

Evaluation of borate formulations as wood preservatives to control subterranean termites in Australia

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Abstract

The termiticidal efficacy of sodium octaborate tetrahydrate, boric acid, borester-7, and tri-methyl borate as wood preservatives was evaluated after each was impregnated into seasoned sapwood of *Pinus radiata* D. Don and *Eucalyptus regnans* F. Muell in laboratory bioassay against *Coptotermes acinaciformis* (Froggatt). There was clear difference between the different borate retentions in treated and untreated blocks, mass loss, and mortality rate of the termite used in the bioassay units. After 8 weeks of laboratory bioassay, the results suggested that borate was toxic to termites even at 0.24% m/m BAE and caused significant termite mortality, but termites were not deterred from attacking the borate-treated timber at a higher retention of >2.0% m/m BAE. These laboratory results indicated that the minimum borate treatment required to protect timber against termite attack and damage was >1.0% m/m BAE.

Keywords: borates; borester-7; boric acid; *Coptotermes acinaciformis*; *E. regnans*; *P. radiata*; sodium octaborate tetrahydrate; tri-methyl-borate.

Introduction

Sole reliance on chemical soil barrier treatments in the protection of timbers in building structures against termite attack and damage has proven impractical. Termites still gain access to buildings by breaching or bridging such barriers. The use of borates in protecting timber in buildings has benefits to health and the environment and is an important alternative method to prevent termite attack and damage to building structures. Combining soil barriers and treated timber in the built environment increases protection against termites and other biological

agents that attack timber (Tamashiro et al. 1987; French 1991; AS 3660.1 2000). Borates as wood preservatives protected wood from decay fungi, wood borers, drywood and subterranean termites (Tisseverasinghe and Jayatil- leke 1975; Barnes et al. 1989; Grace et al. 1990; Williams et al. 1990; Su and Scheffrahn 1991). The use of borates as wood preservatives has been reviewed extensively (Carr 1961; Cockroft and Levy 1973; Dickinson and Mur- phy 1989; Drysdale 1992; Cookson and Pham 1995). Some of these researchers demonstrated that boric acid and sodium octaborate were effective against termites in laboratory bioassays. However, when Synder and Zetek (1934) tested borate compounds as potential wood pre- servatives against field population of termites, that failed to prevent termite attack and damage to treated timber. The failure of the borate compounds maybe resulted from excessive leaching of borate from the treated timber in the field. The difference between wood preservatives used for indoor and outdoor timber treatments requires more careful consideration for application (Drysdale 1992).

In Australia, Gay et al. (1958) and Tamblyn et al. (1959) showed that boric acid, sodium octaborate tetrahydrate, copper borate, and sodium octaborate were toxic against termites at certain levels of concentrations in the labor- atory. These bioassays were conducted against both the higher termites (*Nasutitermes exitiosus*) and the lower termites (*Coptotermes lacteus* and *Coptotermes acinacifor- mis*). The results showed that borate was more toxic to lower termites (0.46–0.56% BAE) than to the higher termites, which survived at a higher concentration (1.09% BAE) without substantial termite mortality. Later labora- tory tests by Johanson and Howick (1975) supported the findings of Gay et al. (1958) and Tamblyn et al. (1959) in that treatment of timber with adequate borate (1.0–1.5% BAE m/m) reduced termite attack. The laboratory results in Australia suggest that the minimum level of borate treatment required to protect against termites is 1.09% (Gay et al. 1958). However, some field studies in Australia indicated timbers treated with borate compounds were susceptible to termite attack at even higher loadings (Moffat and Peters 1993; Kennedy et al. 1996).

In the USA and Europe, many researchers have renewed their interest in borate compounds as wood pre- servatives for remedial and preventative treatments against the most serious economic termite species. Su and Scheffrahn (1991) reported that treatment of *Pinus* spp. with TIM-BOR between 0.51–1.83% BAE and 0.4–1.54% BAE (m/m) reduced feeding by *C. formosan- us* and *R. flavipes*, respectively. However, Grace (1990) reported that higher loadings of borate were required to reduce feeding of *C. formosanus*. Such findings sup- ported the adoption of borate compounds by the U.S. Environmental Protection Agency for remedial and pre- ventive treatments against termites.

This study examined borate-treated and untreated *Pinus radiata* D. Don and *Eucalyptus regnans* F. Muell against the most economically important termite in Australia, the *Coptotermes* species. These timber species are the primary constructional timbers used in building structures in south-eastern Australia. Both timbers are susceptible to termite attack, though *E. regnans* sapwood is by far more susceptible than *P. radiata* (French 1991). The treatment of both timbers with borates will reduce termite damage to the building structures if termite attack occurs. Therefore, their low toxicity to humans and domestic animals and their low adverse environmental effect have high user appeal and could be readily incorporated into termite pest management control systems, especially with the current chemical soil barriers, which are less persistent than the organochlorines. Moreover, borate would also be useful in situations where the soil chemical barriers are impracticable. The combination of soil barrier treatments and borate compounds has potential for future termite pest management (Strickland and Alverson 1997). In the present study, several boron compounds were chosen, including sodium octaborate tetrahydrate, boric acid, borester-7, and trimethyl borate. These compounds have low mammalian toxicity and have proved toxic against termites (Randall et al. 1934; Gay et al. 1958; Dickinson and Murphy 1989; Drysdale 1994; Romero et al. 1995).

