An International Termite Field Test of Wood Treated with Insecticides in a Buffered Amine Oxide Carrier

Paul Ian Morris
J. Kenneth Grace
Tsuyoshi Yoshimura
Kunio Tsunoda†

Abstract

A buffered amine oxide carrier has shown promise to deeply penetrate dry lumber with insecticides for termite control without using pressure treatment. Pine sapwood from trees attacked by mountain pine beetle (MPB) has increased permeability. In this study, short lengths of heavily blue stained, post-MPB lodgepole pine lumber (*Pinus contorta*) were treated with the buffered amine oxide carrier to borate levels less than the retentions recommended for protection against attack by the Formosan subterranean termite (average, 0.5% mass/mass boric acid equivalent), with and without the addition of organic insecticides. Additional samples were pressure treated with alkaline copper quaternary type D carbonate (ACQ-D) and disodium octaborate tetrahydrate (DOT). The boards were installed in field tests in Hawaii and Japan at sites with confirmed populations of Formosan subterranean termites. They were inspected after 2 and 5 years. Dip plus kiln-conditioning treatment with imidacloprid, permethrin plus imidacloprid, and permethrin provided good protection to post-MPB lodgepole pine lumber against termite attack over 5 years in Hawaii and Japan. Dip plus kiln-conditioning treatment with the buffered amine oxide alone provided no protection because of the low loading of borate used as the buffer. Samples that were DOT pressure treated to below the retention required for Formosan termites in American Wood Protection Association standards did not perform as well, possibly as a result of poor heartwood penetration as well as below-standard retentions. Addition of permethrin to DOT pressure treatment improved performance. ACQ pressure-treated samples did not perform as well, with two failures in Hawaii. This was also likely associated with poor penetration in the heartwood because this material was not incised.

Existing markets in the US south and southern Japan, as well as new markets in China and Taiwan, require wood products to be resistant to the highly destructive Formosan subterranean termite (*Coptotermes formosanus* Shiraki). The ability of a proprietary buffered amine oxide carrier (Ross 2007, 2010, 2011;Ward and Scott 2011a, 2011b) to through-treat post–mountain pine beetle (MPB) lumber would minimize the competitive disadvantage of low-permeability Canadian species in comparison with US southern pine and New Zealand radiata pine (*Pinus radiata* Don) in markets where termite and decay resistance are important. Borates are one of the components used as a buffer and carrier, but the low levels are not designed to protect against Formosan subterranean termites without inclusion of carbon-based insecticides in the formulation. Borate-treated wood is susceptible to cosmetic damage when attacked by termites because the borate is not repellent nor immediately lethal to termites (Grace and Yamamoto 1994, Campora and Grace 2007). Such cosmetic damage can be an issue in appearance-based applications such as window and door frames. One of the principal advantages of including carbon-based insecticides is that they may be either repellent or more rapidly toxic to termites and reduce

The authors are, respectively, Research Leader—Durability and Sustainability, FPInnovations, Vancouver, British Columbia, Canada (paul.morris@FPInnovations.ca [corresponding author]); Associate Dean for Research College of Tropical Agric. and Human Resources, Univ. of Hawaii at Manoa (kennethg@hawaii.edu); and Professor and former Associate Professor, Research Inst. for Sustainable Humanosphere, Kyoto Univ., Kyoto, Japan (tsuyoshi@rish.kyoto-u.ac.jp). This paper was received for publication in December 2013. Article no. 13-00095.
† Deceased.

Forest Prod. J. 64(5/6):156–160.
doi:10.13073/FPJ-D-13-00095

or eliminate the possibility of superficial damage from exposure of borate-treated wood to aggressive termites.

British Columbia is faced with harvesting large volumes of mountain pine beetle (MPB)–affected trees and funnelling products made from these trees into existing or new markets. This project capitalizes on documented properties of post-MPB wood, such as low moisture content and increased permeability to preservatives (Byrne 2003, 2004; McFarling and Byrne 2003). Earlier work demonstrated the feasibility of through-treating selected high-sapwood post-MPB lumber via pressure treatment or via the new buffered amine oxide carrier (Morris and Minchin 2006).

In the present study, post-MPB lumber, blue stained on three sides, was either dip or pressure treated with several preservative formulations using the buffered amine oxide carrier and then installed in field tests in Hawaii and Japan at sites with confirmed populations of Formosan subterranean termites. The termite resistance of this material was compared with that of a standard high-loading disodium octaborate tetrahydrate (DOT) pressure treatment and a reference preservative, alkaline copper quaternary type D carbonate (ACQ-D). This article describes the test methods and results after 2 and 5 years.

