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FIELD TESTING OF WOOD PRESERVATIVES XVIII PERFORMANCE OF BORATE-TREATED WOOD AGAINST SUBTERRANEAN TERMITES

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Abstract

In the mid 1990s, FPInnovations - Forintek Division initiated a study of the termite resistance of borate-treated lumber above ground, protected from rain in Canada, Japan and Hawaii. The material included hemlock and amabilis fir lumber treated with disodium octaborate tetrahydrate (DOT) and chromated copper arsenate (CCA). Reference materials included Hinoki in Japan ammoniacal copper zinc arsenate (ACZA) treated Douglas-fir in Hawaii and western red cedar in Canada. The samples were evaluated annually for termite attack. In Canada all of the treated material was found to be performing equally well, with some pieces showing residual signs of early superficial feeding or cosmetic damage. Attack was moderate on untreated controls. Similar results were found in Japan with the exception of 2% borate shell treatments with DDAC in which two samples were rated as moderately or severely attacked. In Hawaii, where termite attack was more severe 2% and 3% BAE (boric acid equivalent) borate through treatments and ACZA performed better than the others.

After ten years, the tests in Japan and Hawaii were terminated. The Hawaii samples, which had suffered the most attack, were examined by Forintek's CT scanner to determine the extent of internal damage not detectable by a visual rating. This revealed that the 3% through borate treatments contained the least termite damage and 2% through borate treatments had negligible attack. The borate treated pieces returned from Hawaii were also subjected to measurements of compression stiffness at seven points along their length. Results showed that the stiffness of any specimen was similar along its length. Only the 2% shell treated samples showed statistically significantly lower stiffness than the 3% through treated samples which had no internal damage.

Five borate-treated dodai from each group from Hawaii and Japan were destructively sectioned for analysis of residual borate. Generally, the amount of borate retained was less on the outer surfaces (top, sides, and bottom). There did not appear to be a correlation between the treatment type and the percentage of borate retained, nor between the rating given the piece for decay and the percent of borate retained.

In summary, ten-year results of field exposure in Hawaii and Japan, in relatively aggressive termite feeding situations, support the conclusion that borate treatments can provide long-term protection from destructive termite attack to structural lumber. A 2% BAE through-treatment performed better than CCA treated hem-fir in Japan and Hawaii. Plantation-grown Hinoki

showed termite attack on both sapwood and heartwood at the same rate as untreated hemlock.

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1. Introduction

Termites are of limited economic importance in Canada but present a more serious threat to Canadian wood products in many of our overseas markets. In Canada, the western subterranean termite (*Reticulitermes hesperus* Banks) is causing economic damage in the Okanagan and Georgia Basin regions of British Columbia, while the Eastern subterranean termite (*Reticulitermes flavipes* Kollar) is causing damage in parts of southwestern Ontario. The latter in particular has received considerable media attention because it affects Toronto, Canada's largest city. Overseas, the Formosan subterranean termite (*Coptotermes formosanus* Shiraki) is generally regarded as one of the most widespread and aggressive species causing economic damage in Southern China, Taiwan, southern Japan, Hawaii and the southern USA mainland.

Wood frame construction must incorporate several lines of defence against termite attack (Morris 2000), and the last line of defence to prevent damage to wood components is the use of treated wood. The preservative disodium octaborate tetrahydrate (DOT) is particularly effective at penetrating deeply into the relatively impermeable Canadian wood species. However, DOT is not fixed in wood and eventually leaches out in ground contact. For this reason, DOT's major commercial application is above ground, protected from liquid water UC1 and UC2 (CSA 2008). To maintain and expand markets for Canadian wood products in areas with termite hazard it is necessary to demonstrate that Canadian treated wood can provide adequate termite resistance.

To evaluate the long term performance of DOT treated Canadian wood a test method was designed to simulate a worst case scenario for sill plates (*dodai*) on concrete foundations as used in traditional Japanese housing construction. These samples were protected from the weather, but exposed to termites (Grace *et al.* 1995). Concurrent experiments of DOT-treated Canadian hem-fir using this test design were initiated between 1995 and 1997 in Canada, Hawaii (Grace *et al.* 2001) and Japan (Tsunoda *et al.* 2002a, 2002b). At the latter two sites the Formosan subterranean termite is present and at the Hawaii site represents an extreme hazard.

In addition to borate shell and through treatments treated at the Forintek Vancouver laboratory, each test plot also included chromated copper arsenate (CCA), treated and untreated control samples of both western hemlock [*Tsuga heterophylla* (Raf.) Sarg] and Pacific silver fir [also called amabilis fir, *Abies amabilis*(Dougl.) Forbes] (commercially sold as hem-fir, a mixture of these two species), and for reference, a locally-used timber considered to be termite resistant.

The material was inspected annually. After ten years of exposure, the tests in Japan and Hawaii were terminated and the test samples were returned to Forintek for analysis of residual borate and strength testing.

2. Materials and Methods

2.1 Preparation of Test material

The preparation of test material was described by Grace et al. (1995). Test specimens, 100 x 100 x 400 mm, were prepared using western hemlock and Pacific silver fir selected from a large number of specimens pressure-treated with an aqueous solution of disodium octaborate tetrahydrate (DOT) to achieve target penetrations and retentions. One set of material was treated, with a DOT solution to which 0.5% of didecyldimethylammonium chloride (DDAC) had been added to improve penetration and provide mould resistance. Shell treatments were dried shortly after treatment. Through treatments were allowed to diffuse to achieve complete cross section penetration. Borate retentions were determined by mannitol titration (Winters ca 1965), and CCA was analyzed by energy dispersive x-ray spectrometry (American Wood Preservers' Association 1997). After cutting to length, the DOT-treated pieces were end-coated with 5% BAE solution.

To compare the performance of borate with that of another preservative, hemlock and fir samples were prepared from incised lumber pressure-treated with chromated copper arsenate (CCA-C) to target retentions of 4.0 kg/m^3 and preservative penetrations of 10 mm or more. The CCA-treated samples met the CSA retention and penetration requirements for lumber exposed above-ground (CSA 1997b). The cut end of each CCA-treated piece of lumber was given a coating of commercial copper naphthenate field-cut preservative.

In each location, a suitable local reference material was obtained. In Canada this was second growth western red cedar (*Thuja plicata* Donn). In Hawaii this was ammoniacal copper zinc arsenate (ACZA) treated Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] and in Japan this was untreated Hinoki (*Chamaecyparis obtuse* Endl.) a naturally durable softwood used in wood construction (Grace 1999, 2000).

2.2 Exposure Method

The exposure test method involved laying wood samples on top of hollow concrete blocks standing on the soil surface and then covering the structures with a box to protect them from rain and maintain high humidity. There was no direct contact between the wood samples and the soil, other than that brought by the termites to construct shelter tubes. The covering boxes in Ontario were constructed from CCA-treated plywood. The inside and outside were painted with exterior primer and two coats of white paint to prevent excessive interior build-up of heat in direct sun. In Hawaii, the plywood covers were untreated and were replaced as necessary due to termite damage and weathering. Again the boxes were painted with exterior primer and two coats of white paint. The covering boxes in Japan were made of white plastic. Within each box at six or eight hollow concrete blocks were placed onto levelled soil 50 mm apart.