Materials and methods

Bioassay methods

The laboratory evaluation was conducted in a no-choice laboratory bioassay of timber specimens (15×25×50 mm). The bioassay was carried out on *P. radiata* and *E. regnans* against *Coptotermes acinaciformis*.

Termite field collection and laboratory separation

The *C. acinaciformis* was collected from the Walpeup field station north-west of Victoria and transported 450 km to the Clayton laboratory. Subterranean colonies of this species were located and bait containers were buried around each colony. After five weeks, the termites in the bait containers were removed and transported to the laboratory. On arrival at the laboratory within the same day, the bait containers were stored in a conditioned room kept at 27°C and 75% RH. The termites were then separated from the field wood stakes and soil in the drum.

Worker termites (i.e., externally undifferentiated larvae beyond the third instar) were used for all the experiments. Five grams (ca. 1370 individuals of *C. acinaciformis*) of termites were used in each test unit. Five replicates per treatment were used.

Timber specimens

Pinus radiata and *Eucalyptus regnans* (mainly sapwood) specimens were used. Laboratory timber blocks of 15×25×50 mm and grain along the 50-mm direction

were cut from the sapwood of several fast-grown *P. radiata* trees from a pruned and thinned forest that had been harvested in the Ballarat area in Victoria. The ages of the trees ranged from 25 to 35 years and were supplied by AKD Softwood VICTORIA P/L.

The *E. regnans* trees were from the East Gippsland region of Victoria. The ages of the trees ranged from 45 to 60 years of age and were supplied by Neville Smith Timber industries P/L, Melbourne, Australia.

Timber specimens were pooled and randomly allocated into treatment groups. The test blocks were oven-dried at a temperature of 40°C until constant mass was achieved. Prior to wood preservative treatments, the mean moisture content of specimens of *P. radiata* and *E. regnans* were calculated from samples that had been oven-dried at 105°C for 24 h. The mean initial specimen mass of *P. radiata* and *E. regnans* samples was 8.9 g and 10.75 g, respectively. The mean density of *P. radiata* and *E. regnans* samples was 468 kg/m³ and 566 kg/m³ and the moisture content was 10.67% and 9.86%, respectively.

Boric acid treatment

The boric acid used was a technical grade (99.5%) from Aldrich Chemical Company P/L Melbourne, Australia. Boric acid powder was dissolved in water to give solutions of varying concentrations depending on the uptake required. For example, a solution with 2 g of boric acid per 100 g of water is 2% solution and had a boric acid equivalent (BAE) of 2%.

Each specimen was weighed; the mass was recorded and allocated an appropriate number (25 specimens per unit treatment) and placed in a beaker of 3-L capacity. All timber specimens were impregnated in a vacuum desiccator. The treatment schedule comprised 30-min vacuum at -85 kPa. Whilst under vacuum, treatment solutions (solvent control of deionised water) were poured over to cover the test specimens in the beaker followed by vacuum release. Specimens were left to soak in the solution at atmospheric pressure for 30 min. The specimens were weighed before and after treatment to determine their retentions. The treated specimens were placed in a plastic bag and put in a glass tank. The glass tank lid was opened slightly (1–2 mm) daily over a 2-week period, in order to allow evaporation of the water slowly from the specimens and to retain the boric acid in the test blocks. This procedure required about 4 weeks. The difference between the initial mass and the final mass was regarded as the uptake.

Using the treatment method described for the controls, groups of 25 specimens were selected at random and treated with different concentrations of each boron compound. The treatment of trimethyl borate was different, with the use of the volatile solvent (methanol) in order to achieve nominal retentions of BAE.

Specimens of each loading were vacuum oven-dried in a separate chamber for 5 days at 40°C and -95 kPa. The specimens were removed from the vacuum ovens and weighed to obtain initial mass. Treated specimens were kept separate to avoid contamination of boric acid between test specimens of different concentrations.

BAE calculation method

$$\text{BAE\%} = \frac{\text{uptake} \times \text{solution strength}}{\text{basic density}}$$

where uptake is the difference between the initial mass and the final wet treated mass of block, solution strength is the percent concentration of boric acid in water, basic density is (mass/Volume) of the sample. The standard density of 468 kg/m³ was used for *P. radiata* and 566 kg/m³ for *E. regnans*.

