Physical and mechanical properties and fire, decay, and termite resistance of treated oriented strandboard

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Abstract

This study evaluated the effects of a number of chemicals on the physical and mechanical properties and fire, decay, andtermite resistance of oriented strandboard (OSB) panels. Disodium octaborate tetrahydrate (DOT), boric acid (BA), melamine phosphate (MP), and a BA/DOT mixture were sprayed onto the furnish at varying concentrations. Thepanels were tested for thickness swell, water absorption, modulus ofrupture, modulus ofelasticity, and internal bond strength according to the procedures defined by ASTMD 1037. All treated panels, except those treated with BA/DOT, were found to comply with CSA 0437 requirements for mechanical properties at a 2 percent concentration level. However, thickness swell and water absorption values were higher compared to CSA 0437 standard values. Laboratory decay tests showed that treated OSB specimens were well protected from both a brown-rot fungus (*Fomitopsis palustris*) and a white-rot fungus (*Trametes versicolor*). Weight losses in MP-treated OSB specimens were higher than those in boron-treated specimens. However, increased MP content caused a decrease in weight loss. In termite tests, BA and DOT were more effective than MP against *Coptotermes formosanus*. Contrary to decay test results, OSB specimens containing higher MP concentrations showed lower resistance against termite attack. In a limited series of cone calorimeter tests, treatments did not substantially improve the fire performance of OSB. Of the treatments studied, the highest retentions of BA and BA/DOT provided some improvement in fire performance. DOT also provided some improvement but it was not commensurate with the amount of chemical added.

Wood composites are susceptible to the same physical, chemical, and biological deterioration as the solid wood from which they are made (Archer et al. 1993). As is the case for most wood and wood-based materials, additional protective treatment is required whenthese materials are exposed to harsh end-use conditions involving fire and attack from decay and termites. Untreated wood-based materials, such as oriented strandboard (OSB), which finds wide use in building construction, are often restricted to end-use applications where fire, decay, and termites are not an issue. To broaden applications for OSB as structural components in building construction under harsh end uses, it is necessary to develop new technologies and methodologies to

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Table 1. — Preservative content of OSB panels.

Panel number	Preservative chemical[a]	Content
		(%)
1	Control	--
2		--
3		--
4	Boric acid	2
5		4
6		6
7	DOT	2
8		4
9		6
10	MP	2
11		4
12		6
13	BA/DOT[b]	2
14		4
15		6

[a]BA = boric acid DOT = disodium octaborate tetrahydrate: MP =melamine phosphate.

[b]Hereafter these will be abbreviated for example, 1% BA/DOT will mean 1% BA + 1% DOT (equals 2% preservative content)

impart fire, decay, and termite resistance (Sean et al. 1999, Akbulut et al. 2002, Baileys et al. 2003).

Problems can be encountered with adding protective chemicals to either the wood furnish or the additives in wood composites. Chemicals must be compatible with resins and other additives in terms of mechanical and physical properties (Laufenberg et al. 1986) and durability against decay fungi and termites. A substantial amount of research has been carried out on the effects of fire-retardant treatment on the strength properties of solid wood and some wood composites such as plywood (Winandy 2001). Fire-retardant systems are generally based on organo-phosphorus and aluminum and magnesium hydrates. Boron-based products are also effectively used as a smoke suppressant, either alone or in conjunction with other fire-retardant chemicals. Another type of fire-retardant chemical, which emerged in the 1990s, is melamine, which basically contains nitrogen and its combination with phosphorus. The fire-retardant chemicals most used for wood products contain phosphorus (LeVan and Winandy 1990). Previous studies have shown that both untreated and fire-retardant-treated wood exposed to elevated temperatures (either in processing or in service) can undergo strength reduction (LeVan et al. 1990, Winandy 1995).

When wood is made fire retardant, phosphoric acid esterifies the wood polysaccharides and water is released, which promotes the dehydration reactions of wood (Grexa et al. 1999). The acids in wood, especially when accelerated by acidic fire-retardant treatments and/or exposure to high temperatures, hydrolyze the cellulose chains. Because cellulose and hemicelluloses are often thought to be responsible for the strength of the wood fiber, reducing the length of cellulose molecules would cause a reduction in macro-strength properties (Sweet and Winandy 1999). The same mechanism of acid dehydration that is useful in reducing flame spread apparently can also lead to premature strength loss in treated wood in some environments (Lebow and Winandy 1999a, 1999b).

Boron compounds can be used to increase the resistance of composites to fire and biodegradation (Barnes and Amburgey 1993, Murphy et al. 1993, Laks and Manning 1997, Tsunoda et al. 2002). Laks and Palardy (1990) showed that addition of zinc borate to flakeboards caused some decrease in mechanical and physical properties as borate content increased. The addition of borate-based buffers to fire-retardant chemicals was found to significantly mitigate thermal degradation (Winandy 1997). On the other hand, Tsunoda et al. (2002) found no significant loss in mechanical and physical properties in medium density fiberboard treated with zinc borate at retentions of 0.25, 0.5, 1, and 1.5 percent boric acid equivalent (BAE).

The purpose of the research reported here was to determine the physical and mechanical properties and fire and biological resistance of OSB panels incorporated with melamine phosphate (MP), disodium octaborate tetrahydrate (DOT), and boric acid (BA) at varying concentrations.