Through the two perforations in each concrete block, 25 x 25 x 300 mm feeder stakes were hammered into the ground so that the top of the stake was within 2–5 mm of the top of the concrete block (Figure 1) to encourage initial termite attack. The feeder stakes were prepared from moderately durable heartwood so that they would remain free from decay and mould long enough to be discovered by a foraging population of termites. The test samples were situated

one per block such that they covered the holes in the block but were not in direct contact with the feeder stake. This was to prevent direct tunnelling by termites from the untreated wood stakes into the test samples. This is an extremely aggressive test since all aspects contravene the protective measures one would normally take in wood frame construction (Morris 2000). This test method has now been standardised as AWPA E21-06 (American Wood Protection Association 2009).

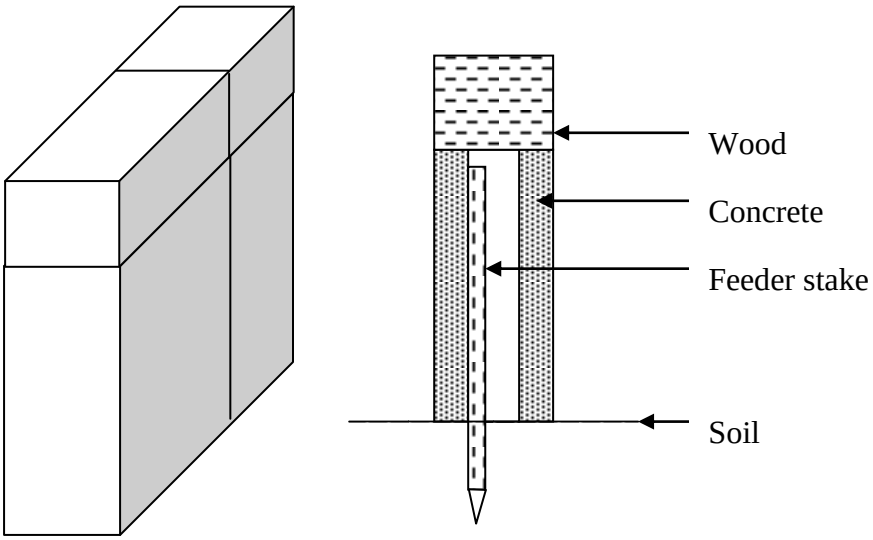

Figure 1 Cross-section of test assembly.

Test material was non-destructively rated on an annual basis using a visual examination for signs of termite attack. Each sample was carefully removed, examined, and assigned a rating on the old 0–10 scale of the American Wood Protection Association (AWPA) (Table 1), before being replaced in the same location. All ratings were subsequently entered into databases.

Table 1 Termite attack grading system

AWPA Rating	Description
10	Sound: surface grazing (nibbling) is permitted, but such cosmetic damage must be noted in the report.
9	Trace of attack: for example, surface erosion up to 5 mm deep, or up to two termite penetrations of up to 10 mm deep.
7	Moderate attack: for example, surface erosion over 5 mm, penetrations over 10 mm deep or ramifying tunnels present.
4	Heavy attack: for example, extensive tunnelling of up to 50–75% of the cross-section.
0	Failure from termite attack.

2.3 Canada

The Canadian test site is located within the town of Kincardine near Toronto, ON. Kincardine

sits at the northern limit of known termite infestation in Ontario. The soil is a sandy loam and this site receives mean annual precipitation of 998 mm and has mean daily maximum and minimum temperatures of -2°C and -10°C in January, and 24°C and 13°C in July with an average yearly temperature of 6.2°C. The climate there also places it within the zone of medium out-of-ground decay hazard with a climate index of 49. The test plot, located on municipal land, supports a population of Eastern subterranean termite, *R. flavipes*.

A set of ten western hemlock pieces were selected with an average of 3.3 kg/m^3 B_2O_3 (1.4% boric acid equivalent, or BAE) in a 25-mm outer shell. This met the Canadian Standards Association (CSA) requirements for borate-treated lumber used for out-of-ground contact (CSA 1997a). Ten fir replicates through-treated to a mean of 2.5 kg/m^3 B_2O_3 (1.3% BAE) in the full cross section were also selected. This material would have just failed the CSA retention requirement of 2.7 kg/m^3 B_2O_3. Ten hem-fir pieces were treated, to a mean retention of 3.2 kg/m^3 B_2O_3 (1.4% BAE) in a 25-mm outer shell, with a DOT plus 0.5% DDAC.

For Kincardine five hemlock and five fir samples were prepared from incised lumber pressure-treated with chromated copper arsenate (CCA-C) to retentions of 4.0 and 5.0 kg/m^3, respectively, Ten untreated samples of western red cedar were also included, along with five each of untreated hemlock and fir controls.

In November 1996, one replicate from each treatment plus two of the untreated controls – a total of six sample – were placed in each of 10 test boxes. To encourage even distribution of termite attack throughout the test plot, feeder strips, 10 x 10 mm in size, were installed in November 1998, linking the 10 individual test boxes. First, the concrete support blocks were lifted, leaving the feeder stakes in place. Small trenches, 25 mm deep, were then dug to join the feeder stakes of one test unit to those of adjacent units and to termite nests or bait stations. The pine heartwood feeder strips were installed end-to-end in the trenches and covered with soil. The support concrete blocks, samples and shelter boxes were then re-assembled.

To monitor conditions inside the test assemblies, a HOBO data logger, programmed to record temperature and relative humidity once per hour, was installed on the interior north wall of one of the boxes in August 1999 and removed a year later.

2.4 Hawaii

The American test plot is on the island of Oahu, Hawaii, located at the Waimanalo Experiment Station of the College of Tropical Agriculture & Human Resources, University of Hawaii at Manoa. Treatments were installed in 1997 and were distributed with one sample from each treatment in each of 10 test boxes. These included ACZA (incised Douglas-fir treated to 4.0 kg/m^3 by J. H. Baxter & Company); CCA (incised hem-fir at 4.0 kg/m^3); and hem-fir treated with disodium octaborate tetrahydrate at 2% boric acid equivalent (BAE) shell treatment, 2% BAE through treatment, 2% BAE+DDAC half shell and half through treatment, 3% BAE shell treatment, and 3% BAE through treatment. The cut end of each ACZA treated piece of lumber was given a coating of commercial copper naphthenate field-cut preservative. Each of the 10 test boxes also contained an untreated hem-fir control sample, and they had to be replaced every one

or two years because of the severe termite hazard. The samples installed in Hawaii were conditioned and weighed before and after exposure.