Materials and Methods

Test materials

Two packages of kiln-dried, 16-foot-long 2 by 4-inch post-MPB lodgepole pine lumber, *Pinus contorta* Douglas, were supplied by Forestry Innovation Investment of British Columbia. Boards with blue stain across one face and 90 percent of two sides were selected for treatment. Thirty boards were cut into eight 0.45-m lengths for the main experiment plus three 0.25-m lengths to use in preliminary trials. Samples for pressure treatment were end sealed with three coats of epoxy resin, while those for the buffered amine oxide carrier received two coats. This step is required to avoid end effects and simulate treatment of longer pieces. The formulation ingredients were supplied by Kop-Coat Inc., with the exception of ACQ-D, which was provided by Timber Specialties Co.

Several trial treatments were carried out to establish optimal solution strengths for the final experimental samples. For preparation of the actual test specimens, sets of 30 test samples were treated in the following eight test groups:

1. Pressure treated with 1.0 percent mass/mass (m/m) ACQ-D
2. Pressure treated with DOT solution at 1.85 percent m/m boric acid equivalent (BAE).
3. Pressure treated with DOT solution at 1.14 percent m/m BAE + 0.02 percent m/m permethrin
4. Dip treated with the buffered amine oxide carrier
5. Dip treated with the buffered amine oxide carrier + 0.175 percent m/m permethrin
6. Dip treated with the buffered amine oxide carrier + 0.0196 percent m/m imidacloprid
7. Dip treated with the buffered amine oxide carrier + 0.175 percent m/m permethrin + 0.0196 percent m/m imidacloprid

In addition to an amine oxide penetration enhancer (concentration undisclosed), the proprietary carrier contains, as a buffer, 0.5 percent m/m BAE in solution in the form of DOT, with an anticipated retention of 0.75 percent m/m BAE in the treated wood.

Pressure treatment

The treating schedule used consisted of an initial 30-minute vacuum at 75 kPa, followed by 2 hours at a pressure of 1,035 kPa, and a final 15 minutes of vacuum at 75 kPa. Samples were weighed before and after treatment. Immediately after treatment the samples were close piled, wrapped on six sides with plastic sheeting, and stored for 1 week before sampling.

Dip plus kiln-conditioning process

Under supervision of Kop-Coat staff, ingredients were mixed at 80°C to 90°C with preheated water in a tank equipped to maintain the solution at 65°C during dip treatment. Each preweighed sample was submerged in the solution for 3 minutes. Upon removal from the solution, the samples were shaken to remove gross excess solution and immediately weighed; then they were close piled and kept covered with a plastic sheet to prevent drying. When dip treating was complete, samples were close piled in a small kiln where the pile was covered on five sides with lumber wrap, leaving the bottom uncovered.

The kiln was operated at 85°C with a minimum wet bulb depression for 72 hours. At the end of the 72-hour cycle, the kiln, with samples still inside, was turned off and left closed overnight. Samples were removed from the kiln and wrapped in plastic on all six sides for 1 week.

Sampling for analysis

We cut a 50-mm slice from one end of each 450-mm-long treated board, leaving a 400-mm test sample for the exposure test. The 50-mm subsamples were oven-dried at 50°C, and two 5-mm slices were removed from the innermost end, one for simulated boring retention and one for whole cross-section retention (with the exception of the ACQ treatment). The remaining subsample was retained for penetration measurement.

Simulated cores, 10 mm wide and 16 mm deep, were removed from one edge of one 5-mm slice per board and were analyzed individually for boron or ACQ retention. Another entire slice was analyzed for DOT by mannitol titration (Winters 1965). ACQ retentions were calculated from copper concentrations determined by energy dispersive X-ray spectrometric analysis (American Wood Protection Association [AWPA] 2002). The freshly cut face of the remaining subsample was sprayed with boron or copper indicator, and the preservative penetration was measured in three ways for each sample: from one edge, from the heartwood face, and the percent total cross section. Cross sections of all samples were sent to Kop-Coat for analysis of termiticides. Four samples from each group were analyzed for permethrin (Standards Australia 2006) by high performance liquid chromatography (HPLC) and for imidacloprid by neutron activation analysis for chlorine (AWPA 2012a). Where both insecticides were used together, the chlorine content of the permethrin calculated from the HPLC results was subtracted to determine the imidacloprid retention.