The borate formulations used were dissolved in various solvents, so the specific gravity of the solvent has to be taken into account. However, for water, the specific gravity is 1 and therefore the calculated BAE will remain the same.

Trimethyl borate treatment

The trimethyl borate was dissolved in various amounts of methanol depending on the solution strengths required. Trimethyl borate has a BAE of approximately 10.4%.

As trimethyl borate reacts with water, it was necessary to oven-dry the blocks prior to treatment to remove moisture down to 6% m.c. This was conducted in an oven at 105°C for approximately 6 h. The oven-dry blocks were reweighed and then stored to minimise any gain in moisture between drying and subsequent treatment.

The blocks were immersed in the trimethyl borate solutions for various lengths of time depending on the uptake required and then transferred directly into plastic bags, sealed, and weighed. This procedure was adopted as trimethyl borate is toxic and can diffuse in the vapour phase until dry. Therefore, blocks of similar uptakes were stored together in order to minimise further uptakes. The blocks were then stored in the bags until dry.

The calculations were similar to the boric acid values except that specific gravity has to be taken into account, as the solvent used was methanol. Therefore, all trimethyl-borate calculations have to be divided by 0.8, which is the specific gravity of methanol (i.e., the BAE%/0.8).

Borocol (glycol borate ester) treatment

The first step is to calculate the BAE of borocol (glycol borate ester). The label of the supplied Winchester bottle reads: 42 g/kg boron (B) present as 200 g/kg disodium octaborate tetrahydrate. The BAE of this solution is therefore 259.69 g/kg or 25.97% m/m [(42 × 61.83)/10]. The calculation of the required solution strengths was similar to that for TMB.

The same procedure for treating the blocks with boric acid (full vacuum for 30 min, soak for 30 min) was followed for the blocks treated with glycol borate ester.

The calculations were similar to the boric acid specimens including using specific gravity equal to 1, so the result remains unchanged.

Borester-7 (hexylene glycol diborate) treatment

The blocks were covered by the solution in a beaker and placed in vacuum oven for 5 min at -10 kPa. The vac-

uum was then released and the blocks were allowed to soak for a further 10 min. After this time, the blocks were removed from the solution and placed into another beaker and elevated up from the bottom. The beaker was returned to the vacuum oven and a full vacuum (-85 kPa) was pulled for 45 min. The blocks were then removed, weighed, and left to air-dry.

Calculations

The calculations were the same as for boric acid except a specific gravity correction was included because the solvent used was kerosene. The specific gravity of kerosene is 0.8, so each BAE calculation had to be divided by this amount.

Crystals formed on the surface of a number of the blocks treated with borester-7. Specimens showing such crystals were not used in the test.

The correction for specific gravity of the methanol and kerosene based on treatments affected the actual values for the uptakes, but these changes were proportional. That is, rather than uptakes of 0.5%, 1%, 2%, 4%, and 8%, they were calculated as 0.6%, 1.1%, 2.1%, 4.1%, and 8.1%. Although these values are different, they have all been changed by the same amount.

No-choice laboratory bioassay

After the conditioning periods, each treated block from each concentration was placed in a separate glass jar (275 mL) containing moist (80–85%) *C. acinaciformis* mound material (70% organic matter). Into each glass jar 5 g of termites (ca. 1370 individuals, with about 5% soldiers) were added and sealed with a vented lid (2-mm-diameter hole). A general purpose trical mesh, (size 6 × 6 mm) was placed on top of the mound material, and the treated blocks were placed on the mesh surface to avoid boron compounds leaching into the substrate, while still allowing access by foraging termites. All treatments were replicated five times using blocks nearest the mean retention. All the bioassay jars were placed in an insectary room at 27°C and 75% RH for 8 weeks. Each glass jar had only one test specimen, moist mound material, 5 g of termites, and the plastic mesh barrier.

Termite activity was visually inspected each week (1–8 weeks). At the end of the test period, termites that survived in the test jars were estimated from the original population placed in the jars. Observations of repellency of boron compounds, any morphological changes to the termites, and the amount of wood blocks eaten were routinely recorded. After 8 weeks of laboratory bioassay, the timber specimens were removed and oven-dried to obtain a final mass loss.

Termite mortality and percent mass loss of the treated specimens provided a guide in deciding the economic lethal threshold levels.

Results and discussion

The analysis of this laboratory result will focus on the relationship of termite mortality, percent mass loss, and termite survival period in the bioassay. The percent mass

Table 1 Percent mass loss of wood (\pm SE) and percent mortality rate of *C. acinaciformis* in the no-choice laboratory bioassay with various retentions of boric-acid-treated specimens and water controls after eight weeks of exposure. Mean of five replicates per treatment regime.