2.5 Japan

The Japanese field test site, maintained by the Research Institute for Sustainable Humanosphere, Kyoto University, is located in Kagoshima Prefecture on the island of Kyushu. The Hawaii and Japan test sites both support active Formosan subterranean termite (*C. formosanus*) populations, although test results (Tsunoda *et al.* 2002b) indicate that termite activity is up to 10-fold greater at the Hawaii site. The more tropical environment in Hawaii facilitates year-round foraging and growth of the colonies, in comparison to the seasonality found in Kagoshima (Grace 2004).

The samples were installed at the test site in Japan in December 1995. Thy were placed in clusters of eight, with one sample from each of the 8 treatments (2% BAE shell, 3% BAE shell, 2% BAE through, 3% BAE through, 2% BAE +DDAC shell, CCA 4 kg/m^3, untreated hem-fir, and untreated hinoki). Each cluster was covered with a PVC box. Feeder stakes were replaced after 3 and 5 years' service at this site. These samples were not weighed before exposure.

2.6 Scanning

Forintek's CT Imaging Centre at the Vancouver laboratory, with a 3.5 MeV industrial x-ray CT scanner, was utilized to examine the samples returned from Hawaii. CT scanning is a nondestructive method for obtaining accurate 2-dimensional images of an object's internal features. The technique uses an x-ray beam that penetrates the object. Transmitted energy is measured by a linear detector array and powerful computers are used to reconstruct 2-dimensional images on a slice-by-slice basis along its length. Slice images can also be assembled to provide a highly accurate 3-dimensional model of the object. During scanning the samples were placed perpendicular to the scanner turntable so the x-ray beam could penetrate through the thickness (Figure 2), and were scanned at 25 mm intervals along the length of the piece.

Figure 2 Dodai from Hawaii on CT scanner turntable

2.7 Strength Testing

To determine whether the presence of termite damage could be detected by strength testing without destroying the samples (since it was desired to perform borate analysis on specific locations within the pieces), the transverse compression stiffness of each piece was measured. The intent was to simulate the function of dodai under compression from vertical posts in traditional Japanese post and beam construction. Since the test was necessarily non-destructive, the ultimate compression strength could not be determined.

The tests were conducted by the Wood Engineering Group at Forintek's Vancouver laboratory. Each specimen was loaded in compression perpendicular-to-the-grain from a location of 25 mm from one end and at 25 mm increments towards the centre. The specimens sat on a loading plate of 38 mm wide that spanned the width of the specimen. The load was applied through a 38 mm wide plate that spanned the width of the specimen and was mounted on a universal loading head (Figure 4). At each location the specimens were loaded to 2000 pounds at a rate of 0.5 inches/minute. The load and actuator deflection were recorded. The stiffness was calculated by regression analysis of the load and actuator deflection, between 1000 and 2000 pounds. The depth, width and weight of each specimen were also recorded.

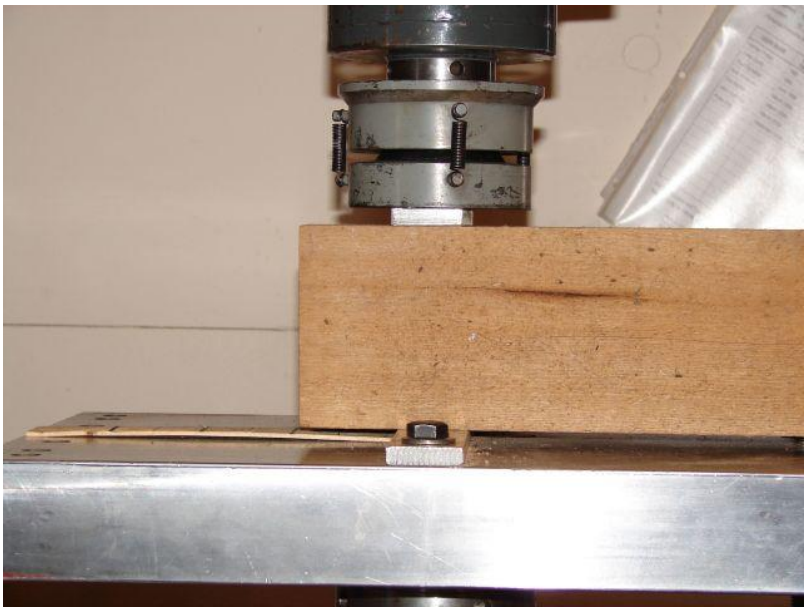

Figure 3 Dodai from Hawaii in strength-testing apparatus

2.8 Borate Analysis

Out of each set of 10 borate-treated replicates from each of the Japan and Hawaii test sites, five samples were chosen randomly for destructive sampling. To minimize the number of analyses, only one quarter of each dodai was sampled (Figure 5). That quarter was sectioned into eight slices, 25 mm thick. Slices #1 (outermost slice), #3, #5, and #7 were further sectioned for analysis into eight equal cubes, each measuring approximately 25 mm^3. Slices which had been removed from each dodai prior to exposure and stored at the Forintek laboratory for 10 years were similarly sectioned. Each cube was ground into sawdust for analysis, and the borate was extracted in hot water. Borate retentions were determined by mannitol titration (Winters ca 1965). The equipment used was a Metrohm 702 SM Titrino Autotitrator fitted with a combined pH glass electrode.

