attack on wood in service in structures by multiple Formosan subterranean termite colonies should be much less than was the case in this field test, and such attacks would likely occur over a period of many years. It is also possible that the repeated drying cyles to which our wood samples were exposed might modify boron distribution in the wood samples to some extent. The affects of such rigorous conditions on boron distribution in pressure-treated wood are currently under investigation (4).

In our view, it is prudent to consider any preservative-treated wood as "termite resistant" rather than "termite proof," and as one component of a termite management program. Termite-resistant architectural design, frequent building inspections, and the presence of chemical or physical barriers in the soil beneath and around the structure are important in reducing termite pressure on both the treated wood and other cellulosic materials within the structure. Under conditions of high Formosan subterranean termite hazard, wood treatment to retentions greater than 1 percent DOT can be expected to provide protection from serious structural damage, although some termite feeding may still occur. Our results demonstrate that wood treatment to progressively higher DOT retentions can be expected to progressively minimize, although not completely eliminate, the possibility of minor cosmetic damage to the wood surface.

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Review of Recent Research on the Use of Borates for Termite Prevention

J. Kenneth Grace

Abstract

This paper presents a critical review of recent research on the use of borates for prevention and control of termites. This includes studies of borates as insecticidal dusts, baits for subterranean termite control, insecticides for soil treatment, and solutions for application to structural lumber. It also includes more traditional uses as preservatives for composite and solid wood products. Although it is not without controversy, research performed within the past few years allows us to draw some general conclusions concerning the potential for the use of borates in these various applications, the relative toxicity of borates to different termite species, and the threshold retentions required for protection of wood products from destruction by termites.

Introduction

In recent years, a number of authors have reviewed the development of borate wood preservatives and their efficacy against insects and decay fungi (2,4,28, 32,52). This paper presents a critical review and analysis of recently published research on the use of borates for termite control. Emphasis is given to wood preservation, either by the application of borate solutions to the surface of lumber; diffusion, pressure, or vapor treatment of wood products; or by incorporation of borates into wood composites or exterior coatings. However, I also include a discussion of other possible borate applications of interest to the pest control industry: insecticidal dusts, soil treatments, and baits for termite control. Papers delivered by members of that industry at this conference demonstrated a great deal of creativity in exploring remedial applications of borate products within termite-infested or termite-threatened structures. It is hoped that this summary of the available technical literature on borate efficacy will be of value both to individuals interested in wood preservation and to those whose focus is pest control in buildings.

Insecticidal dusts

Insecticidal dusts such as Paris green, arsenic trioxide, and mirex have a history of use in termite control (6,27,55). These dusts are either blown into termite galleries in infested lumber; or termites are trapped in cardboard or wood placed in the vicinity of the infestation, dusted by topical application of the insecticide powder, and then released back into the gallery system to be groomed by (and thus kill) other members of the termite colony. Grace et al. (10,14,15) and Myles and Grace (37) investigated such applications of boric acid, barium metaborate, zinc borate, and disodium octaborate tetrahydrate (DOT). Of these, boric acid and barium metaborate proved most effective, while zinc borate was slightly

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The author thanks Mark J. Manning (U.S. Borax Inc.), Paul I. Morris, and Tony Byrne (Forintek Canada Corp.), and Alan F. Preston (Chemical Specialities Inc.) for various helpful discussions; and M.J. Manning and P.I. Morris for their collaboration in regression analysis of the results of field studies. Partial support for University of Hawaii studies referenced in this review was provided by McIntire-Stennis funds and by USDA-ARS Specific Cooperative Agreement 58-6615-4-037. This is J. Series No. 4284 of the Hawaii Inst. of Tropical Agri. and Human Resources.

more effective than DOT with *Reticulitermes flavipes*, but not with *Coptotermes formosanus*. To achieve satisfactory control of the eastern subterranean termite, *R. flavipes*, it was necessary to directly treat at least 10 percent of the total termite population with boric acid or barium metaborate dusts; or about 15 percent of the population with zinc borate or DOT (10,14, 15). However, Myles and Grace (37) found that this proportion could be reduced by about 50 percent when an adjuvant (sticker) was also applied to increase adhesion of particles to the insect cuticle. Borates are less toxic to the Formosan subterranean termite, *C. formosanus*, than to *R. flavipes* (47,49) and dust treatment of about 20 percent of the population was necessary to control this termite species. Certainly, borate dust applications may have application in some field situations, but the very large size of many subterranean termite colonies, numbering into the millions of individuals (11), would appear to make it difficult to trap and treat a large enough proportion of the population to have a significant impact in terms of pest control.

Soil treatment

Despite potential difficulties posed by their movement in liquid water and phytotoxicity in high concentrations, borates have also been investigated as soil insecticides to prevent or remediate subterranean termite infestation in structures (7,9,10,25). In this type of application, soil insecticides are applied as a termite barrier to the soil immediately adjacent to the perimeter building foundation (either by digging and then treating a narrow trench, or by injection through holes drilled through exterior concrete walkways or an interior concrete slab), around piers, and within any earth-filled porches or planters adjoining the structure. However, in laboratory tests both *R. flavipes* and *C. formosanus* tunneled through soil containing as much as 15,000 ppm zinc borate or DOT, due to the lack of repellence and the delayed mode of action characteristic of borates (7,9,10). *Reticulitermes flavipes* was more sensitive to borate toxicity, possibly due to a difference in the tunneling behavior of *R. flavipes* and *C. formosanus*, and these high borate concentrations in the soil caused 70 to 90 percent termite mortality after 1 week of exposure (10). Although borates cannot be relied upon as a traditional insecticide barrier treatment, these results suggest that relatively insoluble borate salts could indeed be applied to the soil around stumps and other cellulosic termite food materials to reduce the population of foraging termites in the vicinity. Although it seems impractical today due to costs and logistics, this integrated pest management approach to termite control could be taken still further in a zone approach by treating the soil immediately adjacent to the structure with a repellent insecticide such as a pyrethroid, and then treating a second outer concentric zone around the structure with a nonrepellent but toxic borate (7).