Materials and methods

Panel manufacturing

Aspen (*Populus* spp.) strands for OSB manufacture were obtained from a commercial OSB manufacturer in northern Wisconsin. Average size was 0.6 by 25 by 80 mm. Strands were produced with a drum flaker and removed from the production line after drying (2% to 3% moisture content) before resin or other chemicals were added. A total of 15 OSB panels was produced **(Table 1).**

Four chemicals were used in the treatments: DOT, $Na_2B_8O_{13}{\cdot}4H_2O$ (U.S. Borax Inc., Valencia, California); BA, H_3BO_3 (U.S. Borax Inc.); MP, $H_3PO_4C_3$- $N_3(NH_2)_3$ (Miljac Inc., New Canaan, Connecticut); and a BA/DOT mixture (1:1). The chemicals were added to the blender at target contents of 2, 4, and 6 percent based on ovendry furnish weight. Aspen strands were then blended with 3.5 percent phenol-formaldehyde (PF) resin (to ovendry solid-wood basis). This study did not include the addition of any external wax or water repellent to the furnish. The typical chemical composition of BA, DOT, and MP is shown in Table 2.

The OSB panels (10 mm thick, nominal 0.72 g·cm^3 air-dry density) were manufactured in the Forest Products Laboratory (Madison, Wisconsin) using standardized procedures that simulated industrial production. Strands with 2 to 3 percent moisture content (ovendry solid wood basis) were placed in a rotary drum-type laboratory blender; powder chemical was sprayed onto the furnish. Phenolic resin was then introduced with an air-atomized metered spray system. The material was allowed to blend for 8 to 10 minutes. Strands were weighed and formed into a mat on an aluminum caul plate using a 560- by 560-mm forming box. Mats were then pressed into panels in a computer-controlled and steam-heated hydraulic press.

Each panel was composed of two face layers and one core layer. Strands in the external layers were aligned parallel to the panel length; strands in the center layer were randomly oriented. Each face layer constituted one-quarter of the total panel weight. Processing parameters were as follows:

- Commercial liquid PF resin, 3.5 percent per dry wood weight in rotating blender
- Wood strands, 0.6 by 25 by 80 mm, aspen (Populus spp.)
- Press temperature, 210° to 215°C
- Press pressure, 3.5 to 4 MPa
- Mat moisture content, 6±1 percent
- Total press cycle, 295 seconds

Table 2. — Typical composition of boric acid (BA), disodium octaborate tetrahydrate (DOT), and melamine phosphate (MP).

Chemcal	Component	Amount
BA	Boric oxide (B_2O_3)	56.3%
	Water (H_2O)[a]	67.1%
	Equiv. boric acid	100%
DOT	Sodium oxide (Na_2O)	14.7%
	Boric oxide (B_2O_3)	67.1%
	Water (H_2O)	18.2%
	Equiv. DOT	98%
MP	Melamine/phosphoric acid[b]	0 95 to 1.1
	Melamine phosphate	98%
	Melamine	54%
	Phosphoric acid	41%
	Water (H_2O)	2%

[a] By difference
[b] Molar ratio

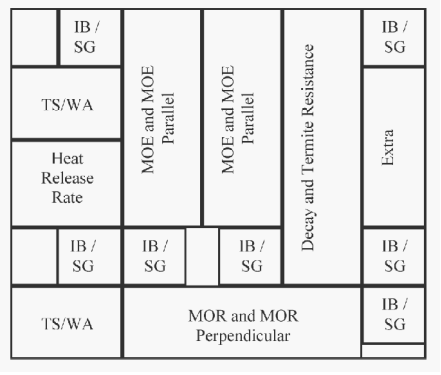

Figure 1. — Schematic diagram of cutting pattern for preparing specimens from 500- by 500-mm panel. IB = internal bond; HRR = heat release rate; MOE = modulus of elasticity; MOR = modulus of rupture; SG = specific gravity; TS = thickness swell; WA = water absorption.

- Press control:
  - Position control, 5 seconds to close to 20 mm
  - 20 seconds to close to 10 mm
  - 255 seconds held at 10 mm
  - 15 seconds to open to 14 mm

Target retentions of the chemicals used are shown in **Table 1.** Except for treatment chemicals, other process options. such as tree species (aspen), resin type (PF), percentage of PF resin, and press parameters, were unchanged in treated panels. All boards were made in the Forest Products Laboratory 500- by 500-mm steam-heated hot-press, which is capable of 220°C using the same press (position control) program.

After cooling. panels were trimmed to a final size of 500 by 500 by 10 mm. (OSB test specimens were subjected to a volatilization schedule to remove free formaldehyde and low molecular weight resin compounds.)

Tests of physical and mechanical properties

Tests of physical and mechanical properties were conducted on specimens cut from the experimental OSB panels. **Figure 1** shows the pattern for cutting specimens from 500- by 500-mm panels. Prior to physical and mechanical property tests, specimens were conditioned for at least 3 weeks at 20°C±2°C and 65±2 percent relative humidity. Air-dry density, thickness swell, water absorption, three-point static bending modulus of rupture (MOR). modulus of elasticity (MOE), and internal bond strength were evaluated according to the test methods and requirements of American Society for Testing and Materials (ASTM) D 1037-99 (ASTM 1999). Tests were conducted at room temperature (23°C).