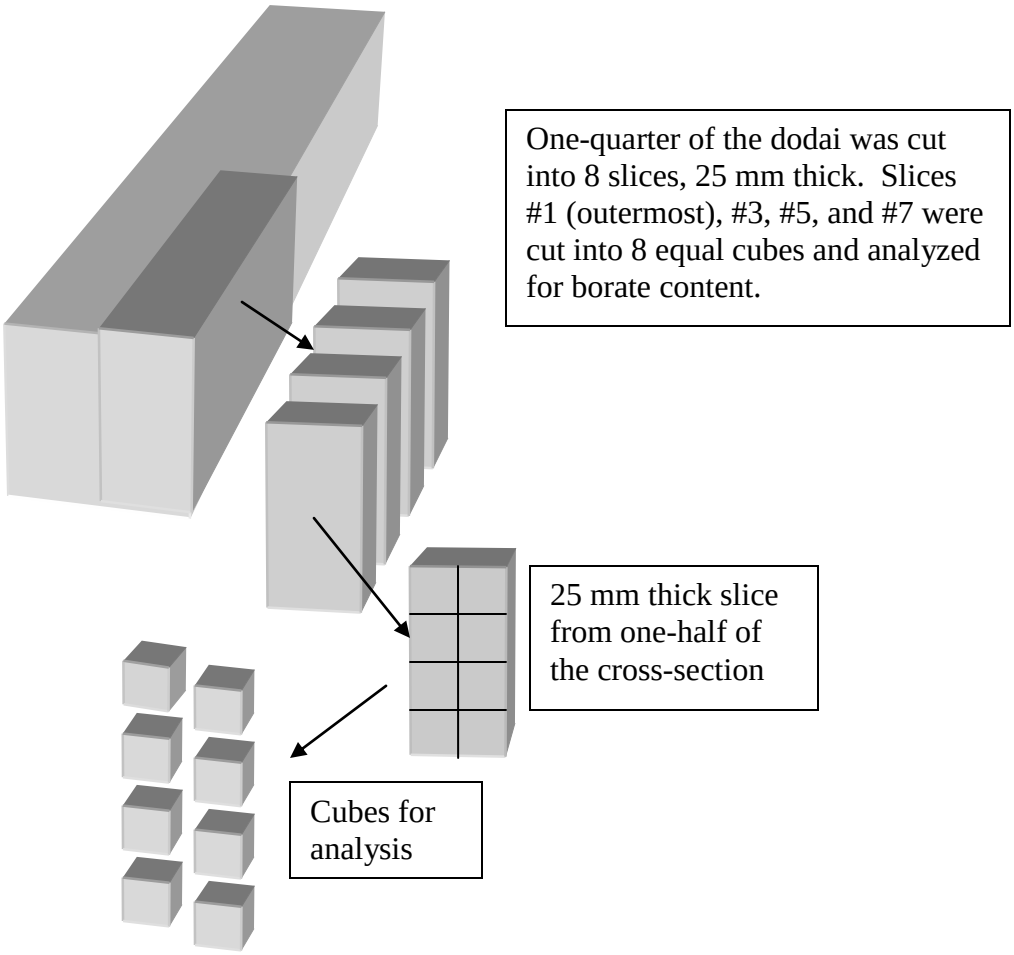

Figure 4 Cutting plan for the dodai

3. Results and Discussion

3.1 Test Conditions

Figure 6 illustrates that the relative humidity inside the boxes at Kincardine remains close to 100% virtually throughout the year, ranging from 75 to 100%, and the temperature ranged from –10°C to 20°C. As a result of such a high humidity, condensation must have formed on the lid of some boxes and could have dripped onto the samples. The tops of samples often appeared wet during inspection. This created a leaching hazard for the borate-treated samples. Similiar conditions of high humidity were noted in the boxes at the Hawaii test site.

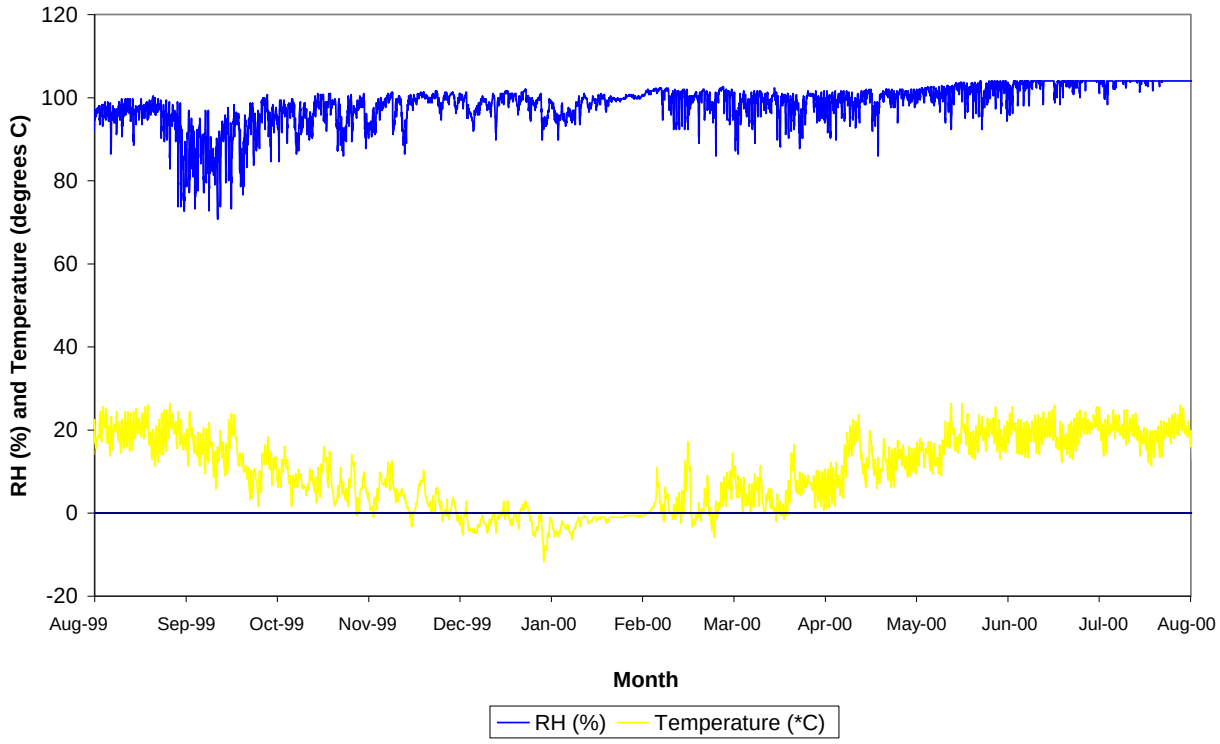

Figure 5 Conditions inside the Kincardine test box during 1999 – 2000

3.2 Termite Attack Ratings

Mean ratings at the 10-year evaluation for untreated wood ranged from 8.6 for the naturally durable western red cedar and 6.2 for hem-fir at Kincardine, to 4.0 for both hinoki and hem-fir at Japan, to 0.0 for hem-fir at Hawaii (Figures 6-8). At the Hawaii site untreated hem-fir dodai were repeatedly destroyed within one to two years (Grace *et al.* 2001). Termite attack was up to 10 times faster on untreated hem-fir than at the site in Japan.

At Kincardine no preservative-treated sample received a rating of less than 9 at the 10-year evaluation. Borate treatments performed as well as CCA treatments, with mean ratings of 9.0 or higher. At this stage, there was also no discernible difference between through- and shell-treatments with borate, or from the addition of DDAC. Evaluations at Kincardine between years 2 and 4 overestimated the level of damage to treated material based on exploratory tunnelling that appeared to penetrate the surface, particularly at incisions, on CCA-treated samples. Continued evaluations and probing with stiff wire revealed that these tunnels were shorter than the depth of preservative penetration and did not increase in depth with time. Grace *et al.* (2001) noted that neither DOT nor CCA is repellent to termites, so minor damage is not unexpected.

In the parallel test situated at the Wood Research Institute in Kagoshima, Japan, attack of preservative-treated samples was comparable to that found at the Canadian site. This may be partly because the Formosan termite there is close to the northern end of its range. In Japan, samples shell- and through-treated to 2% BAE were rated 9.4 and 9.2. Samples treated to 2%

BAE/DDAC were rated 8.8; and samples treated to 4.0 kg/m^3 CCA were rated 9.6.