Baits for termite control

The very properties that are problematic in terms of using borates for soil treatment (lack of repellence and slow toxic action) favor their use in baits to suppress termite populations. In Japan, pulverized newspapers mixed with *o*-boric acid and borax have been applied in a layer under buildings for *C. formosanus* and *Reticulitermes speratus* control (35). It was observed that *R. speratus* activity ceased in less than 1 month, while *C. formosanus* activity disappeared in 6 months to 1 year (35), although few experimental details were provided. Other researchers have tried to define, in laboratory or field tests, the concentrations of borates in bait matrices that would allow continued termite feeding and slow toxicity without stimulating any avoidance behavior on the part of the termite foragers. In a 2-week laboratory test, Jones (24) observed that the desert termite *Heterotermes aureus* fed slightly less on predecayed wood containing 0.96 percent boric acid equivalents (BAE) than on untreated control wood, although there was still extensive feeding on wood containing as much as 1.7 percent BAE. The use of decayed wood, which contains compounds that encourage termite feeding, may account for this relatively high level of borate acceptability, since *H. aureus* was inhibited by 1.2 percent BAE in field tests with treated paper, although readily feeding upon paper with 0.6 percent BAE. From these studies, the author concluded that concentrations of 0.25 to 0.5 percent DOT were optimal for baiting *H. aureus*. These are comparable to the concentrations in treated paper of 0.1 to 0.5 percent barium metaborate (8) and 0.25 percent DOT (15), identified in laboratory studies as acceptable bait dosages for *R. flavipes*. In a laboratory study with vacuum-treated wood wafers, Su and Scheffrahn (45) observed much lower thresholds for borate avoidance, and suggested appropriate targets for bait development to be 0.045 to 0.09 percent DOT with *R. flavipes*, and 0.045 to 0.18 percent DOT with *C. formosanus*. Differences in the borate avoidance thresholds suggested by different researchers may be attributable to the use of different bait matrices, since it is more difficult to obtain uniform impregnation of wood wafers than of paper.

A difficulty in the use of borates as termite baits is the relatively large quantity of boron required for termite mortality and thus the slow mode of action of baits containing small amounts of boron in comparison to other possible bait toxicants (16). Field studies have demonstrated a reduction in the number of termites present following application of borate baits (5,23,24), but the effects may be too subtle to detect for many months or even years when large termite colonies such as those characteristic of *C. formosanus* are involved (22). Thus, as with soil treatment, borate baits would undoubtably be helpful in the long term, but do not appear sufficient as a sole method of structural protection. Given the dramatic effects of termite infestation, it is debatable whether subtly helpful techniques are of real value in control efforts.

Remedial applications to structural lumber

Another borate application of interest to the pest control industry is the use of water-based or glycol-based solutions of DOT for *in situ* applications to structural lumber. In laboratory tests in small containers under conditions of fairly high humidity where termites were very likely to contact the DOT-treated wood surface, both types of DOT solutions caused high termite mortality (18,21,46,50). There was more rapid mortality with glycol-based solutions, possibly due to termite grooming behavior after contact with the treated surface, and a single application of DOT/glycol or multiple applications of DOT/water solutions could prevent termite penetration of the treated surface. However, diffusion of boron into lumber was found to be extremely slow under normal field conditions, and even multiple applications of DOT solutions to the surface provided negligible protection to interior wood further than 6 mm beneath the surface (21). Thus, one or two applications of DOT/glycol or three to four applications of DOT/water-based solutions can provide a protective shell treatment to the wood surface, but pest control professionals should remember that untreated board surfaces and the interior wood are still vulnerable to termite attack. One simply cannot obtain results equivalent to pressure impregnation or dip-diffusion by spraying structural framing with DOT solutions. By the same measure, field tests indicate that termites already tunneling in the interior wood are relatively unaffected by solutions applied to the wood surface (21,44). Despite these limitations, preventing direct termite penetration of the board surface certainly has utility in termite control, possibly in preventing drywood termite alates (swarmers) from colonizing structural lumber.

Toxicity and mode of action

The mechanism of borate toxicity to termites is poorly understood. Although the numbers of symbiotic protozoa harbored in the termite gut decrease in borate-exposed termites, termite mortality occurs more rapidly than can be reasonably explained by defaunation and starvation, and toxic action more likely occurs at the cellular level (22,38,39,48). Certainly, different termite species exhibit different levels of susceptibility to borates, which has implications for both pest control treatments and wood preservation, particularly within geographic regions where a number of different pest species occur. The LD_{50} (dose required to kill 50% of a test population) of boric acid is between 264 to 370 μg/g BAE for *R. flavipes* and between 560 to 722 μg/g BAE for *C. formosanus*, indicating that boric acid is 1.5 to 2.7 times more toxic to *R. flavipes* than to *C. formosanus* (47,49). Tokoro and Su (49) found DOT to be somewhat more toxic than boric acid alone to termites, with LD_{50} values of 168 μg/g BAE for *R. flavipes* and 486 μg/g BAE for *C. formosanus*.

Protection of composite products

The greatest role of borates in termite control is likely to continue to be in pretreatment of wood products used in construction. Certainly, initial results incorporating borates, and particularly less-soluble borates, into composite products are promising. Aspen waferboard incorporating DOT at a concentration of 1 percent BAE showed no evidence of termite feeding in a 32-day laboratory test with *R. flavipes* (36). Similar laboratory tests against *Reticulitermes lucifugus* with OSB vapor-treated with trimethyl borate produced similar results above about 0.18 percent BAE, although slight attack was noted on almost all of the test samples, even with retentions as high as 1.16 percent BAE (40). In field tests with *C. formosanus* in Hawaii, waferboard containing zinc borate at target retentions of 0.5 percent BAE showed very little feeding after 4 years, and boards with zinc borate retentions of 1.5 percent BAE were essentially untouched (26). Waferboard treated with DOT did not perform well in this field test, however, due to leaching of the boron under the conditions of at least 300 cm of rainfall found at this test site. Although the test boards had been placed on hollow concrete blocks above soil grade and covered by a wooden box, chemical analyzes of the test samples after 4 years demonstrated leaching of about 85 percent of the boron from the DOT samples due to water wicking up the concrete blocks from the damp soil (26). Under such rigorous environmental conditions, the low solubility of zinc borate was a distinct advantage.