The borate retentions achieved (Table 1) were lower than the targets. Borate retentions are expressed as percent m/m BAE. For reference, the loading specified in the AWPA standards for Formosan termite zones (AWPA 2012d) is 4.5

Table 1.—Analytical results for samples installed the field tests.[a]

Process	Preservative	Boring ACQ-D (kg/m^3)	Cross section: Permethrin (ppm) Gauge	Permethrin (ppm) Assay[b]	Imidachloprid (ppm) Gauge	Imidachloprid (ppm) Assay[b]	% m/m BAE	Copper/borate penetration: Edge (mm)	Heart (mm)	% m/m cross section
Pressure	ACQ-D	4.9 (0.5)	N/A	N/A	N/A	N/A	N/A	16.0 (0.0)	3.9 (5.3)	75 (20)
Pressure	DOT	N/A	N/A	N/A	N/A	N/A	1.3 (0.8)	16.0 (0.0)	11.4 (4.8)	94 (7)
Pressure	DOT + permethrin	N/A	243 (43)	1383 (307)	N/A	N/A	0.9 (0.2)	16.0 (0.0)	12.6 (4.5)	94 (9)
Dip–kiln[c]	None	N/A	N/A	N/A	N/A	N/A	0.4 (0.1)	14.7 (1.5)	11.6 (2.4)	75 (8)
Dip–kiln[c]	Permethrin	N/A	94 (34)	106 (21)	N/A	N/A	0.4 (0.1)	15.9 (0.7)	12.8 (2.5)	84 (7)
Dip–kiln[c]	Imidacloprid	N/A	N/A	N/A	12 (5)	12 (2)	0.5 (0.2)	14.5 (1.8)	12.7 (3.2)	78 (9)
Dip–kiln[c]	Permethrin + imidacloprid	N/A	118 (62)	146 (21)	13 (7)	17 (2)	0.7 (0.1)	14.8 (1.3)	10.2 (2.6)	77 (8)

[a] Values are means (standard deviations). ACQ-D = alkaline copper quaternary type D carbonate; BAE = boric acid equivalent; DOT = disodium octaborate tetrahydrate; N/A = not applicable.
[b] Four samples only.
[c] Borate present as buffer.

kg/m^3 B_2O_3, which is 2.0 percent m/m BAE in a wood species with a density of 400 kg/m^3.

Field test

Based on the results of the preservative penetration and retention assessments, the 20 samples within each set of 30 closest to the target retention were selected for the field test. The freshly cut ends of the field exposure samples were coated with the field-cut preservative Boracol 20 BD, containing DDAC (Sansin) for the six DOT and buffered amine oxide treatments and copper naphthenate containing 2 percent Cu (Recochem) for the ACQ-D–treated set. Ten boards from each of the eight treatment sets (a total of 80 samples) were shipped to Hawaii and to Japan for installation in termite field trials, which follow the AWPA Standard E21 test method (AWPA 2012b).

The Hawaiian test plot is on the island of Oahu, located at the Waimanalo Experiment Station of the College of Tropical Agriculture and Human Resources, University of Hawaii at Manoa. 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, Japan. Both test sites support active populations of the Formosan subterranean termite, *C. formosanus,* and the Kagoshima test site also has the native subterranean termite, *Reticulitermes speratus* (Kolbe). Results from previous tests have indicated that termite attack on untreated controls is about 10 times faster at the Hawaii site (Tsunoda et al. 2002, Morris et al. 2011). The more tropical environment in Hawaii facilitates year-round foraging and growth of the colonies, in contrast to the seasonality of attack found in Kagoshima (Grace et al. 2004).

The exposure test method (AWPA 2012b) involves 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 to maintain high humidity. There is no direct contact between the wood samples and the soil, other than that brought by the termites to construct shelter tubes. In Hawaii, the white-painted plywood covers were untreated and were replaced as necessary due to termite damage and weathering. The covering boxes in Japan were made of white plastic.

Through the two perforations in each block, 25 by 25 by 300-mm pine or Douglas-fir (*Pseudotsuga menziesii*) feeder stakes were driven into the ground so that the top of the stake was within 2 to 5 mm of the top of the concrete block. 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 designed to prevent direct tunnelling by termites from the untreated wood stakes into the test samples.

Test material was nondestructively rated using a visual examination for signs of termite attack. Each sample was carefully removed, examined, and assigned a rating on the pre-2011 AWPA rating scale (Table 2) in Japan and on the new AWPA scale (Table 3) in Hawaii. The mean ratings of each group were compared with the untreated controls by *t* test, and analysis of variance (ANOVA) was performed with the dip plus kiln treatments.