Specimens for bending tests (MOR and MOE) were 76 by 290 by 10 mm. Three specimens were cut from each panel: two specimens were cut with their long dimension parallel to the outer layer and one specimen with its long dimension perpendicular to the outer layer **(Fig. 1).**

For internal bond tests, seven 50- by 50- by 10-mm specimens were cut from each panel **(Fig. 1)** . The dimensions of each specimen were measured and recorded. A tensile load was applied at a rate of 1 mm/min. The stress was determined using the load at which the specimen failed. Air-dry density of each panel was determined.

Two 150- by 150- by 10-mm thickness swell and water absorption specimens were cut from the center of each panel **(Fig.** 1). The specimens were immediately weighed. Average thickness was determined by taking several measurements at specific locations. After 24 hours of submersion. specimens were drip-dried for 10 minutes, wiped clean of any surface water, and weighed; thickness was determined as described

For physical and mechanical properties, all multiple comparisons were first subjected to an analysis of variance (ANOVA), and significant differences between mean values of control and treated OSB specimens were determined using Duncan's multiple range test.

Fire performance

Relative fire performance was evaluated at the Forest Products Laboratory using an oxygen consumption calorimeter, commonly known as a cone calorimeter. In the test, a 100-mm-square specimen is exposed to a constant external heating flux. Ignitability is determined by observing the time for sustained ignition of the specimen. The potential contribution of the burning material to the growth of a fire is obtained by measuring the heat release rate (HRR) caused by combustion. For the duration of the cone calorimeter test, HRR of the burning specimen is determined using oxygen consumption methodology. This methodology is derived from the observation that the net heat of combustion is directly related to the amount of oxygen required for combustion. The oxygen concentration and the exhaust gas flow are measured in the test. In addition, the mass loss of the burning specimen is recorded.

The cone calorimeter method for determining HRR is described in ASTM E 1354-02 (ASTM International 2002) and ISO 5660-1 (ISO 1993). In this study, the external heat flux was 50 kW/m^2 and the retainer frame (without wire grid) was placed over the specimen. The electric spark igniter was placed above the specimen until ignition was sustained. The specimen was tested horizontally. with the conical radiant electric heater

located above the specimen. Three specimens of the untreated control material were tested, but only a single specimen of each treated material was tested.

The HRR is a critical factor in the spread of flames over a surface and the overall growth of a compartment fire. It is an option for evaluating the degree of combustibility of different materials. Fire-retardant treatments for wood products are designed to reduce their flammability In the United States, the regulatory test for flammability of building products is the 7.32-m tunnel test, ASTM E 84 (ASTM International 2001). The cone calorimeter has been used to provide estimates of the flame spread index obtained in the tunnel test (Dietenberger and White 2001).

Fungal bioassay

A laboratory decay test was conducted according to modified Japan Wood Preserving Association (JWPA) Standard 3 (JWPA 1992a) using the brown-rot fungus *Fomitopsis palustris* (Berk. et Curt) Gilbn. & Ryn and the white-rot fungus *Trametes versicolor* (L. ex Fr.) Quel. The OSB and solid wood specimens (20 by 20 by 10 mm) were sterilized with gaseous ethylene oxide after ovendried weight was measured. Three OSB specimens of the same OSB board were placed in a glass jar containing 250 g quartz sand and 80 mL nutrient solution with active fungal mycelial growth. Specimens were incubated at 27°C for 12 weeks. Nine replicates were tested for each decay fungus and OSB panel. Specimen weight loss after the decay test was determined based on the difference between initial and final ovendry weights (60°C) after debris of fungal attack had been removed.

Termite bioassay

Termite tests were conducted according to JWPA Standard 11(1) (JWPA 1992b). The OSB and solid wood specimens (20 by 20 by 10 mm) were placed in the center of a hard plaster breeding container (80 mm in diameter, 60 mm high); 150 workers and 15 soldiers of *Coptotermes formosanus* Shiraki were introduced into each container. The assembled containers were put on dampened cotton pads to supply water to the specimens and kept at 28°C and >80 percent relative humidity for 3 weeks in a dark conditioning room. Termite mortality was determined regularly. Weight loss after termite attack was determined based on the difference between initial and final dry weights of specimen after debris of the termite attack had been removed. Five replications were made for each board type.

Results and discussion

Physical and mechanical properties

Results ofphysical andmechanical tests on OSB panels are presented in **Table 3.** Air-dry density values of the specimens ranged between 0.70 and 0.74 g/cm^3. Specimens treated with BA, DOT, MP, and BA/DOT at all concentration levels showed no differences in density when compared to control specimens. Our results showed that the density values of all OSB panels meet the requirements of the CSA 0437 standard (between 6.103 and 7.031 kg/m^2; CSA 2000). Canadian standards are used here for comparison of physical and mechanical properties since there are no established minimum properties for strandboard in U.S. standards.