Mean retention (boric acid)		Termite colony A			Termite colony B		
Soln. (%)	*Mean BAE (% m/m)	Mass loss (%)	Mort. (%)	Surv. (days)	Mass loss (%)	Mort. (%)	Surv. (days)
<i>E. regnans</i>							
WC	0	49.3 (7.0)	29 (4.0)	56	44.8 (3.7)	25.4 (4.1)	56
0.24	0.14–0.26	30.8 (2.2)	64 (4.3)	56	27.3 (3.2)	66 (4.3)	56
0.48	0.26–0.30	13.2 (1.4)	72 (7.4)	56	14.1 (1.9)	80 (8.9)	56
0.96	0.81–1.38	6.0 (0.9)	100	56	7.81 (1.9)	100	56
1.92	1.34–1.38	0.7 (1.5)	100	50 (1.9)	0.58 (1.2)	100	50 (2.5)
3.84	2.10–2.37	2.4 (1.2)	100	44.6 (1.6)	1.0 (3.4)	100	41.8 (1.0)
<i>P. Radiata</i>							
WC	0	48.9 (15.0)	25.4 (5.0)	56.0	53.7 (8.3)	27.2 (1.7)	56.0
0.28	0.25–0.43	21.1 (3.6)	65 (13)	56	23.7 (2.8)	66 (9.7)	56
0.53	0.7–0.7	5.0 (2.1)	95 (7.8)	56	9.78 (3.1)	91 (9.8)	56
1.1	1.5–1.7	4.0 (1.5)	100	54 (2.8)	4.65 (2.6)	100	54.4 (2.0)
2.1	2.2–2.8	1.5 (2.4)	100	50.4 (1.9)	2.2 (1.4)	100	44.4 (3.4)
4.3	5.5–5.6	0.55 (1.5)	100	34.8 (1.0)	1.6 (1.8)	100	34.4 (2.6)

*=range of retention within the treated blocks, Mort.= % mortality, Surv.= number of days termites survived, WC=water control. Numbers in brackets are the standard error of the mean.

loss of test specimens indicates the efficacy of a candidate wood preservative against a termite's ability to attack and damage treated specimens. Termite mortality and the period of survival indicate the toxicity of the products against biological agents. These three evaluation criteria will be used to assess the efficacy against termites of the borate compounds in this experiment.

Boric acid treatment

The mean percent mass loss of wood brought about by *C. acinaciformis* in the no-choice laboratory bioassays after 8 weeks of exposure in the laboratory with various retentions of boric acid is shown in Table 1. Boric-acid-treated specimens experienced less termite attack and damage than the untreated controls. And comparing boric-acid-treated specimens, the lower retentions (<1.0% BAE) had a higher percentage of mass loss (6–31%) than the higher retention of boric-acid-treated specimens (>1.0% BAE). The result suggests that the percent mass loss of wood depends on the retentions of boric acid in treated timber, that is, percent mass loss decreases with increasing retentions of boric acid. All borate-treated samples were consumed significantly less than the untreated controls.

Comparison between *P. radiata* and *E. regnans* treated specimens and controls

Termites attacked and damaged more of the solvent controls of both timber specimens than the treated timbers. When comparing their solvent controls, *E. regnans* had a percent mass loss of 44–49%, which was similar to that for the *P. radiata* specimens (49–54%) as in Figures 2 and 4 and Figures 1 and 3, respectively. However, the percent mass loss of wood treated with boric acid was less than the solvent controls especially at the higher retentions. With a single specimen in each jar, the solvent controls of both timber species did not differ from each other in the no-choice bioassay. If the two specimens had been in the same jar and the mass loss had been different, this would have indicated termite preferences

for the timber species, which was not the intention of this study.

According to the results of these laboratory studies, the most effective treatment with boric acid for both timber species was when the boric acid retentions in the timber exceeded 1%.

Borocol- and borester-7-treated specimens

The percent mass loss of wood specimens by *C. acinaciformis* and the percent mortality in the no-choice laboratory bioassay of a single wood block treated with various retentions during the 8-week test are shown in Tables 3 and 4. Except for borate retentions over 1%, all the lower retentions of the borate compounds behaved similarly. Untreated specimens had a higher percent mass loss than all the treated specimens. This confirms that boron treatment affects termite consumption rates.

The higher retentions of both borate formulations behaved similarly to the higher retentions of boric acid in the treated specimens. This suggests that when the boron content is higher than 1% BAE in the wood, boron-based preservatives will protect the timber from termite attack and damage. It is interesting to note that all borate compounds behaved the same with increasing retentions; consequently, with retentions below 1%, termites can attack and damage the treated specimens. Therefore, according to the termite percent mass losses, decreased wood consumption occurred with increased retentions of the borate compounds.