Results and Discussion

DOT pressure treatment resulted in good penetration of sapwood but poor penetration of heartwood. Use of the buffered amine oxide carrier resulted in more even penetration (shell treatment) around the perimeter of the test specimens. After 2 years of exposure in Hawaii, the imidacloprid and permethrin plus imidacloprid samples dip treated with the buffered amine oxide carrier were in perfect

Table 2.—Termite attack visual rating system in the American Wood Protection Association (AWPA) E21 field test prior to 2011.

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

Table 3.—Termite attack visual rating system in the American Wood Protection Association (AWPA) E21 field test after 2011.

AWPA rating	Description
10	Sound
9.5	Trace: surface nibbles permitted
9	Slight attack: up to 3% of cross-sectional area affected
8	Moderate attack: 3%–10% of cross-sectional area affected
7	Moderate/severe attack: penetration, 10%–30% of cross-sectional area affected
6	Severe attack: 30%–50% of cross-sectional area affected
4	Very severe attack: 50%–75% of cross-sectional area affected
0	Failure

condition, with average ratings of 10 (Table 4). All but one of the samples treated with permethrin in the buffered amine oxide carrier were completely sound, but one had failed (rated 0). The samples treated with the buffered amine oxide carrier with no added insecticides had all failed with an average rating of 0, showing that the ca. 0.5 percent m/m BAE loading of buffer (lower than the 0.75% m/m BAE targeted) provides no protection against *C. formosanus* at this aggressive test site. The DOT pressure-treated samples with 1.3 percent m/m BAE had an average rating of 8, and the ACQ pressure-treated samples had an average rating of 9.2, with one sample rated as low as 4. At this point, 8 of the 10 untreated controls were rated 0, 1 was rated 8, and 1 was rated 10.

After 5 years in Hawaii, the samples that were imidacloprid and permethrin plus imidacloprid dip treated with the buffered amine oxide carrier were still in perfect condition with average ratings of 10 (Table 4). There was no further progress in deterioration of the amine oxide permethrin-treated dip-treated samples, with 9 of 10 completely sound (rated 10). The one sample that had failed at 2 years was removed from the test after the 5-year exposure, cross cut, and half was sent to Kop-Coat for chemical analysis (see below). The DOT pressure-treated samples with 1.3 percent m/m BAE had an average rating of 7.2 with no sample rated lower than 6. The attack was primarily in the heartwood, which had received poor penetration compared with the dip plus kiln-conditioning treatments. Better heartwood penetration can be achieved using hot treating solutions (Baker et al. 2000). The DOT pressure-treated samples with 0.9 percent m/m BAE plus permethrin had an average rating of 9.5 with no sample rated lower than 8. The ACQ pressure-treated samples had an average rating of 7.7 with two samples failing (rated 0). These failures may have been associated with poor penetration in the heartwood (Table 2) because this material was not incised. Incising is required in Canadian (Canadian Standards Association 2008) and American (AWPA 2012c) standards for lodgepole pine to be used as sill plates, irrespective of sapwood content. At the 5-year inspection, all the untreated controls were rated 0.

As with a previous 10-year field test (Morris et al. 2011), termites at the Japan test site were much less aggressive against the untreated controls than was the case at the Hawaii test site, although there was more surface damage to the treated samples. After 2 years of exposure in Japan, all samples were sound except one from the control group and one from the group treated with the buffered amine oxide carrier with no added insecticides (Table 4). After 5 years of exposure in Japan, the samples that were permethrin, imidacloprid, and permethrin plus imidacloprid treated with the buffered amine oxide carrier had, respectively, average ratings of 9.4, 9.5, and 9.5 with six, five, and two samples rated 9 (however, the permethrin plus imidacloprid formulation also had one sample rated 7). The samples treated with the buffered amine oxide carrier with no added insecticides had an average rating of 7.1, which was the same as the untreated controls. The DOT pressure-treated samples with 1.3 percent m/m BAE had an average rating of 8.4 (two rated 7), and the ACQ pressure-treated samples had an average rating of 8.9 (one rated 7 and one rated 8). All the controls had failed after 5 years of exposure. After 5 years, all of the preservative-containing treatments were statistically significantly different from controls using a *t* test, with the exception of DOT and ACQ-D pressure treatments at the Japan test site. The three buffered amine oxide carrier dip treatments with insecticides were statistically significantly different from dip treatment with no preservative using ANOVA.