In general, MOE and MOR values at the 2, 4, and 6 percent levels of BA, DOT, and BA/DOT treatments were significantly decreased when compared to control values. Except for MP, increasing chemical retention generally caused greater reduction in mechanical properties. Panel MOE and MOR perpendicular to the plane were sometimes affected, but less so than parallel-to-plane properties. MP generally increased parallel and perpendicular MOE and MOR. This improvement in mechanical properties was estimated from the cross-linking effect of MP Melamine is a very stable compound in its pure form. One well-known use is in melamine-formaldehyde resins, which are used in laminates such as in furniture. The cross-linking effect of MP needs to be investigated. MOR values of panels treated with DOT were better than that of panels treated with BA. Panels treated with BA/DOT had the lowest MOR and MOE values at all concentration levels. Perpendicular-to-plane MOE and MOR values of all treated panels met minimum requirements (1.5 GPa and 12.4 MPa, respectively) of CSA 0437 at all retention levels. However, parallel-to-plane MOE and MOR values of BA, DOT, and BA/DOT treated panels met CSA 0437 values (5.5 GPa and 29 MPa, respectively) at only the 2 percent retention level.

Internal bond values showed similar trends and results to those for MOE and MOR. The internal bond strength of the single DOT, BA-, and BA/DOT-treated panels generally decreased with increasing DOT and BA content. The performance of MP-treated panels was better than that of other treated panels. Internal bond strength values of DOT treated panels were higher than those of BA-treated panels. At the lowest concentration, BA, DOT, and BA/DOT were found to comply with CSA 0437 (internal bond strength minimum property requirement of 0.345 MPa).

Thickness swell and water absorption values of treated panels were significantly increased compared to those of control boards. The best performance was that of the MP-treated panels. Thickness swell and water absorption values decreased with increasing MP content. Thickness swell values of all treated specimens exceeded the OSB minimum property requirement of 15 percent based on the CSA 0437 standard.

Fire performance

The primary result from the cone calorimeter test is an HRR curve over the duration of the test. The typical curve for wood is an initial increase to a peak HRR, then a drop to a steady-state HRR, which is followed by a second peak as the final portion of the specimen is consumed. The typical curve for wood products was observed in all the tests. A very low or non-existent first peak that is sometimes observed with very good fire-retardant treatment was not observed in these tests.

There was variability in the test data for the three replicates of the untreated OSB control specimens **(Figs. 2** to **4).** Only one replicate of each treated OSB panel was tested. As a result, it is difficult to make any statistical conclusions based solely on these data.

For reporting purposes, the heat release curve is often reduced to single numbers via the initial peak HRR and average HRR over a set time (60, 180, and 300 sec.) after the specimen ignites. The HRR is measured in kilowatts per square meter (kW/m^2). Data for HRR **(Fig. 2)** suggest that fire resistance was obtained with BA at 6 percent concentration, DOT at all three concentrations, and DOT/BA at 3 percent concentration. The data did not indicate any improvement in HRR with MP treatment.

Table 3. — Physical and mechanical properties of treated OSB specimens.[a]

Treatment	Thickness swell	Water absorption	Air-dry density	MOE		MOR		Internal bond strength
				Parallel	Perpendicular	Parallel	Perpendicular	
	(%)		(g/cm^3)	(GPa)		(MPa)		
Control	90.86 (8.93)	101.50 (3.53)	0.73 (0.04)	5.19 (0.29)	3.65	31.17 (5.37)	16.49	0.36 (0.05)
BA								
2%	107.12 (8.45)	126.50 (10.60)	0.71 (0.04)	5.29 (2.64)	3.85	29.78 (1.61)	21.24	0.38 (0.06)
4%	122.51 (19.23)***	129.50 (6.36)***	0.70 (0.09)	4.76 (2.49)***	3.47	22.77 (0.5)***	17.86	0.30 (0.05)***
6%	141.75 (3.68)***	164.00 (7.07)***	0.73 (0.05)	4.31 (0.19)***	3.11	20.86 (0.68)***	17.07	0.27 (0.05)***
DOT								
2%	151.68 (1.59)***	149.50 (9.19)***	0.71 (0.04)	5.43 (0.29)	3.88	30.79 (1.72)	21.54	0.43 (0.08)***
4%	168.66 (6.78)***	146.50 (9.19)***	0.74 (0.02)	4.68 (0.45)***	3.53	25.68 (1.68)***	20.93	0.38 (0.05)
6%	157.02 (1.66)***	165.00 (14.14)***	0.75 (0.07)	4.00 (0.13)***	2.97	22.92 (2.53)***	20.10	0.33 (0.06)
MP								
2%	125.57 (16.36)***	130.50 (0.70)***	0.74 (0.04)	5.59 (0.29)***	3.86	30.61 (1.55)	21.29	0.39 (0.08)
4%	113.24 (17.02)	121.50 (2.12)	0.71 (0.06)	6.28 (0.23)***	4.25	34.04 (1.66)	27.08	0.44 (0.04)***
6%	76.14 (9.74)	107.00 (24.04)	0.73 (0.03)	6.64 (0.34)***	4.69	37.61 (1.74)***	31.57	0.58 (0.10)***
BA/DOT								
1% BA/DOT	109.61 (0.12)	105.00 (5.65)	0.72 (0.03)	4.51 (0.31)***	3.55	24.06 (1.61)***	20.42	0.36 (0.06)
2% BA/DOT	161.49 (25.06)***	148.00 (0.00)***	0.70 (0.05)	3.87 (0.23)***	4.23	23.49 (1.09)***	24.06	0.33 (0.06)
3% BA/DOT	149.73 (5.71)***	142.50 (21.92)***	0.74 (0.04)	3.52 (0.31)***	3.93	19.93 (1.41)***	23.49	0.28 (0.04)***
Quality requirements[b]	15	Not specified		5.5	1.5	29	12.4	0.345