The solvent controls had a higher percent mass loss and a lower mortality rate than the borate-treated samples. Meanwhile, borate compounds with retentions above 1.34% m/m BAE out-performed the low-retention treated borate compounds and the solvent controls. The controls between the two termite colonies were similar.

Mortality rates

The percent mortality rates for the borocol and borester compounds are shown in Tables 2 and 3. At the higher retentions, none of the borate-compound-treated spec-

C. acinaciformis attack and damage on Boric acid and water treated *P. radiata* blocks (50 x 25 x 15 mm) after eight weeks of exposure in laboratory.

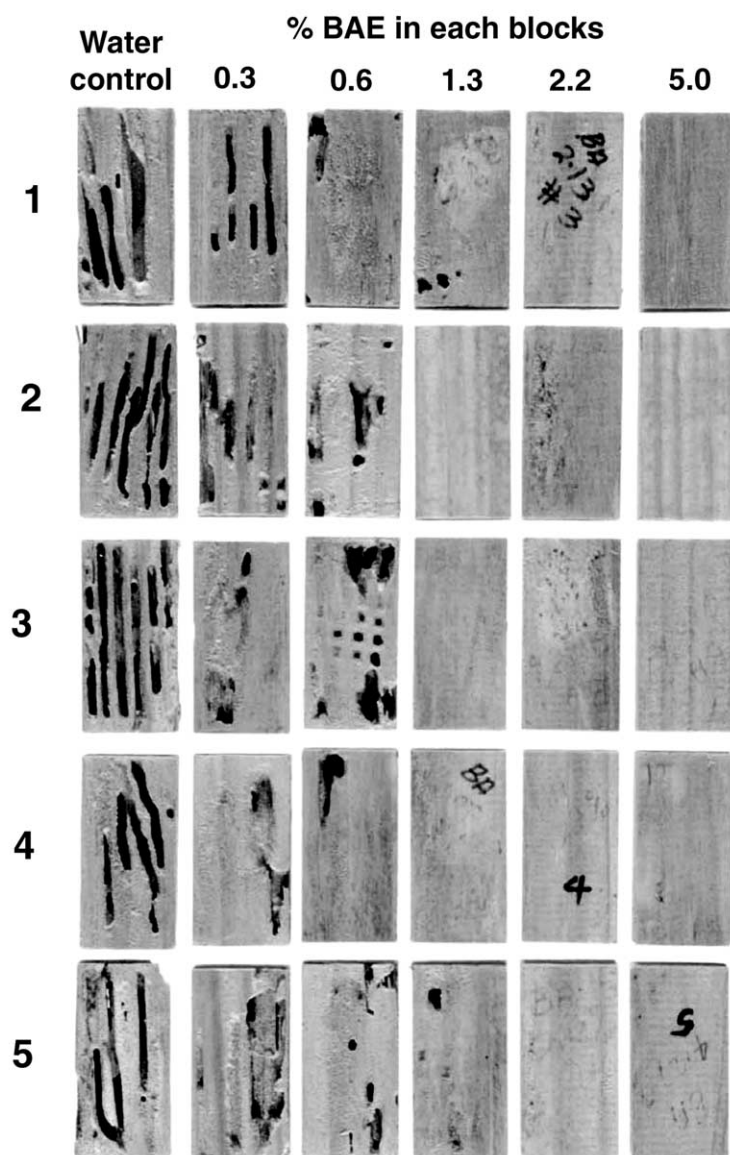


Figure 1 Termite attack and damage of boric-acid-treated *P. radiata* in laboratory bioassay.

imens were attacked or nibbled at the surface by *C. acinaciformis*, and there was 100% termite mortality. The result of this study indicates that borate compounds at higher retentions affect feeding and act as both contact and stomach poison. This suggests that the termites die either due to feeding on boron-treated wood or from leachates, or from a combination of both. The treated timber specimens were not placed directly into the substrate, so the amount of boron expected to leach was attributed to the termite regurgitated/faecal material activity in treated blocks.

Trimethyl borate (TMB)-treated specimens

Unlike the other borate-treated specimens, the termite interactions on the TMB treatments exhibited a different type of attack pattern. Termites attacked specimens along the grain direction of the test specimens and not randomly through the surface of the test blocks. This observation was similar for both timber species and both termite colonies.

The reason that the termites attacked along the grain direction could be either due to the blocks being treated on the surface or due to an even distribution of borate in the timber. The pattern of termite attack would suggest that the borate was concentrated mainly in the first few millimetres of the surface thickness. Unlike the untreated control, the treated specimens had no sign of termite attack on the surface. The percent mass loss of treated timbers ranged between 5% and 9% for *E. regnans* and between 6% and 19% for *P. radiata* (Table 4).

Termite mortality rate

Termite mortality rate was similar with all borate formulations. Mortality rates increased with increasing borate retentions in the wood. The results suggest that borate was toxic to the foraging termites in the test.