In the other parallel test located in Waimanalo, Hawaii, where the climate is highly favourable to termite activity throughout the year, attack was more advanced than at the other two sites. Shell treatments were more severely attacked than through treatments. Mean ratings ranged from 7.4 and 8.8 for the 2% and 3% shell treatment groups, to 8.7 and 9.6 for the 2% and 3% through treatment groups,. All borate treated samples were rated 7 or higher with the exception of one 2% + DDAC shell treated sample rated 4 and one 2% shell treated sample rated zero. There was no significant difference in ratings, based on *t*-tests at the 95% confidence level, between the 2% BAE through, 2% BAE shell, 2% BAE plus DDAC shell/through, and 3% BAE shell treatments. There was also no significant difference in ratings between the 3% BAE through and CCA shell treated hem-fir, which were both significantly higher than the other borate treatments. The ACZA treated Douglas-fir significantly outperformed the other treatments. Although DDAC has not proved to have any additional efficacy against termites in the field tests (Tsunoda *et al.* 1998a; 2000; 2002; 2004; 2006; Grace *et al.* 2000; 2001; 2004; 2006), a three–week lab test on borate with and without DDAC treatment showed a small amount of DDAC substantially reduced weight loss of borate-treated wood (Tsunoda *et al.* 1998a).

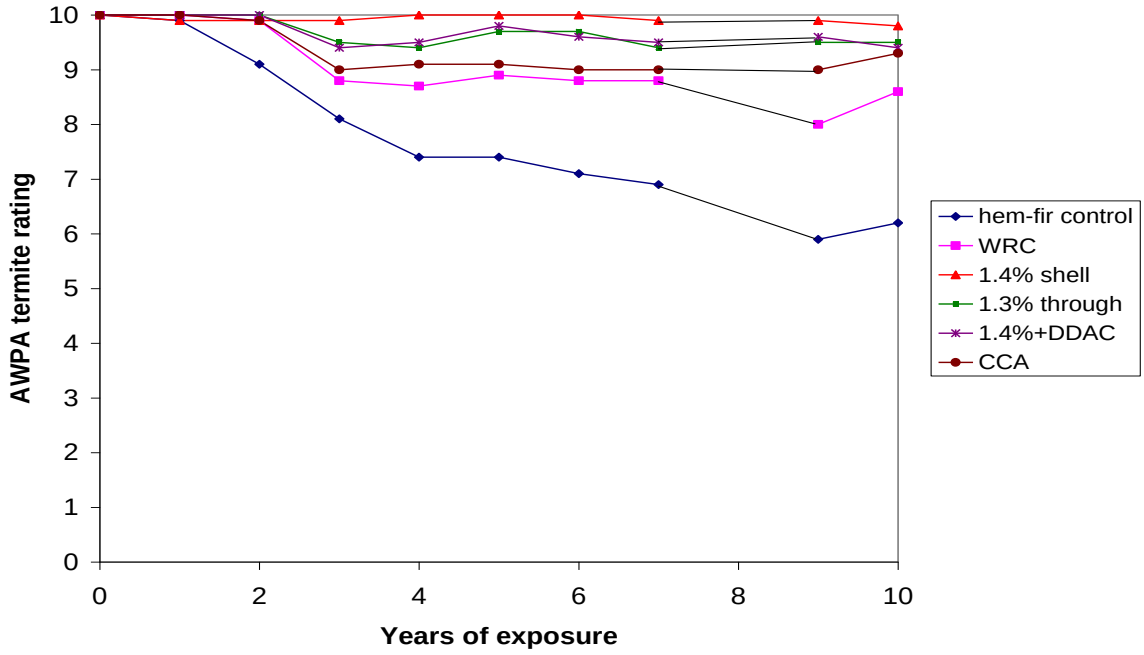

Figure 6 Performance of samples at Kincardine, Canada

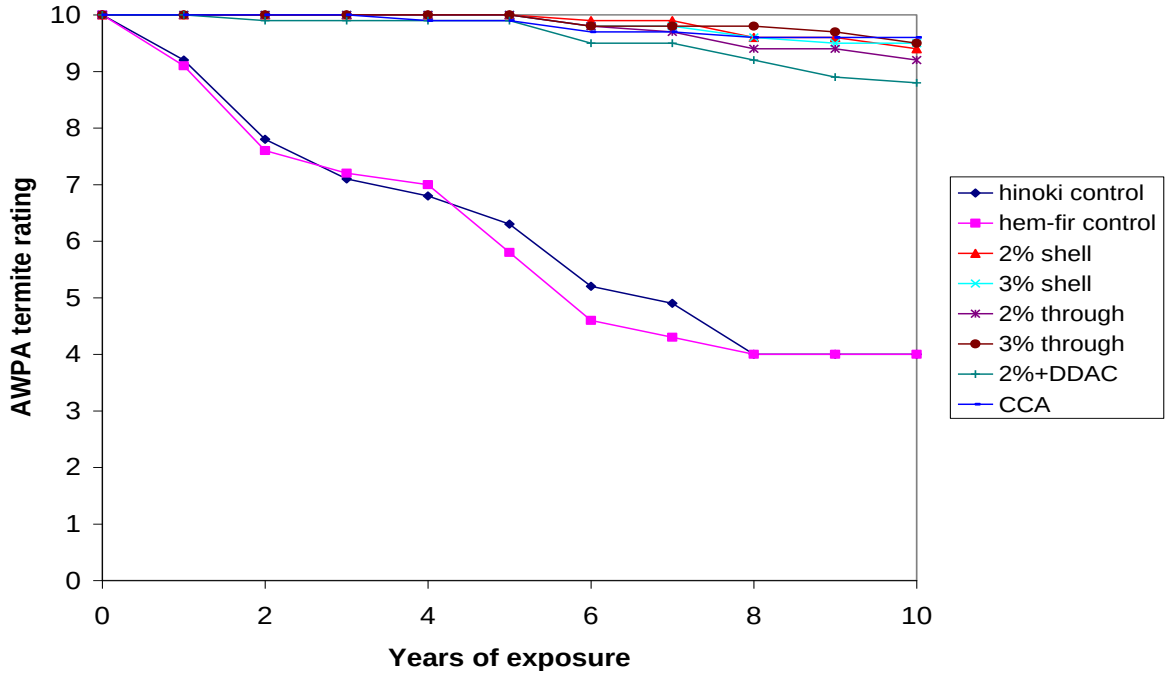

