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

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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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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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