Tables 1–4 showed percent termite mortality over time. While only visual estimates of termite mortality were recorded, the tables show the toxic effects of the various retentions of borate compounds in the test against the

C. acinaciformis attack and damage on Boric acid and water treated *E. regnans* blocks (50 x 25 x 15 mm) after eight weeks of exposure in laboratory.

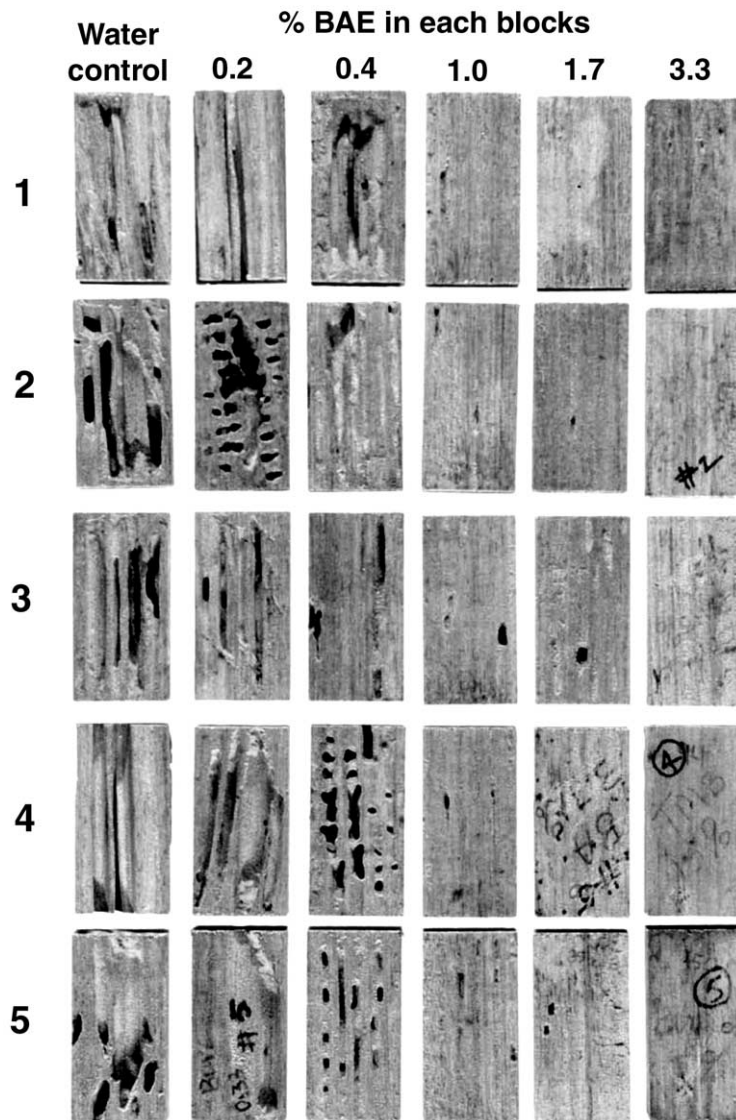


Figure 2 Termite attack and damage of boric-acid-treated *E. regnans* in laboratory bioassay.

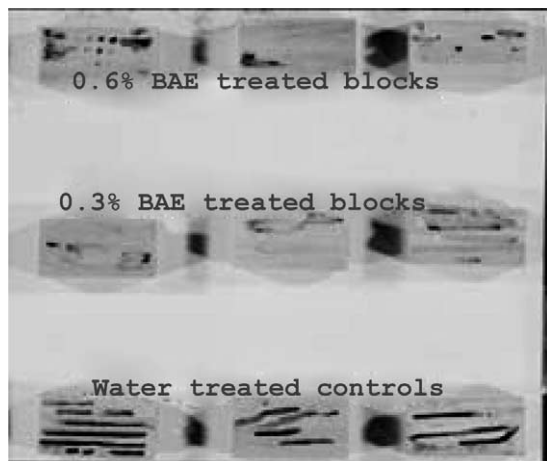


Figure 3 Termite pattern of attack on water controls, 0.3% and 0.6% BAE-treated *P. radiata* blocks from laboratory bioassay.

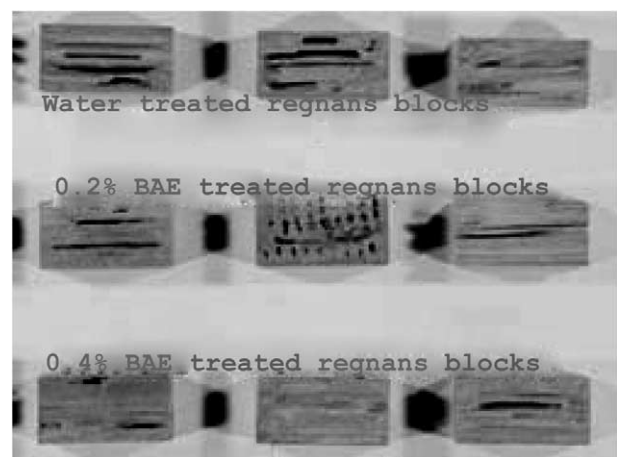


Figure 4 Termite pattern of attack on water controls, 0.2% and 0.4% BAE-treated *E. regnans* blocks from laboratory bioassay.