Figure 7 Performance of samples at Kagoshima, Japan

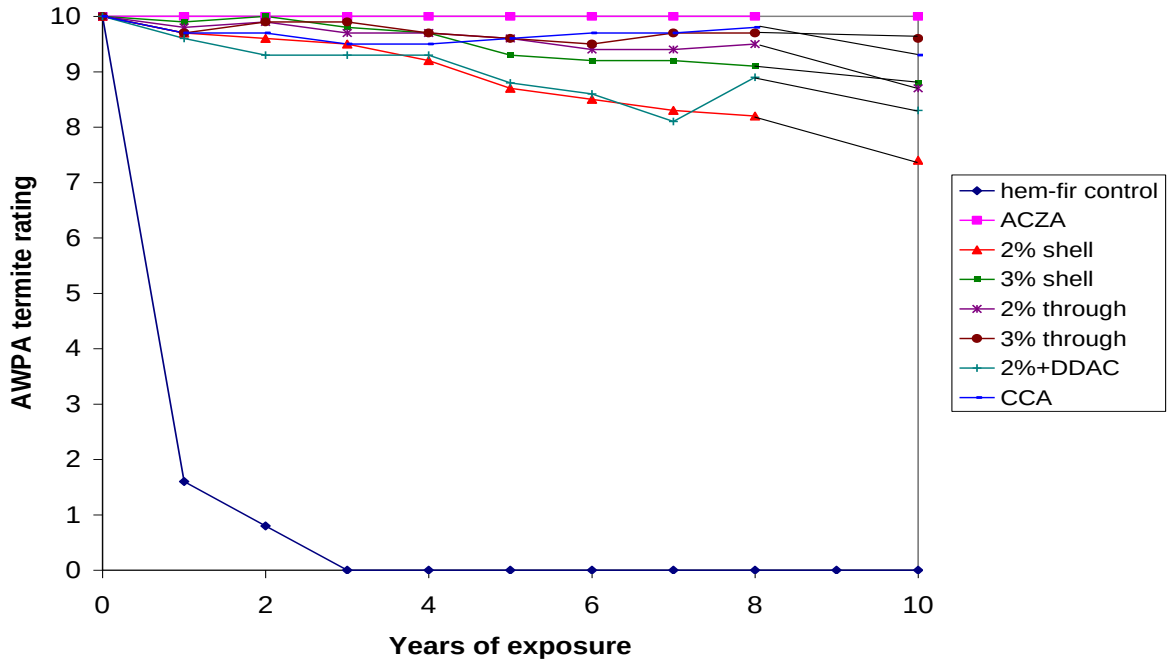

Figure 8 Performance of samples at Waimanalo, Hawaii

3.3 Scanning

Representative images of cross-sections taken half-way along the length of the piece are shown for each borate treatment group returned from Hawaii, as well as for the CCA-treated samples (Figures 9–14). Dark areas in the images represent a lower density area, indicating a void.

The CT scans generally confirmed the field visual ratings, however some internal damage was revealed by the CT scans that could not be detected by an external examination of the samples. In particular, internal voids were seen in three CCA-treated pieces (Figure 14). These had been rated 7, 9, and 9 in the field. The 3% borate through-treatment was the only group with no internal damage (Figure 12) but the 2% borate through treatment had negligible attack.

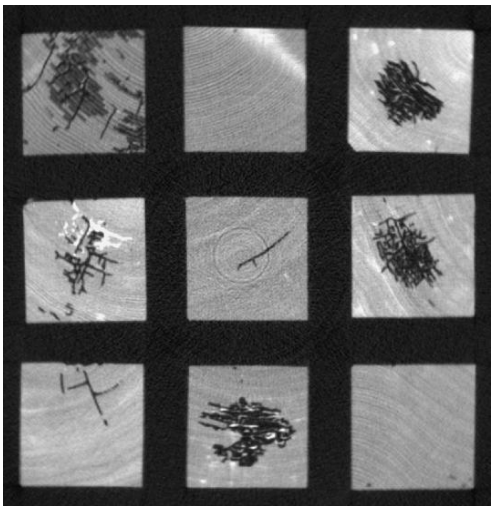

Figure 9 Cross sections of 2% borate shell -treated dodai

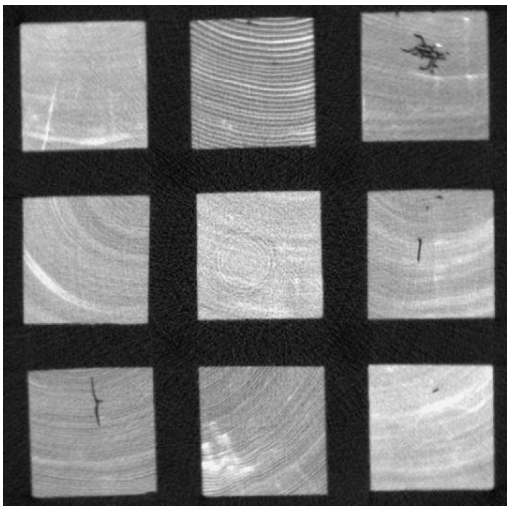

Figure 10 Cross sections of 2% borate through -treated dodai

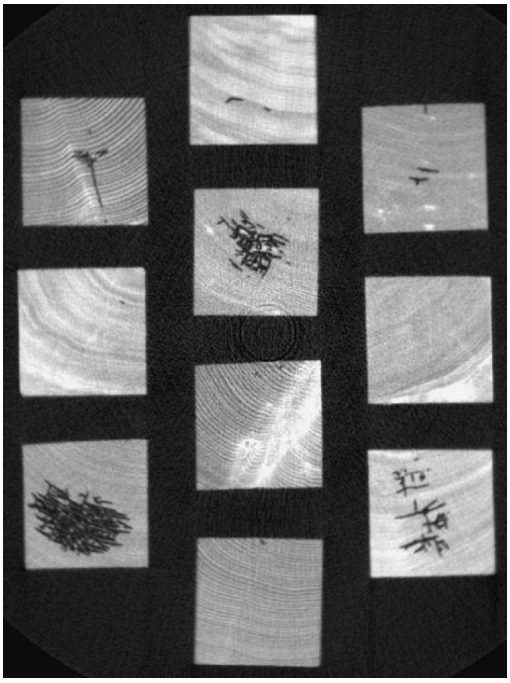

Figure 11 Cross sections of 3% borate shell -treated dodai

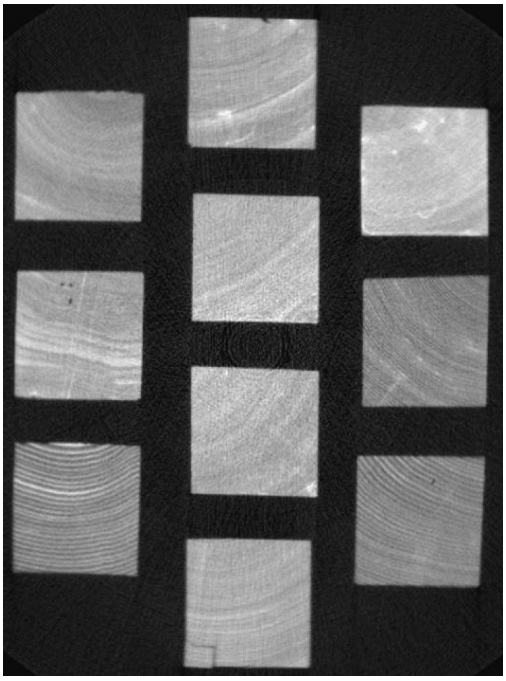

Figure 12 Cross sections of 3% borate through -treated dodai

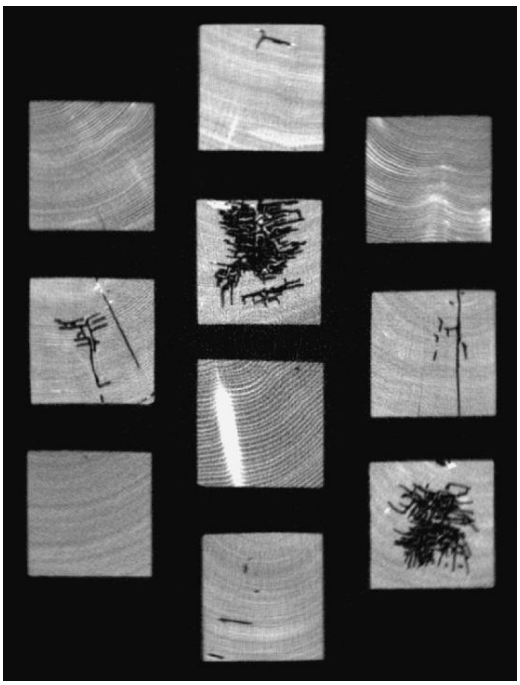

Figure 13 2% borate + DDAC shell/through -treated dodai. The shell treated samples are those with the most damage left/centre, middle/top 2 and right/bottom two. Through