Protection of solid wood products

Dip-diffusion and pressure treatment of solid wood products are currently, and historically, the most popular applications of borates in wood protection. Although the knowledge base on termite performance from laboratory and field studies continues to expand, and is not without controversy, sufficient information is available to allow us to draw some general conclusions concerning the threshold boron retentions required for protection from *Reticulitermes* and *Coptotermes*. Given the differential toxicity of borates to these two different termite genera (47,49), it is not surprising that greater retentions are required for *Coptotermes*. On the other hand lower concentrations appear to be effective against the dampwood termite *Zootermopsis angusticollis* (30).

In laboratory studies with *Reticulitermes*, a 0.3 percent BAE retention in banak held wood mass loss to 2.5 percent or less (53); while in two additional studies, treatment of southern pine to 0.1 to 0.3 percent BAE (depending upon the particular test) (33), and to 0.11 to 0.43 percent BAE (45) was sufficient to hold wood mass loss to less than 3 percent. In an additional laboratory study, filter papers impregnated with 0.6 percent BAE sustained an average 6.5 percent mass loss, but their placement in direct contact with damp sand likely led to depletion of boron from the papers during the test and lower actual BAE levels than reported (15).

Effective values from field tests with *Reticulitermes* fall well within the range of retentions indicated by the laboratory tests. Southern pine treated to a target 0.13 percent BAE was protected from significant damage for at least 16 months (42); while in another field test, pine treated to 0.1 percent BAE received an average visual rating of 7.5 on the 0–10 AWPA scale after 18 months, and 0.3 percent BAE resulted in almost no visible termite feeding (rating of 9.6) in this same period (33).

Higher thresholds than those recorded with *Reticulitermes* termites are reported from laboratory and field studies with *C. formosanus*. In laboratory studies, 0.64 percent BAE was required in banak for a maximum 2.5 percent mass loss (53), while 0.54 percent BAE (33) and 0.43 to 0.86 percent BAE (again, depending upon the particular test conditions) were needed in southern pine to hold mass loss to 4 percent or less (45). In laboratory tests with Douglas-fir heartwood, 0.8 percent BAE resulted in a 3.6 percent mass loss, and 1.18 percent BAE held mass loss to less than 3 percent (22,48). Treatment of sugi (*Cryptomeria japonica*) sapwood to the slightly lower retention of 0.67 percent limited wood mass loss from *C. formosanus* feeding to 2 percent (51).

In field studies with treated southern pine, no visible evidence of attack was noted on samples treated to 1.24 percent BAE after 2 years of exposure at a site infested by *C. formosanus*. Samples treated to 0.54 percent BAE had minimal damage in this same period (rating of 9) (43). A 5-week field test of hoop pine and slash pine against the Australian species *Coptotermes acinaciformis* led Moffat and Peters (34) to fit a dose-response curve to these data, indicating that approximately 0.5 percent BAE was necessary for 3 percent or less wood mass loss. These authors cautioned that the large degree of variation in borate distribution within treated boards and in the pattern of attack by different termite species make values based upon average borate retentions in the treated material somewhat misleading (34). Indeed, the distribution of boron in treated boards, and subsequent redistribution or depletion of boron with moisture flux, are important concerns both in evaluating the results of field tests and in commercial treatment of refractory species.

In a 2-1/2-year field test of treated Douglas-fir against *C. formosanus*, 21 samples treated to an average 0.63 percent BAE by uptake sustained severe feeding on 10 of the samples (rated 2 to 4 on a 0–4 scale), while 11 of the samples were untouched (1). The authors recently reinterpreted these data, commenting that individual samples up to the highest target retention of about 1.0 percent BAE included in this test were destroyed by termite attack after 3 years of exposure (41). Although the authors attribute these failures to lack of efficacy of the target BAE retentions, one cannot discount the possible impacts of nonhomogeneous distribution of boron in this refractory species and/or depletion of boron from the samples during the exposure period, as was documented with waferboard tested under similar conditions in this same geographic location (26).

The difficulty of obtaining a homogeneous distribution of boron by pressure treatment and the possibility of termite attack upon specific sections of the treated boards where the local boron concentration may fall below the necessary retention are key problems in commercial treatment, particularly with refractory wood species (19,31,34). For example, although small Douglas-fir heartwood boards carefully treated to 1.02 percent BAE held wood mass loss to 2.5 percent in a 23-week *C. formosanus* field test (22), Grace and Yamamoto (19) found that thin cross-sectional slices from a single commercially treated (target 1.32% BAE) 2 by 4 board actually ranged from 0.77 percent BAE to 1.34 percent BAE. *Coptotermes* feeding on cross-sectional slices with retentions of 1.0 percent BAE or greater was minimal (rating of 9), while sections with retentions of 0.77 percent BAE and 0.91 percent BAE received proportionally greater attack (rating of 7). On a commercial scale, the difficulty of obtaining homogeneous treatment could be addressed either by treatment to high target retentions to insure that all portions of the treated lumber are above the required boron threshold, or by the use of incising technology to enhance preservative penetration.

Termites will attempt to feed when they encounter borate-treated wood, due to the nonrepellent nature of borates. This is true of waterborne preservatives such as CCA as well (3,13,29), but the need to ingest a greater quantity of boron and its slower mode of action compared to arsenic result in slower termite mortality and therefore a greater degree of cosmetic damage to the wood surface. Although it has yet to be demonstrated in the field, it is likely that termites dying in the vicinity of the treated wood deter other termites from foraging in the area. In a field test in which borate-treated Douglas-fir was deliberately exposed to different termite colonies by moving the wood from one field site to another for a total of four successive exposures, minor feeding occurred each time a new colony encountered the wood, although 1.92 percent BAE held the final 40-week mass loss to 3.1 percent (20). It should be stressed that this was not equivalent to, and likely to be more rigorous than, a single 40-week exposure at one field site. Rather, the wood was placed directly in contact with foraging termites from a series of different colonies, each numbering in the millions of individuals, in order to simulate the type of termite exploration that might occur over a long period of time in a structure invaded repeatedly by new termite colonies.

In a 2-year field test in Kagoshima, Japan, with both *R. speratus* and *C. formosanus*, Pacific silver fir samples treated to 1.2 percent or 2.2 percent BAE were rated 0.3 (two out of eight rated one) and 0.1 (one out of eight rated one), respectively, on the IUFRO scale of 0 (sound) to 4 (destroyed), in contrast to a rating of 2.2 for the controls (51). In a similar 1-year field test against *C. formosanus* in Hawaii, fir treated to 1.2 percent BAE sustained an average mass loss of 4.5 percent, while 2.2 percent BAE held mass loss to 1.2 percent in comparison to the 34.7 percent mass loss of untreated control boards (17).