Table 2 Percent mass loss of wood (\pm SE) and percent mortality rate of *C. acinaciformis* in the no-choice laboratory bioassay with various concentrations of borocol-treated specimens and water controls after eight weeks of exposure. Mean of five replicates per treatment regime.

Mean retention (Borocol)		Termite colony A			Termite colony B		
Soln. (%)	*Mean BAE (% m/m)	Mass loss (%)	Mort. (%)	Surv. (days)	Mass loss (%)	Mort. (%)	Surv. (days)
<i>E. regnans</i>							
SC	0	49.3 (7.0)	29 (4.0)	56	44.8 (3.7)	25.4 (4.1)	56
0.33	0.18–0.23	22.3 (2.5)	76 (2.9)	56	19.4 (3.9)	82 (5.2)	56
0.65	0.33–0.43	14.3 (3.3)	94 (4)	56	17.1 (2.5)	92 (5.8)	56
1.32	0.98–1.0	3.7 (0.6)	100	53.6 (1.5)	2.8 (1.1)	100	56
5	3.90–4.00	1.1 (1.0)	100	37.6 (2.0)	1.5 (0.8)	100	38 (1.4)
<i>P. radiata</i>							
SC	0	48.9 (15.0)	25.4 (5.0)	56.0	53.7 (8.3)	27.2 (1.7)	56.0
0.22	0.3–0.3	19.4 (6.6)	62 (11.2)	56	29.1 (9.3)	62 (8.1)	56
0.45	0.7–0.7	20.7 (14.9)	80 (7.1)	56	18.7 (5.8)	86 (3.7)	56
0.9	1.2–1.6	6.3 (3.6)	100	52.4 (3.2)	5.6 (2.8)	100	51.8 (3.5)
1.8	2.5–2.6	1.7 (1.6)	100	45.8 (2.5)	1.3 (3.1)	100	46 (2.4)
3.6	5.1–6.4	0.1 (1.3)	100	37 (3.4)	0.6 (2.4)	100	32.8 (1.9)

*=range of retention within the treated blocks, mort. = % mortality, Surv. = number of days termite survived, WC = water control. Numbers in brackets are the standard error of the mean.

Table 3 Percent mass loss of wood (\pm SE) and percent mortality rate of *C. acinaciformis* in the no-choice laboratory bioassay with various concentrations of borester-7-treated specimens and water controls after eight weeks of exposure. Mean of five replicates per treatment regime.

Mean retention (Borester)		Termite colony A			Termite colony B		
Soln. (%)	*Mean BAE (% m/m)	Mass loss (%)	Mort. (%)	Surv. (days)	Mass loss (%)	Mort. (%)	Surv. (days)
<i>E. regnans</i>							
WC	0	49.3 (7.0)	29 (4.0)	56	44.8 (3.7)	25.4 (4.1)	56
0.5	0.2–0.2	21.7 (2.0)	69 (6.0)	56	22.8 (2.4)	63 (5.4)	56
0.9	0.4–0.5	7.2 (2.4)	77 (7.0)	56	10.3 (4.9)	86 (6.4)	56
2	0.9–1.1	5.0 (2.3)	88 (6.4)	56	3.9 (2.2)	79 (6.4)	56
4.0	2.3–2.4	0.2 (0.4)	98 (2.0)	47 (1.0)	1.1 (0.7)	100	46.8 (1.5)
<i>P. radiata</i>							
WC	0	48.9 (15.0)	25.4 (5.0)	56	53.7 (8.3)	27.2 (1.7)	56.0
0.6	0.5–0.81	17.8 (2.7)	60 (11.4)	56	24.9 (7.2)	70 (15.8)	56
1.1	1.1–1.3	8.36 (9.9)	62 (12.8)	56	15.2 (6.1)	80 (19.0)	56
2.1	1.5–1.6	1.9 (2.2)	89 (10.2)	56	3.4 (3.7)	93 (9.8)	52.6 (2.9)
4.1	3.9–4.6	1.9 (3.1)	100	45.8 (2.0)	0.3 (0.2)	100	46 (1.8)
8.1	4.6–5.7	0.25 (1.2)	100	35.8 (2.3)	0.51 (1.5)	100	34.2 (1.2)

*=range of retention within the treated blocks, Mort. = % mortality, Surv. = number days termite survived, WC = water control. Numbers in brackets are the standard error of the mean.