[a]Asterisks denote significant difference compared with untreated control OSB specimens: *** $p = 0.001$. MOR = modulus of rupture; MOE = modulus of elasticity; Parallel = parallel to major axis of panel; Perpendicular = perpendicular to major axis of panel; $n = 2$ for thickness swell/water absorption; $n = 3$ for MOR and MOE; and $n = 7$ for air-dry density and internal bond strength. Values in parentheses are coefficients of variation.
[b]Quality requirements according to CSA 0437 (grade O-2) (CSA 2000).

Many traditional fire-retardant treatments for wood increase the residual mass fraction after combustion of the treated wood. Using the initial and final mass of the specimens, residual mass fractions (percentage) were calculated (Fig. 3). Treated specimens had consistently higher residual mass fractions than those of the controls. The 3 percent BA/DOT mixture had the highest residual mass fraction. These mass loss results are for the samples as tested. No correction was made for the mass of the chemical treatment.

Estimates for ASTM E 84 flame spread were calculated from peak HRR, total heat release, and time to sustained ignition **(Fig. 4)**. The procedure is discussed in Dietenberger and White (2001). The equations used to estimate the flame spread index are not sensitive to index variations greater than 75. Estimates are for the standard test duration of 10 minutes as specified in ASTM E 84. As with the test data, results for the estimated flame spread index were variable for the three controls. The estimates for flame spread index in ASTM E 84 suggest that none of the treated specimens will obtain the flame spread index of ≥ 25 required for the most restrictive classification (Class I) in U.S. building codes. In the United States, fire-retardant-treated wood is required to have a Class I classification. For classification as fire-retardant-treated wood, the normal 10-minute tunnel test is increased to 30 minutes.

The flame spread estimates for the treated specimens suggest that 6 percent BA, all three levels of DOT, and 3 percent BA/DOT improved the flame spread index compared to that of untreated OSB **(Fig. 4)**. However, the improvements provided by these treatments were not sufficient to meet all performance requirements for fire-retardant-treated wood. We believe that the resins were being catalyzed by biocides and fire-retardant chemicals and were setting before the press closed. With additional work, this shortcoming may be overcome.

Fungal resistance

Treatment had a significant effect on the susceptibility of OSB specimens to both *Fomitopsis palustris* and *Trametes versicolor* Specimens

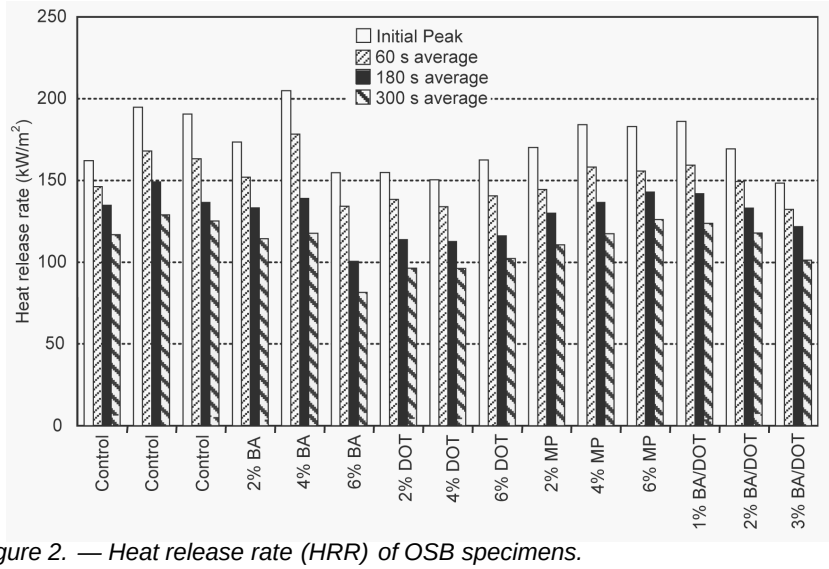

Figure 2. — Heat release rate (HRR) of OSB specimens.

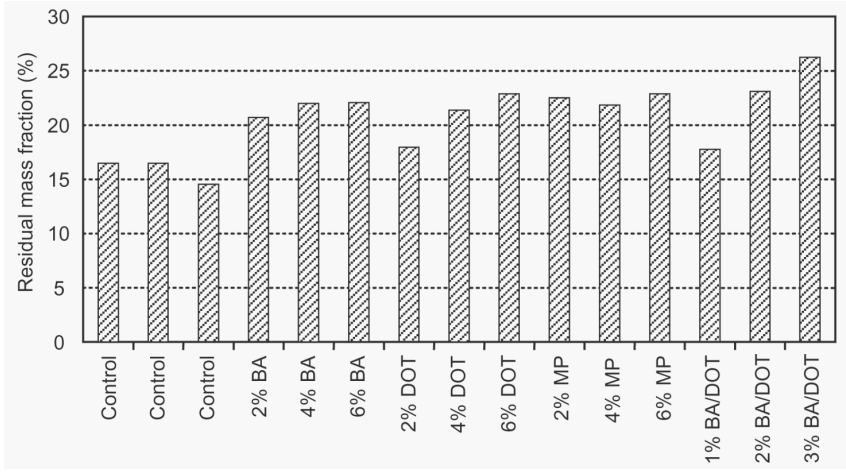

Figure 3. — Residual mass fractions (%) of OSB specimens.