Table 4.—Ratings of treated post–mountain pine beetle ponderosa pine lumber samples installed in termite field tests in Hawaii and Japan after 2- and 5-year exposures.[a]

		AWPA termite rating, mean (SD)[b]			
		Hawaii		Japan	
Process	Preservative	2 y	5 y	2 y	5 y
Pressure	ACQ	9.2 (1.8)[c]	7.7 (4.1)[c]	10.0 (0.0)	8.9 (0.4)
Pressure	DOT	8.0 (1.1)[c]	7.2 (0.6)[c]	10.0 (0.0)	8.4 (0.5)
Pressure	DOT + permethrin	9.6 (0.4)[c]	9.2 (0.7)[c]	10.0 (0.0)	9.5 (0.3)[c]
Dip–kiln[d]	None	0.0 (0.0)	0.0 (0.0)	9.9 (0.3)	7.1 (0.5)
Dip–kiln[d]	Permethrin	9.0 (3.2)[c,e]	9.0 (3.2)[c,e]	10.0 (0.0)	9.4 (0.5)[c,e]
Dip–kiln[d]	Imidacloprid	10.0 (0.0)[c,e]	10.0 (0.0)[c,e]	10.0 (0.0)	9.5 (0.5)[c,e]
Dip–kiln[d]	Permethrin + imidacloprid	10.0 (0.0)[c,e]	10.0 (0.0)[c,e]	10.0 (0.0)	9.5 (1.0)[c,e]
Control	None	1.8 (3.8)	0.0 (0.0)	9.9 (0.3)	7.1 (1.7)

[a] AWPA = American Wood Protection Association; ACQ = alkaline copper quaternary; DOT = disodium octaborate tetrahydrate.
[b] Visual ratings using AWPA scale of 10 (sound) to 0 (failure).
[c] Significantly different from controls at the 5 percent level using a *t* test.
[d] Borate present as buffer.
[e] Significantly different from dip–kiln with no preservative at the 5 percent level using analysis of variance.

Analysis of the sample treated with permethrin in the buffered amine oxide carrier that had failed in Hawaii revealed 106 ppm of permethrin and 0.13 percent m/m BAE in the intact treated shell, with no permethrin (below detection limit) and 0.36 percent m/m BAE in scrapings from the hollow interior. It appeared that termites had found a weak point in the treated shell, possibly where the preservative penetration was not as deep.

Conclusions

- Dip plus kiln-conditioning treatment with imidacloprid, permethrin plus imidacloprid, and permethrin in a buffered amine oxide carrier has provided good protection to post-MPB lumber over 5 years in Hawaii and Japan.
- Dip plus kiln-conditioning treatment with the buffered amine oxide alone provided no protection because of the low loading of borate used as the buffer.
- Samples that were DOT pressure treated to below the retention required for Formosan termites in AWPA standards did not perform as well as dip plus kiln-conditioning treatment with imidacloprid, permethrin plus imidacloprid, or permethrin. This may have been due to poor heartwood penetration. Better heartwood penetration can be achieved using hot treating solutions or by incising. Addition of permethrin to DOT pressure treatment improved performance.
- ACQ-D pressure-treated samples performed similarly to DOT pressure treatment but had two failures, likely associated with poor penetration in the heartwood because this material was not incised. Incising is required in Canadian and US standards for lodgepole pine sill plates, irrespective of sapwood content.

Acknowledgments

Treatment of material for this field test was financially supported by BC Forestry Innovation Investment. Ongoing monitoring by FPInnovations was financially supported by the Canadian Forest Service under the Contribution Agreement existing between the Government of Canada and FPInnovations. We thank Maria Aihara-Sasaki and Robert Oshiro for field assistance, and Alan Ross and staff of Kop-Coat Inc. for assistance in preservative preparation. Further support for this work was provided by Kop-Coat Inc., and McIntire Stennis funds for forestry research awarded by the USDA National Institute for Food and Agriculture.

Literature Cited

American Wood Protection Association (AWPA). 2002. Standard method for analysis of treated wood and treating solutions by x-ray spectroscopy. AWPA A9-01. AWPA, Birmingham, Alabama. 3 pp.

American Wood Protection Association (AWPA). 2012a. Standard method for determination of iodine and chlorine in wood using neutron activation analysis. AWPA A91-12. AWPA, Birmingham, Alabama. 2 pp.