Table 4 Percent mass loss of wood (\pm SE) and percent mortality rate of *C. acinaciformis* in the no-choice laboratory bioassay with various concentrations of trimethyl borate (TMB)-treated specimens and solvent controls after eight weeks of exposure. Mean of five replicates per treatment regime.

Mean (TMB)		Termite colony A			Termite colony B		
Soln.%	*Mean BAE (% m/m)	Mass loss (%)	Mort. (%)	Surv. (days)	Mass loss (%)	Mort. (%)	Surv. (days)
<i>E. regnans</i>							
SC	0	48.8 (6.0)	26 (5.8)	56	53.3 (5.3)	28 (6.8)	56
0.25	0.3–0.3	8.8 (2.7)	95 (3.2)	56	12.1 (2.4)	88 (5.8)	56
1	0.6–0.8	4.9 (2.1)	100	56	6.1 (2.9)	100	56
<i>P. radiata</i>							
SC	0	47.5 (15.0)	29.2 (5.0)	56	48.9 (8.6)	23.4 (4.2)	56
0.25	0.3–0.4	13.4 (7.7)	79 (16.9)	56	14.6 (8.7)	76 (22.1)	56
0.5	0.6–0.7	18.9 (4.4)	98 (17.2)	56	15.6 (2.6)	95 (16.1)	56
1.0	1.1–1.2	5.9 (2.1)	100	52.6 (2.8)	6.1 (3.6)	100	53.8 (2.9)

*=range of retention within the treated blocks, Mort. = % mortality, Surv. = number of days termite survived, SC = solvent control, WC = water control.

Numbers in brackets are the standard error of the mean.

termites. All borates at high retentions, 1.3–1.4% in *E. regnans* and 1.5–1.7% in *P. radiata*, were toxic to termites, resulting in 100% mortality within about 35 to 50 days.

The percent mortality of the controls (water and solvent) indicated that natural mortality after 56 days of exposure did not exceed about 30% of the termite populations in the test. This mortality included termite recovery from the test jars during the bioassay period, because termites were established in the nest material (mound material) for 56 days. It would appear that natural mortality was not important because for most boric acid retentions, the mortality rate was 100% and occurred between 35 to 56 days of the test period. It was only at the lowest retentions of borate (0.1–0.3%) that about 70% mortality occurred, and some of the dead termites may be attributed to natural mortality. Thus it was considered that the adjustment for natural termite mortality was slight.

The results indicate that with higher levels of retention, the mean termite survival time decreases but only up to a certain level. The controls have a significantly longer mean termite survival time than the borate formulations-treated test. While, within the borate-treated specimens, the lower retentions of boric acid produced slightly longer survival times than the higher retentions, there was no difference between the higher boric acid retentions, which had similar survival times.

Discussion and conclusions

The no-choice laboratory bioassays, using *C. acinaciformis* as the test termite, were used to evaluate the borate compounds under test when impregnated into wood blocks as potential wood preservatives for the hazard level two (H2) (AS 1604 2000). The mortality percent indicated that with treated specimens with the higher-retention borate compounds, 100% mortality was achieved within the 35 to 50 days. The majority of the termite populations in the tests acquired a lethal dose of borate compounds from the treated specimens, with a high termite mortality rate between 70% and 100%. These laboratory results support Su and Scheffrahn (1991) who found that, in specimens treated with BORA-CARE at >2500 ppm, the majority of termites out of ca. 2000 individuals apparently acquired a lethal dosage with a 86–100% mortality rate.

Generally, in the boron compound bioassays, the results were consistent in that as the concentration of boron increased the mean survival time decreased. TMB had a slightly longer survival time than the other borate compounds, which showed similar survival times. Results using the “rule of thumb” assessment showed that borax, borocol, borester, and trimethyl borate within the retentions of >1% m/m BAE affected protection from termite attack and damage. Under 1% m/m BAE retention, the borate-treated specimens failed to provide protection from termite attack and damage.

The broad picture in the borate compound bioassays indicated that at low retentions, termite survival rates were on average longer, whereas at high retentions there was a 100% termite mortality within the five to six weeks

of test. These findings support Grace et al. (1992) and Su and Scheffrahn (1991), who suggested that higher borate retentions had a feeding deterrence effect on foraging populations of subterranean termites in laboratory bioassays.

However, the higher-retention borate treatments were the most repellent and/or toxic to *C. acinaciformis*. All the termites were dead before the end of the test period. Borate retentions over 1% m/m BAE would be expected to prevent termite attack and damage. Whether levels of these retentions could be impregnated into structural building timbers or used as remedial treatment to timber-in-service to be effective over an extended period of time (such as 5–10 years) needs further study. Higher retentions of borate formulations would provide adequate protection from subterranean termites over an extended period of time.

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Received April 15, 2003