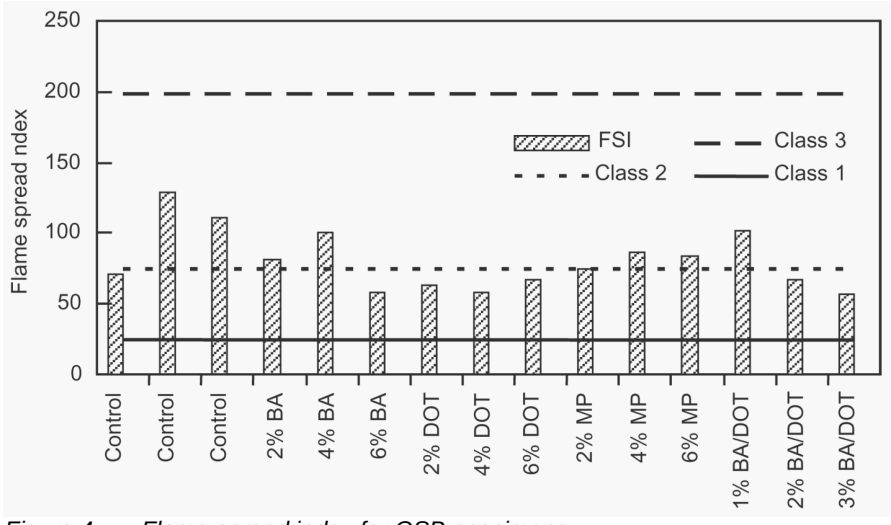

Figure 4. — Flame spread index for OSB specimens.

were generally more resistant to *T. versicolor* than to *F. palustris.* Average weight loss in control specimens exposed to *F. palustris* and *T. versicolor* was 18.77 and 16.23 percent, respectively **(Figs. 5** and **6).** However, the fungi did not cause any significant weight loss in treated OSB specimens, which were almost free from fungal attack. On the other hand, treatment with varying concentrations of MP resulted in relatively higher weight losses compared to BA treatment. As MP concentration increased, specimen weight loss decreased for both *F. palustris* and *T. versicolor.*

Termite resistance

All treatments resulted in greater resistance to termites compared to that of controls. In the first 2 weeks of exposure, the greatest termite mortalities were observed in specimens treated with BA and DOT, followed by MP. However, at the end of the exposure period, termite mortalities of all treated specimens except those treated with 6 percent MP reached 100 percent. These results suggest that boron compounds and MP are slow-acting toxicants that kill termites when they ingest treated OSB, rather than through physical contact.

Treated OSB specimens were found almost intact after 3 weeks of exposure to termites **(Figs. 7** and **8).** In general, termite mortality conformed to specimen weight loss. The single-chemical BA and DOT treatments appeared to be more effective than the combination of these chemicals based on weight loss, although termite mortality in these specimens was the same at the end of the exposure. Weight loss was higher in specimens treated with 6 percent MP compared to lower concentrations. On the other hand, treatment with MP resulted in relatively higher weight loss than treatment with boron compounds.

Concluding remarks

Bending strength and stiffness values were significantly reduced for all treatments and all loading levels when compared to control board values. Higher retentions generally caused greater property reductions. Only MP indicated a different trend in bending values. In summary, the lowest concentration (2%) of BA, DOT, and BA/DOT was found to comply with the CSA 0437 requirement. In general, thickness swell and water absorption values for treated specimens were significantly increased (poorer performance) when compared to that for control boards.

In a very limited series of cone calorimeter tests, the treatments used in this study did not significantly improve fire performance compared to the controls. Of the treatments studied, the highest concentrations of BA and BA/DOT pro-

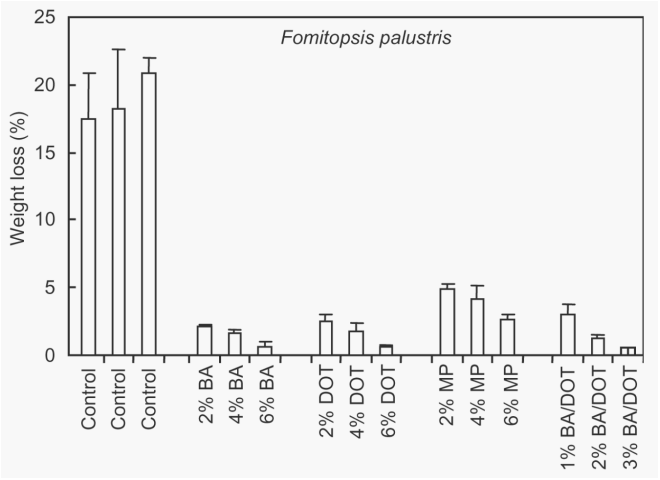

Figure 5. — Weight loss after 12 weeks of exposure to Fomitopsis palustris.

