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The combined effects of boron and oil heat treatment on the properties of beech and Scots pine wood. Part 2: Water absorption, compression strength, color changes, and decay resistance

Eylem Dizman Tomak · Hannu Viitanen ·
Umit C. Yildiz · Mark Hughes

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Abstract The effect of oil treatments on several properties of wood treated with boron compounds was studied: water absorption, water repellent efficiency, compression strength parallel to grain, color changes, and decay resistance against *Coniophora puteana* and *Coriolus versicolor*. Oil heat treatment evidently decreased the water absorption to approximately 20% and increased water repellent efficiency to 80–90% after 2 weeks immersion in water. Compression strength was not adversely affected by oil heat treatment at 160 °C. Oil impregnation as a second treatment step caused remarkable color changes especially in specimens pretreated with 5% boric acid. Boric acid treatment protected the specimens against brown and white rot when no leaching prior the decay test was used, but the protective effect was low when boron was leached. Oil treated specimens gave better efficiency against fungal decay compared to controls; however, the effect was not within the range of the efficacy needed for a wood preservative. Double treatment gave synergistic effect for both in unleached and leached specimens.

E. D. Tomak (✉) · U. C. Yildiz
Faculty of Forestry, Forest Industry Engineering Department,
Karadeniz Technical University, 61080 Trabzon, Turkey
e-mail: eylemdizman@yahoo.com

H. Viitanen
VTT Building and Transport, P.O. Box 1806,
02044 VTT Espoo, Finland

M. Hughes
Department of Forest Products Technology, School of Science
and Technology, Faculty of Chemistry and Materials Sciences,
Aalto University, P.O. Box 16400, 00076 Aalto, Finland

Introduction

Wood is a renewable and natural organic material that is commonly used in engineering and structural applications. However, it has some undesirable properties such as dimensional instability, biodegradability, and flammability. These problems can be partially overcome by modification or impregnation of the wood. Conventional heavy duty wood preservatives such as chromated arsenicals, pentachlorophenol, and creosote have been banned for some applications due to their mammalian toxicity and their adverse effect on the environment [1]. New, eco-friendly, but nevertheless still effective protection systems, are needed to protect wood in high moisture environments such as may be experienced outdoors. Boron compounds have been used for a long time to protect timber against wood destroying organisms such as decay fungi and termites. Boron compounds are colorless, odorless and can reduce the severity of thermal degradation [2, 3]; however, they may accentuate the hygroscopicity of wood [2, 4]. Wood treated with inorganic flame-retardant salts is more hygroscopic than untreated wood, particularly at high relative humidity. The hygroscopic behavior depends upon the type of chemical, the level of chemical retention, and the size and species of the treated wood [3]. The hygroscopic nature of some boron salts may adversely affect the dimensional stability of wood under humid service conditions and may cause strength losses at high loading levels [2, 4]. The future of boron preservatives largely depends on enhancing their stability in wood in outdoor conditions and limits some adverse effects of boron on wood properties by supplemental treatments [4, 5]. More dimensionally stable products with reduced moisture contents and increased biological durability can be obtained by adding water repellents to the common wood preservatives. Furthermore, by adding such water repellants the leaching of toxic preservatives to the environment can be reduced [6]. Physically restricting the access of water to wood by using water repellents or coatings, for example, may be the simplest way of preventing water uptake in boron based formulations. Natural oils are potentially capable of decreasing the water uptake of wood by creating a protective layer on the surface [6].

The objective of the study reported in this series was to screen for any possible synergistic effects between a range of plant oils in combination with boric acid, borax and an agricultural-boron compound. Wood impregnated by the three aforementioned boron compounds was subsequently oil heat treated. The ability of the oils to inhibit water uptake by creating a hydrophobic surface layer and the influence of the combined oil heat treatment and boron treatment on the decay resistance of the treated wood was investigated. Moreover, the effect of boron impregnation and oil heat treatment on the compression strength parallel to grain and its color was also investigated.

Materials and methods

The material used in this study was the sapwood of Scots pine (*Pinus sylvestris*) and beech (*Fagus oriantalis*). Specimens having four different configurations were prepared. The specimen dimensions were 20 × 20 × 30 mm (for compression strength), 30 × 30 × 15 mm (for the water absorption tests), 19 × 19 × 19 mm (for color measurement), and 15 × 5 × 30 mm for the fungal tests (Radial, Tangential, and Longitudinal). Boric acid (BA), borax decahydrate (BX), and agricultural-boron product (TB) were provided by the Turkish National Boron Research Institute (BOREN), Turkey. Agricultural-boron compound known as Tarim-Bor trade name is developed by BOREN in the last years and consists 59% boron oxide (B_2O_3) and 18% boron (B) while these values are 56 and 17% for boric acid; 37 and 11% for borax, respectively. The solubility rate of TB in water at room temperature is more than three times greater than that of boric acid and borax. It has been using on crops for plant nutrition [7]. Due to being patented compound, there is little information about its efficacy on wood treatments [8].