When the results of a series of published *C. formosanus* field tests performed over the past several years by University of Hawaii researchers (17,20,22, 48) are normalized to reflect mass loss over a 52-week period, regression of percentage wood mass loss as a function of borate retention takes the form of an exponential equation $y = 80.33e^{-2.4165x}$ with $r^2 = 0.88$. This is similar in form to the exponential relationships reported by Williams et al. (53) from laboratory tests with both *C. formosanus* and *R. flavipes*, and by Moffat and Peters (34) from field studies with *C. acinaciformis*. However, Preston and colleagues (41) reported a very weak exponential correlation ($r^2 = 0.31$) between borate retention and performance in a 1-year above-ground field test with short lengths of DOT-treated Douglas-fir 2 by 4 boards. In large part, this poor correlation can be attributed to severe damage by *C. formosanus* (rating of 3 on a scale of 0–4) to three boards treated to overall average retentions of 1.41 percent, 1.66 percent, and 3.02 percent BAE. Lesser but significant damage (rating of 2) was also noted to three boards treated to average retentions of 1.36 percent, 1.45 percent, and 1.45 percent BAE (41).

It is interesting to note that a much stronger exponential relationship between borate retention and performance, and one similar to the regressions mentioned above from other studies, can be derived from the data of Preston et al. (41) if the three individual boards with the greatest amount of damage are removed from the analysis. This raises the question of whether the observed damage might be attributable, at least in part, to heterogenous distribution of boron in the wood samples and/or depletion of boron by leaching in the course of the study. It is not possible to directly assess the impact of treatment procedures or moisture conditions on these results, since average (whole-board) borate retentions were based upon treating solution uptake, and chemical analyses of within-board boron distribution and post-test retentions were not part of this particular study. However, similar pressure-treatment of short (43 to 61 cm) Douglas-fir 2 by 4s was reported to result in a 2- to 9-fold differential in DOT retentions from the ends to the centers of the boards (31). The value of assessing borate retentions at the end of the field exposure, as well as the beginning, is emphasized by the 85 percent depletion of boron from DOT-treated waferboard samples after 4 years of exposure in this same geographic location (Hilo, Hawaii), also in a protected above-ground test on hollow concrete blocks (26). Still another variable that can impact field results is the unpredictable foraging behavior of *C. formosanus*. This can result in variable attack on the different test units, an effect that can be minimized by "prebaiting" termites at a particular field site and then placing the test samples directly into the already established foraging locations (12).

Concluding remarks

In summary, the technical information developed on borates in the past several years has helped to better define their conditions of use and is generally supportive of their role in protecting wood from termite attack. However, both the target termite species and the wood species need to be considered in wood preservative treatment. Architects and contractors also need to make appropriate use of borate-treated wood products and recognize conditions where depletion could occur. In remedial treatments, pest control operators need to have realistic expectations since surface applications of borate solutions can provide protection to treated surfaces, but wood has limited permeability under normal structural conditions. Neither borates nor any other currently available wood preservative nor termite control product should be considered a "miracle drug" to completely alleviate the threat of termite infestation. Rather, a multi-tactic approach is required to construct buildings that are as termite-resistant as possible and to protect existing structures. Such an approach represents the integration of good architectural design, physical barriers to termite penetration, steps to modify environmental conditions conducive to termite growth and survival, appropriate termite-resistant wood products, insecticides, baits, and possibly even biological control agents.

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Summary of the Efficacy of Borate Pressure-Treatment in Protecting Wood from Attack by Formosan Subterranean Termites

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As requested by the Director and Building Superintendent, here is a brief summary of relevant laboratory and field evaluations of the efficacy of borate treatment in protecting wood from attack by Formosan subterranean termites, *Coptotermes formosanus*. For each study, I have given the affiliation of the principle author, and the date that the report was published or distributed.

<u>Laboratory Tests:</u>

There is no single accepted laboratory measure for determining if a wood preservative treatment is effective against termites. In practice, researchers tend to consider preservatives "effective" if the wood test pieces suffer less than about 5% weight loss, or are rated close to 9 on the AWPA visual rating scale of 0 - 10. I have indicated the borate retentions in percent boric acid equivalents, or % BAE. 1% BAE is equivalent to 0.83% DOT (disodium octaborate tetrahydrate, or Tim-Bor, the preservative used to treat Hi-Bor wood in Hawaii), or about 0.23 pcf Tim-Bor.

1. K. Tsunoda; Wood Research Institute, Kyoto University; 1996 (personal communication): Laboratory tests (165 termites for 3 weeks) with Sugi sapwood (*Cryptomeria japonica*) indicated that borate retentions of 0.67% BAE and 0.83% BAE held wood weight losses to 2.0% and 1.4%, respectively. Termite feeding on wood treated to 0.24% BAE resulted in a 6.0% weight loss. This study was based upon a Japanese standard method. On the basis of this test, retentions equal or greater than 0.67% BAE would be considered acceptable for wood protection.

2. L.H. Williams, T.L. Amburgey, B.R. Parresol; USDA Forest Service (Gulfport, MS); 1990: Laboratory tests (100 termites for 6 weeks) with banak wood (*Virola* spp.) indicated that 0.89% BAE limited wood weight loss to 1%. These researchers suggested that a retention nearer to 1.24% BAE would probably be necessary to prevent damage under field conditions.

3. J.K. Grace, R.T. Yamamoto, M. Tamashiro; University of Hawaii; 1992: Laboratory tests (400 termites for 4 weeks) with Douglas-fir heartwood indicated that 0.80% BAE and 1.18% BAE held wood weight losses to 3.6% and 2.9% respectively. This suggested that retentions of at least 0.80% BAE would be needed for field tests. This study was based upon the AWPA (and ASTM) standard methods. [Results of this study were also distributed to members of a wood research society in 1991 in a report by M. Tamashiro, R.T. Yamamoto, J.K. Grace].