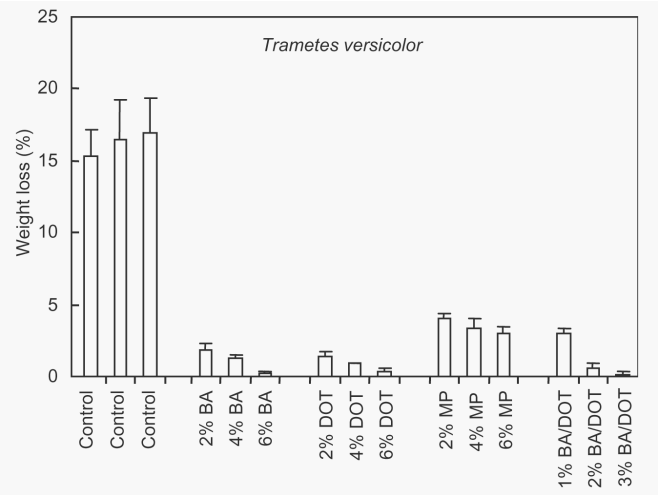

Figure 6. — Weight loss after 12 weeks of exposure to Trametes versicolor.

vided some improvement in fire performance. In the three tests of DOT-treated samples, fire performance improved to some extent, but the sample with the highest treatment level did not show the most improvement. Work continues toward improving the fire performance of OSB.

Treatment had a significant effect on susceptibility to both *Fomitopsis palustris* and *Trametes versicolor*. The OSB specimens were generally more resistant to *T. versicolor* than to *F. palustris.* However, these fungi did not cause any significant weight loss in treated specimens whereas control specimen weight loss exceeded 15 percent; treated OSB specimens were almost free from attack by the fungi.

All treated OSB specimens had greater termite mortality than did control specimens, suggesting that treatment improved resistance to termites. After 2 weeks of exposure, the greatest termite mortality was observed in specimens treated with BA and DOT, followed by MP. Treated specimens were found almost intact after 3 weeks of exposure. The single-component BA and DOT treatments appeared to be more effective than was the combination of these chemicals based on weight loss, although termite mortality in all specimens was the same at the end of the exposure period.

Literature cited

Akbulut, T., Y. Goker, and N. Ayrilmis. 2002. Using OSB panels instead of plywood. Review of Faculty of Forestry, Istanbul Univ., Series A 52(1):65-79.

Archer, K.J., D.A. Fowlie, and A.F. Preston. 1993. Test methods and treatments in the development of protected composite products. *In*: Proc. IUFRO Symp. on Protection of Wood-Based Composite Products. Forest Prod. Soc., Madison, WI. pp. 38-43.

American Society for Testing and Materials (ASTM). 1999. Evaluating the properties of wood based fiber and particle panel material. ASTM D 1037-99. ASTM, West Conshohocken, PA.

ASTM International. 2001. Standard test method for surface burning characteristics of building materials. ASTM E 84-01. Am. Soc. for Testing and Materials Inter., West Conshohocken, PA.

_____. 2002. Standard test method for heat and visible smoke release rates for materials and products using an oxygen consumption calorimeter. ASTM E 1354-02. Am. Soc. for Testing and Materials Inter., West Conshohocken, PA.

Baileys, J.K., B.M. Marks, A.S. Ross, D.M. Crawford, A.M. Krzysik, J.M. Muehl, and J.A. Youngquist. 2003. Providing moisture and fungal protection to wood-based composites. Forest Prod. J. 53(1):76-81.

Barnes, H.M. and T.L. Amburgey. 1993. Technologies for the protection of wood composites. *In*: Proc. IUFRO Symp. on Protection of Wood-Based Composite Products. Forest Prod. Soc., Madison, WI. pp. 7-11.

Canadian Standards Association (CSA). 2000. OSB performance by design. CSA 0437 (Grade O-2), Structural Board Assoc. CSA, Toronto, Ontario, Canada. www.osbguide.com.

Dietenberger, M.A. and R.H. White. 2001. Reaction-to-fire testing and modeling for wood products. *In*: Proc. 12th Annual BCC Conf. on Flame Retardancy. Business Communications Co., Inc., Norwalk, CT. pp. 54-69.

Grexa, O., E. Horvathova, O. Besinova, and P. Lehocky. 1999. Flame retardant treated plywood. Polymer Degradation and Stability 64: 529-533.

International Organization for Standardization (ISO). 1993. Fire tests. Reaction to fire. Part 1. Rate of heat release from building products (Cone calorimeter method). ISO 5660-1. ISO, Geneva, Switzerland.

Japan Wood Preserving Association (JWPA). 1992a. JWPA Standard 3: Method for laboratory evaluation to determine decay resistance of wood composites. JWPA, Tokyo, Japan.

_____. 1992b. JWPA Standard 11(1): Method to evaluate effectiveness of termiticides applied by brush-, spray-, or dip-treatment (1). Laboratory method. JWPA, Tokyo, Japan. (in Japanese).