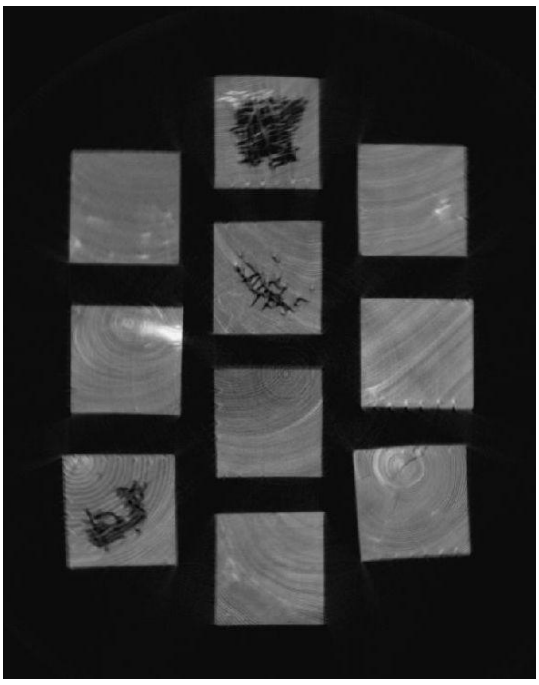

Figure 14 Cross sections of CCA shell -treated dodai.

treated samples have negligible or no damage.

3.4 Strength Testing

The average stiffness for each borate treatment group was comparable, with the exception of the 2% shell treatments (Figure 15). For any given specimen, the stiffness of any specimen was similar along its length. CT scans of the dodai showed substantial voids in all groups except the 3% through-treated samples. While there was no comparable strength testing done before exposure, the undamaged 3% through treated samples provide a useful reference against which to compare the stiffness of the groups that did have internal damage. Only the 2% shell treated samples showed statistically different stiffness from the 3% through-treated samples, based on *t*-tests at the 95% confidence level.

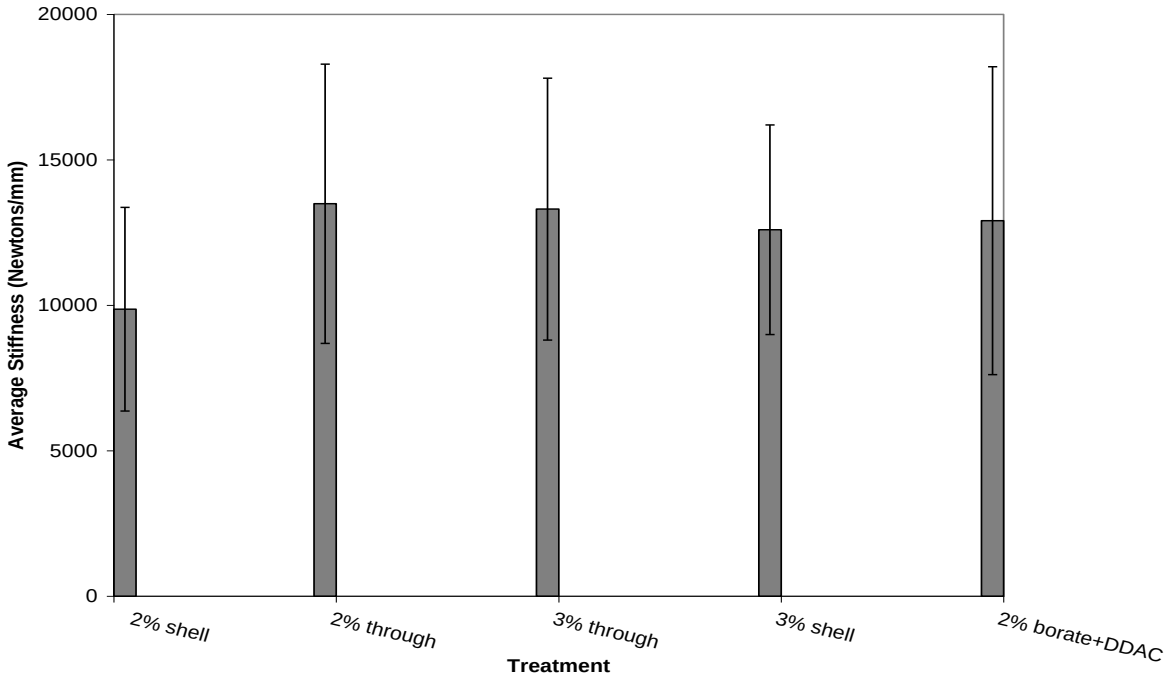

Figure 15 Average compressive stiffness of each treatment group

3.5 Borate analysis

There did not appear to be a correlation between the treatment type (i.e. shell or through, 2% or 3%) and the percentage of borate retained, nor between the rating given the piece for termite damage and the percent of borate retained (Tables 2 and 3). Although there was large variation among samples, a pattern of loss could be discerned in the individual analysis blocks from these samples (data not shown). Generally, the amount of borate retained was less on the outer surfaces. Some samples had losses from the top, some from the sides, and some from the bottom. In most cases there were combinations of each type of loss. Borate loss caused by condensation dripping on the samples from the covering box, as well as boron diffusion into the supporting concrete blocks may explain these findings.