Field Tests:

As with laboratory tests, there is no universally accepted time period for the study, nor level of damage that clearly determines whether or not a wood preservative treatment is considered "effective." The longer the test period and the less the damage, the better. Test pieces are rated either by visual inspection (using the AWPA scale of 0 - 10, a different regional or organizational "standard" scale, or a scale developed by that particular researcher), or on the basis of the weight loss due to termite feeding. As in laboratory tests, "acceptable" weight losses are usually less than 5% - although the length of the field exposure, the size of the test pieces, and other factors will obviously have an effect on this.

All of the field tests described below, except for the last test (#8), were performed in Hawaii.

1. A.F. Preston, P.A. McKaig, P.J. Walcheski; Michigan Technological University; 1986 [an earlier report on the test was also distributed in 1985]: In a 2-year field test with southern pine, test pieces treated to 0.54% BAE (about 0.10 pcf Tim-Bor) received an average visual rating of 9.0, indicating minor damage; while 1.24% BAE (about 0.24 pcf Tim-Bor) provided protection from any damage (rating of 10).

2. K.J. Archer, D.A. Fowlie, A.F. Preston, P.J. Walcheski; Laporte Timber Division; 1991: In a 2.5-year field test with Douglas-fir, 10 of 21 test pieces treated by dip-diffusion to an average retention of 0.63% BAE (about 0.14 pcf Tim-Bor) were badly damaged (visual ratings of 2-4 on a 0-4 scale, with 4 indicating destruction), while 11 of the 21 pieces received little or no feeding (visual rating of 0-1). The average visual rating was 1.95.

3. J.K. Grace, R.T. Yamamoto, M. Tamashiro; University of Hawaii; 1992: In a 23-week (162 days, or about 6 months) field test with Douglas-fir 1x4 lumber, wood pressure-treated to 1.02% BAE (about 0.85% or 0.24 pcf Tim-Bor) sustained a small 2.5% weight loss from termite feeding . Results of this study were also distributed to members of a wood research society in 1991 in a report by M. Tamashiro, R.T. Yamamoto and J.K. Grace. An earlier report to the preservative manufacturer (U.S. Borax) on the test from M. Tamashiro was provided to the Building Dept. by the manufacturer to support approval of a target retention of 1.10% Tim-Bor (0.31 pcf Tim-Bor, or 1.32% BAE) in treatment of Hi-Bor wood in Hawaii.

4. J.K. Grace, R.T. Yamamoto; University of Hawaii; 1994: In a 40-week field test with Douglas-fir 1x4 lumber, wood pressure-treated to retentions of 1.06% BAE, 1.48% BAE, 1.92% BAE, or 2.52% BAE was exposed to four different termite colonies, each for 10 weeks. This test was performed to determine (1) whether repeated attacks by different termite colonies invading a building during the life of the structure would cause greater and greater damage to borate-treated lumber, and (2) whether higher levels of borate treatment could completely stop termite feeding on the wood and prevent even cosmetic damage. At the highest two retentions, termites caused only very minor surface scarring of the wood in 40 weeks; although the borate treatment did not repel the termites, and about the same amount of termite attack occurred with each new termite colony. Individual termite colonies appeared to initially attack, and then retreat from the treated

wood. At the two lower borate retentions, the wood suffered total weight losses from 8.7% to 10.2%. It was felt that this test was more rigorous than would normally be the case for treated lumber in buildings, that treatment to borate retentions higher than 1% Tim-Bor would protect wood from serious damage, and that greater borate retentions could be used to further reduce (although not completely eliminate) termite scarring of the wood surface.

5. J.K. Grace, R.T. Yamamoto; University of Hawaii; 1994: In a 6-week field test, termite attack on cross-sectional "slices" from locally-obtained Douglas-fir 2x4 boards treated with either CCA, ACZA (Chemonite), or Hi-Bor was compared to feeding on untreated control boards and teak wood. Because teak was the wood of interest in this test and it is difficult to compare woods of different densities on a weight basis, the test pieces were visually rated by the AWPA 0-10 scale. There was no visible termite feeding on any of the teak or ACZA samples, nor on 9 of the 10 CCA samples. Termites penetrated the center of 1 CCA sample (rating of 7). Two of the Hi-Bor samples were fully penetrated by termites (rating of 7), while the other 3 suffered surface scarring (rating of 9). Chemical analysis indicated that the two samples suffering the most damage contained 0.64% and 0.76% Tim-Bor, and the other three samples contained 0.83%, 0.96%, and 1.12% Tim-Bor. The authors suggested that this degree of variation in boron content within a single Hi-Bor board indicated that a greater safety factor than the current 1.10% (0.31 pcf) Tim-Bor target retention might be necessary to obtain more uniform treatment of Hi-Bor lumber.

6. A. Preston, L. Jin, K. Archer; Chemical Specialities Inc.; 1995: In a 1-year field test with pressure-treated Douglas-fir 2x4 boards, three boards treated to retentions of 0.33 pcf, 0.39 pcf, and 0.71 pcf Tim-Bor were severely damaged. In treating the boards, the authors also noted a great deal of variation in the solution uptake of different Douglas-fir boards and their resulting borate retentions. [A report on variation in borate concentrations within similarly-prepared test boards was submitted to the Building Dept. by U.S. Borax; and comments on the Chemical Specialities Inc. test were submitted to the Building Dept. by J.K. Grace and by M. Tamashiro].

7. J.K. Grace, K. Tsunoda, T. Byrne, P.I. Morris; University of Hawaii; 1995: In a 1-year field test with pressure-treated Pacific silver fir (*Abies amabilis*) 4x4 boards, boards treated to an average retention of 1.2% BAE (0.9-1.8% BAE) or 2.2% BAE (2.0-2.8% BAE) sustained weight losses of 4.5% and 1.2%, respectively, while untreated control boards suffered a mean weight loss of 34.7%.

8. K. Tsunoda, J.K. Grace, T. Byrne, P.I. Morris; University of Kyoto; 1996 (personal communication): In a 2-year field test in Japan identical to that described above (#7), none of the borate-treated boards were damaged by termites.