American Wood Protection Association (AWPA). 2012b. Standard test method for the evaluation of preservative treatments for lumber and timbers against subterranean termites in above-ground, protected applications (UC1 and UC2). AWPA E21-11. AWPA, Birmingham, Alabama. 4 pp.

American Wood Protection Association (AWPA). 2012c. Use category system: Processing and treatment standard. AWPA T1-12. AWPA, Birmingham, Alabama. 37 pp.

American Wood Protection Association (AWPA). 2012d. Use category system: User specification for treated wood. AWPA U1-12. AWPA, Birmingham, Alabama. 67 pp.

Baker, C., C. Wilson, S. M. McFarling, and P. I. Morris. 2000. Pressure treatment of Canadian SPF with heated borate solutions. *Proc. Can. Wood Preserv. Assoc*. 21:69–78.

Byrne, A. 2003. Characterising the properties of wood containing beetle-transmitted bluestain: Background, material collection and summary of findings. Report to Forest Innovation Investment. Forintek Canada Corp., Vancouver, British Columbia. 9 pp.

Byrne, A. 2004. Opportunities with beetle-killed lodgepole pine. *Proc. Can. Wood Preserv. Assoc*. 25:186–195.

Campora, C. E. and J. K. Grace. 2007. Foraging behavior of the Formosan subterranean termite (Isoptera: Rhinotermitidae) in response to borate treated wood. IRG Document No. IRG/WP 07-10605. International Research Group on Wood Preservation, Stockholm. 13 pp.

Canadian Standards Association (CSA). 2008. Wood preservation. CSA O80 Series-08. CSA, Mississauga, Ontario. 117 pp.

Grace, J. K., T. Byrne, P. I. Morris, and K. Tsunoda. 2004. Six-year report on the performance of borate-treated lumber in an above-ground termite field test in Hawaii. IRG Document No. IRG/WP 04-30343. International Research Group on Wood Preservation, Stockholm. 7 pp.

Grace, J. K. and R. T. Yamamoto. 1994. Repeated exposure of borate-treated Douglas-fir lumber to Formosan subterranean termites in an accelerated field test. *Forest Prod. J.* 44(1):65–67.

McFarling, S. and A. Byrne. 2003. Characterizing the dimensional stability, checking, and permeability of wood containing beetle-transmitted bluestain. Report to Forest Innovation Investment. Forintek Canada Corp., Vancouver, British Columbia. 13 pp.

Morris, P. I., K. Grace, and K. Tsunoda. 2011. Ten year field tests of borate-treated wood against subterranean termites. IRG Document No. IRG/WP/11-30557. International Research Group on Wood Preservation, Stockholm. 21 pp.

Morris, P. I. and D. Minchin. 2006. Through-treating post-mpb lumber: Technical feasibility and process development. Forintek Canada Corp. report to Forest Innovation Investment Ltd. Forintek Canada Corp., Vancouver, British Columbia. 31 pp.

Ross, A. S. 2007. TRU-CORE infusion treatment for wood and wood composites. *Proc. Can. Wood Preserv. Assoc*. 28:95–99.

Ross, A. S. 2010. TRU-CORE protection system for wood. *Proc. Am. Wood Prot. Assoc*. 106:197–203.

Ross, A. S. 2011. TRU-CORE process for treatment of refractory wood species and engineered wood products. IRG Document No. IRG/WP 11-40573. International Research Group on Wood Preservation, Stockholm. 8 pp.

Standards Australia. 2006. Methods for sampling and analyzing timber preservatives and preservative-treated timber. Part 3. Analysis methods for determination of preservative. Australian Standard AS/NZS 1605.3. Standards Australia, Sydney, New South Wales.

Tsunoda, K., A. Adachi, T. Byrne, P. I. Morris, and J. K. Grace. 2002. Performance of borate-treated sill plates (dodai) in a protected, above-ground field test in Japan. IRG Document No. IRG/WP 02-30278. International Research Group on Wood Preservation, Stockholm. 6 pp.

Ward, H. A. and C. Scott. 2011a. Method of protecting wood through enhanced penetration of wood preservatives and a related solution. US patent 7,896,960.

Ward, H. A. and C. Scott. 2011b. Method of protecting wood through enhanced penetration of wood preservatives and a related solution. US patent 7,655,281.

Winters, F. T. n.d. [ca. 1965]. Determination of borates in wood—A simplified analysis for plant operations. Unpublished bulletin. United States Borax and Chemical Corp., Los Angeles. 2 pp.