Laks, P.E. and M.J. Manning. 1997. Mobility of zinc borate wood composite preservative. IRG/WP 97-30153. Inter. Res. Group on Wood Preservation, Stockholm, Sweden.

_____ and R.D. Palardy. 1990. The development of borate-containing flakeboard. *In*: Proc. 1st Inter. Conf. on Wood Protection with Diffusible Preservatives. Proc. No. 47355. Forest Prod. Soc., Madison, WI. pp. 76-79.

Laufenberg, T., S. LeVan, and V. Bruci. 1986. Investigation of fire-retardant treatments for flakeboards. Drvna Industrija 36(3-4):65-70.

Lebow, P.K. and J.E. Winandy. 1999a. Verification of a kinetics-based model for long-term effects of fire retardants on bending strength at elevated temperatures. Wood and Fiber Sci. 31(1):49-61.

Lebow, S.T. and J.E. Winandy. 1999b. Effect of fire-retardant treatment on plywood pH and the relationship of pH to strength properties. Wood Sci. and Tech. 33(4):285-298.

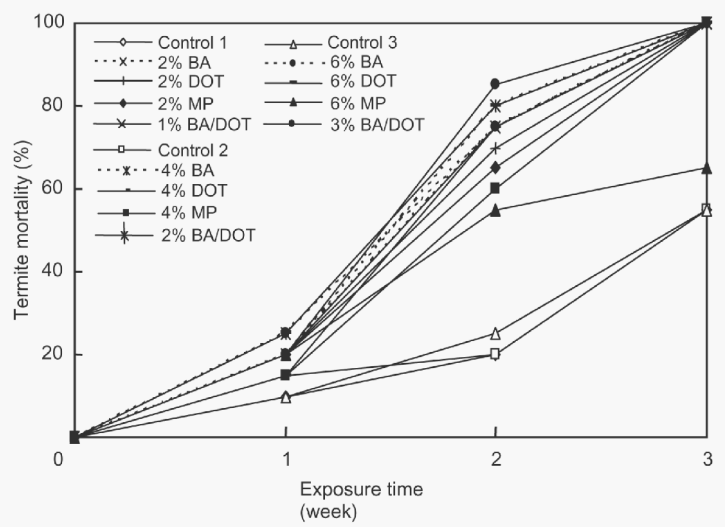

Figure 7. — Termite mortality after 3-week termite test.

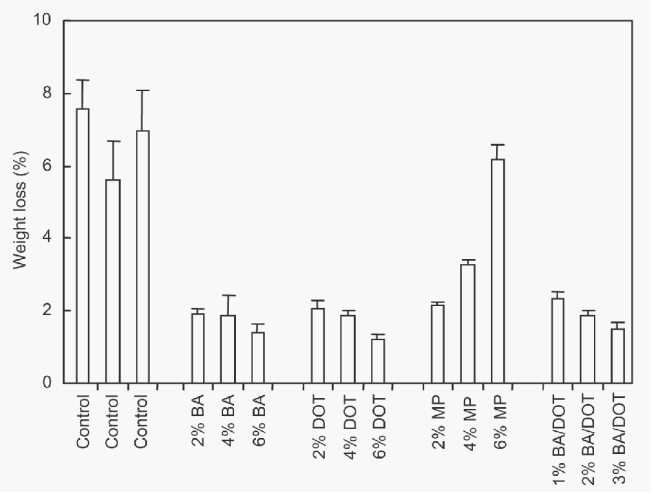

Figure 8. — Weight loss during termite assay.

LeVan, S. and J.E. Winandy. 1990. Effects of fire-retardant treatment on wood strength: A review. Wood and Fiber Sci. 22(1):113-131.

_____, J.R. Ross, and J.E. Winandy. 1990. Effects of fire retardant chemicals on bending properties of wood at elevated temperatures. Res. Pap. FPL-RP-498. USDA Forest Serv., Forest Prod. Lab., Madison, WI.

Murphy, R.J., D.J. Dickinson, P. Turner, P.J. Wickens, and R. Hashim. 1993. Vapor boron treatment of wood composites. *In*: Proc. IUFRO Symp. on Protection of Wood-Based Composite Products. Forest Prod. Soc., Madison, WI. pp. 49-56.

Sean, T., G. Brunette, and F. Cote. 1999. Protection of oriented strandboard with borate. Forest Prod. J. 49(6):47-51.

Sweet, M.S. and J.E. Winandy. 1999. Influence of degree of polymerization of cellulose and hemicellulose on strength loss in fire-retardant-treated southern pine. Holzforschung 53(3):311-317.

Tsunoda, K., H. Watanabe, K. Fukuda, and K. Hagio. 2002. Effects of zinc borate on the properties of medium density fiberboard. Forest Prod. J. 52(11/12):62-65.

Winandy, J.E. 1995. Effects of fire retardant treatments after 18 months of exposure at 150°F (66°C). Res. Note FPL-RN-0264. USDA Forest Serv., Forest Prod. Lab., Madison, WI.

_____. 1997. Effects of fire retardant retention, borate buffers, retention, and redrying temperature after treatment on thermal-induced degradation. Forest Prod. J. 47(6):79-86.

_____. 2001. Thermal degradation of fire-retardant-treated wood: Predicting residual service life. Forest Prod. J. 51(2):47-54.