Resistance of borate-treated Douglas-fir to the Formosan subterranean termite

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Abstract

Toxicity of disodium octaborate tetrahydrate (DOT as TIM-BOR®)[1] to Formosan subterranean termites and termite feeding on treated Douglas-fir heartwood were evaluated in laboratory and field tests. Feeding on filter papers impregnated with borate solutions reduced but did not eliminate termite gut protozoan populations. In a forced-feeding laboratory assay, Douglas-fir heartwood treated to retentions ≥0.35 percent boric acid equivalents (BAE) drastically reduced termite feeding and resulted in 100 percent termite mortality within 3 weeks. Gradual and significant mortality (49%) after 4 weeks of feeding at 0.16 percent BAE suggests that this or lesser concentrations may be useful in baits for remedial termite control. After 162 days of field exposure to an active termite colony, moderate feeding was noted at 0.65 percent BAE (13.6% weight loss) and 0.73 percent BAE (16.9% weight loss), and only slight damage (2.5% weight loss) at the highest retention field-tested of 1.02 percent BAE. These results indicate that treatment with DOT provides protection from Formosan subterranean termite attack, but that some cosmetic damage occurs even at high retentions. This cosmetic damage is unlikely to create a structural hazard, but additional field evaluations are needed to determine whether borate treatments will provide protection to visible timbers that will be acceptable to the consumer.

The use of preservative-treated lumber in building construction is an important component of integrated pest management of termites (Isoptera) in Hawaii (21,23). The termite species involved are the highly destructive Formosan subterranean termite, *Coptotermes formosanus* Shiraki (Family Rhinotermitidae), and the West Indian drywood termite, *Cryptotermes brevis* Walker (Family Kalotermitidae). Untreated or inadequately treated lumber can be quickly destroyed by these termites.

Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) heartwood is the principal construction lumber used in Hawaii (25). Unfortunately, Douglas-fir is both highly susceptible to Formosan subterranean termite attack (18) and resistant to preservative penetration. Treatment with ammoniacal-copper-zinc-arsenate (ACZA) has been demonstrated to provide protection against Formosan subterranean termites (22), but the required incisions and discoloration of the treated wood prevent the use of ACZA for exposed building timbers. Moreover, arsenical wood treatments in general have raised environmental and public health concerns (3).

Wood treatment with disodium octaborate tetrahydrate (DOT, as TIM-BOR®)[1] has no aesthetic drawbacks, low mammalian toxicity, can provide adequate penetration of Douglas-fir heartwood (2,12,26), and has been demonstrated to be toxic to termites (5,7,27-29).

[1] Mention of trade names is for informational purposes only and does not constitute an endorsement by funding agencies or by the University of Hawaii.

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although leachability of borates from wood exposed to high moisture levels could be a problem. This study was performed to determine the effectiveness of DOT in protecting Douglas-fir heartwood from feeding by Formosan subterranean termites. This required 1) determining the toxicity of DOT to Formosan subterranean termites and their intestinal protozoa; and 2) evaluating its effectiveness as a treatment for Douglas-fir heartwood in laboratory and field studies.

Experimental procedure

Toxicity test

Borates are considered stomach poisons, and toxicity was assessed by placing Formosan subterranean termites on treated filter paper (Whatman No. 2). A stock solution was made by dissolving 120 g DOT (TIM-BOR, United States Borax and Chemical Corp., Los Angeles, Calif.) in 1 liter of distilled water. Aliquots were further diluted to achieve test concentrations of 120, 12.0, and 1.2 g/l, or 14.4, 1.40, and 0.14 percent BAE (weight/volume).

Each filter paper was completely saturated by dipping in a solution of a particular concentration, and air-dried. It was then placed in a glass petri dish and 2 ml of distilled water was added to moisten the paper. Thirty termite workers, collected immediately before use from an active field colony (20), were introduced into each dish. The dishes were held in an unlighted incubator at 29°C and checked daily for mortality and symptoms of toxicity. Eight replicates were prepared of each solution concentration: five were monitored for termite mortality and the remaining three were used to determine the effect of DOT on the symbiotic gut protozoa *Pseudotrichonympha grassi* Koidzumi, *Holomastigotoides hartmanni* Koidzumi, and *Spirotrichonympha leidyi* Koidzumi.

After 1, 2, 4, 7, 9, 11, 16, and 18 days of DOT exposure, three termites from each solution concentration were dissected and the protozoa in the hind gut identified by species and counted (10). Due to large individual and daily variations in protozoan numbers, the daily counts were grouped for analysis over days 1 to 11 and 16 to 18. Data within each of these groups were subjected to analysis of variance (ANOVA) blocked by day, and means were separated by the Ryan-Einot-Gabriel Welsch multiple F test (16).

Laboratory test of treated wood

Laboratory tests on the efficacy of DOT as a wood treatment for Douglas-fir heartwood were conducted using 1.9 by 1.9 by 1.9 cm cubes (approx. 2.5 g) pressure-impregnated with TIM-BOR by a modified full-cell process (13). Wood pieces were placed in a tray, weighted down, and immersed in the appropriate TIM-BOR solution. The trays were then placed in a pressure cylinder and subjected to 1 hour of vacuum (28 in. Hg) and 18 hours of pressure (140 to 150 psi). After treatment, the wood was dried (50°C) to constant weight, and selected pieces were assayed for boron content.

DOT retentions were determined by ashing selected pieces, extracting the residue with dilute HCL, and analyzing the residue for boron content with a spectrophotometric method using the complexing agent azomethine-H (4,6). A small number of samples were also assayed using a hot water extraction method, and results were consistent with those obtained from ashing (13).

The Douglas-fir cubes were treated to 6 DOT retentions: 0.08, 0.13, 0.29, 0.45, 0.67, and 0.98 percent (weight/weight percentage). There were five replicates for retentions of 0.13 percent and higher, and four replicates for 0.08 percent and the untreated controls.

The force-feeding assay with Formosan subterranean termites was a modification of the ASTM D3345-74 (Reapproved 1980) (1) method (similar to AWPA M12-72). The method was modified as follows: 1) ovendry weight loss instead of visual estimation was used to measure damage; and 2) more termites were used in the test and termite mortality was evaluated. The treated cubes were ovendried (63°C for 7 days), weighed, placed individually in plastic containers (9.5 cm diameter by 3.5 cm high), and covered with 150 g coral sand (washed and ovendried). This was a sufficient amount of sand to cover all but the upper surface of the test block. Thirty ml of distilled water was added to each container before adding the termites. Termites were collected as described previously, 400 workers were placed in each container, and the containers were held in an unlighted incubator at 29°C.