Table 2 Retained borate and visual termite rating in Hawaii samples after 10 years

Sample	Treatment Group	Mean %BAE of Cross-sections 3,5,7	%BAE Unexposed	% retained	10-year termite rating
AE	2% shell	0.9	1.9	48	9
CK	2% shell	0.6	0.9	75	7
AT	2% shell	0.8	1.3	61	7
BP	2% shell	1.0	1.6	63	9
BA	2% shell	0.7	1.6	44	9
			mean	58	
			std dev	12	
HB	2% through	0.6	2.4	26	9
EO	2% through	1.5	3.2	48	9
FK	2% through	1.6	1.5	110	9
GJ	2% through	1.3	3.2	40	9
EN	2% through	1.3	2.4	54	9
			mean	61	
			std dev	32	
BG	3% shell	0.7	1.0	71	9
BB	3% shell	1.9	5.7	34	9
BW	3% shell	0.9	1.7	53	9
BV	3% shell	0.6	1.4	44	9
AO	3% shell	2.0	2.7	72	9
			mean	55	
			std dev	17	
FN	3% through	3.8	3.6	106	9
GC	3% through	2.0	3.1	64	10
GK	3% through	2.9	3.4	86	10
EV	3% through	0.8	2.2	34	9
HN	3% through	1.7	3.0	57	10
			mean	85	
			std dev	28	
HP	2%-DDAC through	0.6	1.8	36	9
EK	2%-DDAC through	1.9	2.1	90	9
HA	2%-DDAC through	0.8	2.2	36	9
CP	2%-DDAC shell	0.7	1.2	54	9
			mean	54	
			std dev	26	

Table 3 Retained borate and visual termite rating in Japan samples after 10 years

Sample	Treatment Group	Mean %BAE of Cross-sections 3,5,7	%BAE Unexposed	% retained	10-year termite rating
EE	2% shell	0.8	2.3	35	10
AU	2% shell	0.4	1.9	22	10
BC	2% shell	0.9	1.0	89	10
AG	2% shell	0.6	1.4	43	9
CE	2% shell	1.7	1.0	169	9
			mean	72	
			std dev	60	
HI	2% through	1.3	3.4	39	9
FZ	2% through	1.3	1.5	82	9
GA	2% through	0.7	3.5	20	10
			mean	47	
			std dev	31	
BK	3% shell	0.8	1.9	41	9
AY	3% shell	1.2	3.8	31	9
AI	3% shell	1.6	1.4	113	10
CB	3% shell	1.1	1.4	78	9
AH	3% shell	1.4	1.9	74	9
			mean	67	
			std dev	33	
HE	3% through	0.7	2.6	28	9
dN	3% through	2.0	2.0	102	10
Gd	3% through	2.2	2.4	91	9
FP	3% through	3.2	3.4	94	10
			mean	79	
			std dev	34	
HC	2%-DDAC shell	0.7	1.9	36	10
HJ	2%-DDAC shell	0.8	2.7	28	10
dT	2%-DDAC shell	1.4	1.9	74	9
EL	2%-DDAC shell	0.9	1.7	53	10
dO	2%-DDAC shell	1.9	1.6	115	10
			mean	61	
			std dev	35	

Table 4 shows the % weight loss in the Hawaii samples after 10 years. Correlation between weight loss and termite rating was inconsistent. One 2% shell-treated sample rated as failed (0) had a weight loss of 27%. Similarly, a sample treated with 2% borate-DDAC and rated 4 for termite damage had a 26% weight loss, and a CCA-treated sample rated 7 had a 29% weight loss. However, other samples rated 7 for termite attack did not suffer large weight losses.

Table 4 Weight loss in Hawaii samples after 10 years

Sample	Treatment Group		% Weight Loss	10-year termite rating
dS	2% shell		12	9
AE	2% shell		3	9
AQ	2% shell		3	7
CK	2% shell		5	7
dX	2% shell		0	10
AT	2% shell		2	7
AZ	2% shell		3	7
BP	2% shell		11	9
BA	2% shell		16	9
dK	2% shell		27	0
		mean	8 (8)*	
HB	2% through		4	9
EO	2% through		6	9
FK	2% through		6	9
GJ	2% through		3	9
EN	2% through		7	9
GR	2% through		5	9
FE	2% through		5	9
GH	2% through		3	7
dW	2% through		3	10
EC	2% through		3	7
		mean	4 (1)	
BG	3% shell		3	9
Ad	3% shell		3	9
BW	3% shell		2	9
BM	3% shell		11	9
CC	3% shell		7	7
AV	3% shell		3	9
BB	3% shell		3	9
dG	3% shell		5	9
BV	3% shell		19	9
AO	3% shell		2	9
		mean	6 (6)	

* Standard deviation given in parentheses

Table 4 Continued.

Sample	Treatment Group		% Weight Loss	10-year termite rating
FN	3% through		5	9
GC	3% through		7	10
GK	3% through		12	10
dA	3% through		4	10
dB	3% through		7	9
EV	3% through		7	9
GY	3% through		6	9
HN	3% through		5	10
GB	3% through		5	10
FY	3% through		5	10
		mean	6 (2) [NB]	
EK	2%-DDAC through		3	9
CQ	2%-DDAC through		6	9
dQ	2%-DDAC through		4	9
HP	2%-DDAC through		5	9
HA	2%-DDAC through		6	9
		mean	5 (1)	
CN	2%-DDAC shell		26	4
EQ	2%-DDAC shell		4	7
CT	2%-DDAC shell		5	9
dU	2%-DDAC shell		4	9
CP	2%-DDAC shell		16	9
		mean	11 (10)	
F9	4 kg/m^3 CCA		12	10
F19	4 kg/m^3 CCA		15	9
F11	4 kg/m^3 CCA		11	10
F10	4 kg/m^3 CCA		8	10
F8	4 kg/m^3 CCA		8	10
H6	4 kg/m^3 CCA		29	7
H18	4 kg/m^3 CCA		12	9
H22	4 kg/m^3 CCA		19	9
H15	4 kg/m^3 CCA		14	9
H5	4 kg/m^3 CCA		10	10
		mean	14 (6)	

[NB] There appears to have been an operational weight loss of around 6% due to change in sample conditioning before and after exposure, since the 3% through-treated samples did not suffer any internal termite damage (voids).

4. Conclusions

Ten-year results of field exposure in Hawaii and Kagoshima, Japan, in relatively aggressive termite feeding situations and in Kincardine, Ontario, show borate treatments, as well as CCA and ACZA treatments, can provide long-term protection from termite attack to structural lumber.

At both the Kincardine and Japan sites, all borate treatments performed as well as CCA shell treatments, with mean visual ratings of 9.0 or higher after 10 years exposure. Borate treatments also performed better than the naturally durable species, western red cedar in Kincardine and Hinoki in Japan.

At the Hawaii site, there was no significant difference in visual rating between the 2% BAE through, 2% BAE shell, 2% BAE plus DDAC shell, and 3% BAE shell treatments. CCA shell-treated hem-fir and 3% BAE through-treatments performed comparably, and better than the other borate treatments in terms of visual rating. The 2% and 3% BAE through treatments, as well as the 3% BAE shell and 2% BAE plus DDAC through-treatments, performed significantly better than CCA in terms of weight loss.

CT scans on samples from Hawaii revealed some internal termite damage not found by probing the surface. The 3% BAE through-treatment was the only one to show no damage from termite attack based on CT scans, but the 2% BAE through-treatment showed negligible damage.

Compression stiffness was similar along the length of the dodai. Only the 2% shell treated samples showed statistically significantly lower stiffness than the 3% through-treated samples which had no internal damage.

Depletion of borate from the top, sides and bottom of samples from both Hawaii and Japan suggest condensation from boxes has dripped onto the samples and boron diffusion has occurred into the concrete blocks.

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