Containers were examined weekly to visually estimate termite mortality. Four weeks after the initiation of the test, the cubes were removed, cleaned, ovendried, reweighed, and total termite mortality was determined. Data were subjected to ANOVA and means were separated by Duncan's multiple-range test (16).

Field test of treated wood

Nonleaching, aboveground field tests were conducted in a vigorous colony of Formosan subterranean termites located on the Manoa campus of the University of Hawaii. This colony is monitored on a regular basis and the foraging population is periodically assessed using mark-release-recapture methods (11,19).

Douglas-fir heartwood boards 2.5 by 10.2 by 20.4 cm (approx. 165 g) were pressure impregnated with DOT as described previously to four retentions: 0.18, 0.54, 0.61, and 0.85 percent (wt/wt). Although these boards were not assayed for boron content in a zonal fashion, analysis in three equal layers of similarly treated boards demonstrated essentially uniform retention for the three layers (13).

Rectangular traps or test boxes (10.2 by 10.2 by 20.4 cm) were constructed using two 2.5- by 10.2- by 20.4-cm boards treated to the same retention and two untreated 2.5- by 5.1- by 20.4-cm boards as sides, as described by Tamashiro et al. (22). Each test box was placed within a covered 5-gallon metal can (with the can bottom removed) on the soil surface. Termites had been actively foraging on untreated wood boxes placed within these cans for several years. To minimize leaching of the preservative, a small hollow concrete block (5.1 cm high) was first placed on the soil surface within the can. A short wood stake was driven through the hollow center of the block into the soil (and the termite foraging galleries), and a 6-mil polyethylene sheet (with a hole for the stake) was laid over the top of the block. The test box was then placed on the plastic sheet, with the wood stake allowing the termites direct access from the soil to the box.

The hollow interior of each test box was filled with paper toweling, and the top of each box was capped with an untreated 2.5- by 10.2- by 10.2-cm Douglas-fir heartwood board. Control test boxes were constructed in a similar manner with untreated wood. Each preservative retention was replicated with four test boxes, for a total of eight boards per treatment.

Traps were examined at weekly intervals to determine when the termites initially attacked each test box. Formosan subterranean termites are capricious in their pattern of attack, and termites were noted in some traps within a few days, while others were untouched for several months. In order to standardize the exposure period, each test box was removed 162 days (23 weeks) after the initial termite attack on the untreated wood in that particular test box was observed. Thus, each treated board was exposed for 162 days to actively foraging termites. After removal from the field, each test box was dismantled, cleaned, ovendried, and the boards weighed to determine weight loss from termite feeding. Data were analyzed by ANOVA and Duncan's multiple-range test (16).

TABLE 1. — *Mean cumulative percentage mortality of Formosan subterranean termite workers fed filter paper impregnated with DOT.*[a]

Day	Solution concentration (g/l) 0.0	1.2	12.0	120.0
	(%)			
1	1.3	2.7	1.3	0.0
2	1.3	3.3	2.0	10.0
3	5.3	4.7	3.3	47.3
4	8.0	9.3	6.7	70.0
5	10.0	17.3	13.3	90.0
6	13.3	29.3	24.7	96.7
7	14.0	38.0	36.7	100.0
8	18.7	42.7	44.7	
9	20.7	46.7	55.0	
10	24.0	54.7	86.7	
11	25.3	64.7	95.3	
12	28.0	72.7	100.0	
13[b]				
14[b]				
15	36.6	88.7		
16	39.3	92.0		
17	44.0	95.3		
18	46.0	96.7		

[a] Mean of 5 groups of 30 termite workers.
[b] Data not collected on days 13 and 14.

TABLE 2. — *Mean numbers of protozoa in individual Formosan subterranean workers over days 1 to 11 and 16 to 18 of feeding on filter paper impregnated with DOT.*

	Solution concentration (g/l)				
	Days 1 to 11			Days 16 to 18	
Protozoa	0.0	1.2	12.0	0.0	1.2
Pseudotrichonympha grassi	442 A[a] (±65)[b]	493 A (±79)	200 B (±85)	207 A (±91)	0 B (±0)
Holomastigotoides hartmanni	851 A (±129)	687 A (±107)	331 B (±80)	133 A (±46)	80 A (±55)
Spirotrichonympha leidyi	1024 A (±177)	1087 A (±148)	858 A (±184)	353 A (±163)	233 A (±122)

[a] Mean count per termite. Three termites per treatment were dissected each day. Means within a row, within each day category, followed by different capital letters are significantly different at the $p = 0.05$ level.
[b] Values in parentheses represent standard errors of the mean.

Results and discussion

Toxicity test

Forced feeding on DOT was toxic to Formosan subterranean termite workers in a concentration dependent manner (Table 1). At the highest DOT concentration (120 g/l), populations of the gut protozoa *P. grassi* and *H. hartmanni* were greatly reduced by the fourth day, but were not all killed or eliminated until the termite died. Populations of *S. leydei* were not affected until the seventh day, when both termites and protozoa were dead.

Susceptibility of the protozoa appeared to be directly proportional to their size and location in the hindgut. *P. grassi*, the largest species, is predominant in the anterior part of the hindgut; *H. hartmanni*, the medium-sized species, is found in the middle; and *S. leydei*, the smallest and least-susceptible species is predominantly found in the posterior part of the hindgut (10). Analysis of protozoan counts for the two

TABLE 3. — *Estimated rate of termite mortality, final mean percent mortality, and mean amounts of DOT-treated Douglas-fir heartwood blocks (each approx. 2.5 g) eaten by Formosan subterranean termites in a 4-week laboratory test.*

Percent rentention		Mean percent mortality[b]				Wood weight loss	
%DOT[a]	%BAE[a]	Week 1	Week 2	Week 3	Week 4	Mean weight loss[c]	Percent weight loss
		(%)				(g)	(%)
0.00	0.00	0	0	0	18	1.231 A	53.4
0.08	0.10	0	0	0	23	1.339 A	47.6
0.13	0.16	0	0	0	49	0.784 B	33.4
0.29	0.35	0	39	100		0.211 C	8.4
0.45	0.54	0	73	100		0.141 C	5.4
0.67	0.80	0[d]	94	100		0.091 C	3.6
0.98	1.18	0[d]	99	100		0.074 C	2.9

[a] DOT = disodium octaborate tetrahydrate: BAE = boric acid equivalents.
[b] Mean of 5 replicates for 0.13 percent DOT and higher and 4 replicates for 0.08 percent and the untreated controls (400 termites per replicate).
[c] Mean weight losses followed by different capital letters are significantly different at the $p = 0.05$ level.
[d] Termites affected: activities slowed but no mortality.

TABLE 4. — *Mean amounts of DOT-treated Douglas-fir heartwood boards (each approx. 165 g) eaten by Formosan subterranean termites durin days of exposure to an active termite colony in a field test.*

Percent rentention		Weight retention[b]				Wood weight loss	
%DOT[a]	%BAE[a]	DOT	BAE	DOT	BAE	Mean weight loss[b]	Percent weight
		(pcf)		(kg/m^3)		(g)	(%)
0.00	0.00	0.00	0.00	0.00	0.00	115.9 A	70.0
0.18	0.22	0.05	0.06	0.80	0.96	105.5 A	60.2
0.54	0.65	0.15	0.18	2.40	2.88	24.1 B	13.6
0.61	0.73	0.17	0.20	2.72	3.27	28.9 B	16.9
0.85	1.02	0.24	0.29	3.84	4.61	3.7 C	2.5

[a] DOT = disodium octaborate tetrahydrate; BAE = boric acid equivalents.
[b] Mean weight losses followed by different capital letters are significantly different at the $p = 0.05$ level. N = eight boards per treatment.

lowest concentrations (12.0 and 1.2 g/l) over the first 11 days, and over days 16 to 18 of exposure (i.e., sublethal effects) demonstrated reductions in *P. grassi* and *H. hartmanni* numbers, but no statistically significant change in *S. leydei* relative to the control (Table 2). Termite mortality is not the direct result of starvation due to the reduction in protozoa numbers, since defaunated Formosan subterranean termites can survive as long as 30 days (9).

From this study, we could not determine whether DOT is directly toxic to the protozoa, or whether the protozoa are affected secondarily as a result of borate toxicity to the termite. Kard (8) also noted reductions in protozoan complement in eastern subterranean termite (*Reticulitermes flavipes*) workers exposed to soil treated with boric acid. However, frequent fluctuations in intestinal symbiont populations and the difficulty of defining primary effects on obligative symbionts have complicated other attempts to determine the mode of action of borate toxicity (29).

Laboratory test of treated wood

At the higher DOT retentions, termites feeding on treated Douglas-fir cubes were visibly affected (sluggish) after the first week, and high mortality was apparent at the end of the second week (Table 3). Termite feeding did not differ significantly from the controls at 0.10 percent BAE, but was significantly reduced at 0.16 percent BAE (Table 3). However, despite 49 percent termite mortality at 0.16 percent BAE, a mean 33.4 percent weight loss was observed. At retentions ≥0.35 percent BAE, all the termites died within 3 weeks, and wood weight losses did not exceed 10 percent. These results are in agreement with the conclusions from similar laboratory tests of Williams et al. (28) that *C. formosanus* failed to survive for 7 weeks on banak (*Virola* spp.) wood with ≥0.125 percent BAE, and of Williams and Amburgey (27) that retentions in banak >0.17 percent BAE were toxic to eastern subterranean termites (*R. flavipes*). Su and Scheffrahn (17) reported similar reductions in Formosan subterranean termite feeding, although less termite mortality in tests with DOT-treated pine blocks (DOT retentions were estimated from treating solution uptake).

Field test of treated wood

All of the boards, both treated and untreated, exposed to a field colony of Formosan subterranean termites were attacked to some extent, with ana indicating three damage levels (Table 4). The con and those containing 0.22 percent BAE were es tially destroyed (range of 32.8% to 94.8% weight l Weight losses at 0.65 and 0.73 percent BAE ra: from 4.3 to 34.9 percent. At the highest retentic 1.02 percent BAE, an average 2.5 percent weight was recorded, with individual board weight lo ranging from 0.2 to 6.8 percent. Although the dar at 1.02 percent BAE was cosmetic and did not a the structural integrity of the boards, this damage easily noticeable.

This was a rigorous field test, since samples placed directly into active termite feeding sites then monitored to insure that foraging termite wor contacted them. During the 162 days of exposure untreated boards in each test box were almost c pletely consumed, with no statistical differe: among the traps. This type of field test may be r applicable to the Formosan subterranean termite more common "graveyard" style tests, since this cies does not feed on all the available food items i foraging territory in a homogenous fashion. For ex ple, in tests with gravel barriers to foraging termit a heavily infested location in Hawaii, only half o: control stakes have been attacked after 5 years (2

There was a good relationship between re: obtained with the highest borate retentions teste the laboratory (1.18% BAE) and the field (1.02% E These results also agreed with the report of Prest al. (14,15) that 1.24 percent BAE was require protect southern yellow pine from Formosan sul ranean termite feeding. However, significant dar occurred with 0.65 and 0.73 percent BAE in the test, even though comparable retentions in the l ratory killed all termites and prevented much feec Estimation of termite populations in the field co before and after this study did not indicate a dec in numbers, and no reduction in feeding was n that would indicate a decline in colony vigor. Term feed alternately at many sites in the field (19), w reduces the frequency of exposure of individuals particular poisoned feeding site. Therefore, in ord prevent any damage to the treated wood, it ma necessary to use preservative retentions that are e toxic or repellent on the basis of a single exposur

Summary and conclusions

In the laboratory test, forced feeding by Formosan subterranean termites on DOT-treated Douglas-fir containing 0.16 percent BAE resulted in significant termite mortality (49%) within 4 weeks, while concentrations ≥0.35 percent BAE killed all termites within 3 weeks, and resulted in less that 10 percent weight loss in the treated blocks. However, laboratory tests alone, with small confined groups of termites, cannot accurately predict the retentions necessary for protection from termite feeding under field conditions.

In field tests, 1.02 percent BAE was required to limit termite feeding on the treated Douglas-fir to the status of cosmetic damage. These results indicate that DOT can protect Douglas-fir heartwood from Formosan subterranean termite attack, but it is not possible to predict a retention where absolutely no feeding would occur. Field evaluations of retentions >1.02 percent BAE are needed to determine the treatment requirements for visible timbers in areas of high Formosan subterranean termite hazard. But cosmetic damage to hidden structural timbers may not pose a problem, as long as repeated termite attacks on those timbers do not occur.

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