For the impregnation procedure aqueous solutions of the boron compounds having concentrations of 1, 2, and 5% (w/v) were prepared at 20 °C with distilled water. Nut, sunflower, soybean, canola, and corn vegetable oils were provided by the Ordu Oil Company, Turkey, while used (waste) vegetable oil was obtained from various fast food restaurants in Trabzon, Turkey.

Impregnation procedure for boron compounds and oils

The specimens were first vacuum impregnated with the boron solutions at 760 mmHg for 60 min at 20 °C. Following this, the specimens remained immersed in the solutions for 60 min at atmospheric pressure. Then the specimens were removed from the solutions and excess solution removed by dabbing with a tissue.

Oil heat treatment was carried out in a two-stage process as described by Lyon et al. [9] and Podgorski et al. [10]. Selected boron treated and untreated wood specimens were first placed in an oil bath containing oil at ambient temperature and then the temperature was raised to 160 °C at a rate of 5 °C/min. Once the target temperature had been reached, the temperature was held constant for 30 min after which the specimens were quickly transferred to another bath containing oil at room temperature where they remained immersed for a further 30 min. The treated specimens were subsequently conditioned for 4 weeks at 20 °C and 65%.

Water absorption and water repellent efficiency test

Oven-dried wood specimens with dimension of 30 × 30 × 15 mm were placed into a 500 mL beaker filled with deionised water. Six replicates were used for in treatment group. After 6, 24, and 48 h, and thereafter at 48-h intervals, the specimens were removed from the beaker and excess water was removed by dabbing with a tissue. After the dimensions and weights of the specimens had been recorded the specimens were again placed in the beaker and the water replaced. The test was continued for a total of 14 days. Relative water uptake (WA) and water repellent efficiency (WRE) were calculated after each water replacement according to Eqs. 1 and 2.

$$\mathrm{WA} = \left[\frac{W_2 - W_1}{W_1}\right] \cdot 100 \tag{1}$$

$$\mathrm{WRE} = \left[\frac{\mathrm{WA_c} - \mathrm{WA_t}}{\mathrm{WA_c}}\right] \cdot 100 \tag{2}$$

where W_2 = wet weight of the wood specimens after wetting with water, W_1 = initial dry weight, $\mathrm{WA_c}$ = Water absorption rates of untreated controls, and $\mathrm{WA_t}$ = Water absorption rates of treated specimens.

Compression strength parallel to grain test

Compression strength parallel to grain was determined to according to TS 2595 [11] using a Zwick universal testing machine. Conditioned wood specimens having dimensions of 20 × 20 × 30 mm were used. Seven replicates were tested for each treatment group.

Color measurements

Color measurements were carried out using a Minolta CM-2600d spectrophotometer. The L^*, a^*, and b^* color coordinates were measured on the tangential face of five replicates for each treatment. These values were used to calculate the total color change (ΔE^*) as a function of the treatments applied to the wood specimens according to Eq. 3. A low ΔE^* value corresponds to a low color change or a stable color [12].

$$\Delta E^* = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}} \tag{3}$$

where ΔL^*, Δa^*, and Δb^* are the changes between before and after treatment values.

Decay tests

The decay testing was carried out according to the principle of EN 113 [13], however, instead of agar, vermiculite was used as the growth medium and plastic boxes were used instead of kolle flasks. The size of wood specimens was 15 × 5 × 15 mm, obtained by cutting the 15 × 5 × 30 mm specimens in half, yielding in total eight replicates for each variation exposed to fungal attack. One of the transverse sections of the freshly cut specimens was coated with epoxy resin to prevent the boron and oil from leaching from this section. Apart from these specimens, four treated and untreated control specimens were used for every treatment group to determine operational weight losses.

Decay testing was carried out on both leached and unleached specimens. Leaching was conducted according to the AWPA E11-97 [14] standard method, without stirring. The water-holding capacity (WHC) of the vermiculite media was determined using the method described in CEN prENV 807 [15]. Containers were filled with 25 g of commercial vermiculite. Malt extract agar of 5% concentration had been poured to each container and mixed with vermiculite. Then the containers were sterilized in an autoclave for 60 min at temperature of 120 °C and pressure of about 0.1 MPa. The specimens were also sterilized in dry air conditions at 125 °C for 55 min in an autoclave. Three treated and three control specimens were placed on vermiculite in each container. After cooling, the specimens and vermiculite were inoculated with the brown rot fungi *Coniophora puteana* for Scots pine and the white rot fungi *Coriolus versicolor* for the beech wood specimens. The containers were stored in a climate room at a temperature of 25 °C and 65% relative humidity. All specimens were cleaned, dried at a temperature of 103 ± 2 °C, weighed and the mass loss calculated after 60 days exposure.

Results and discussions

Water absorption and water repellent efficiency

The relative water absorption levels and the water repellent efficiency of the specimens during the immersion tests are shown in Figs. 1, 2, and 3. The WA levels of the untreated control specimens were found to be 146 and 96% after 336 h immersion in distilled water for pine and beech, respectively. Boron impregnation had seemed to have no positive effect on WA and WRE. For the reader's convenience these results are not shown in the figures. Indeed, the WA of the boron treated specimens was slightly higher than that of the control specimens during both the early and latter stages of the test. This was also demonstrated by Baysal et al. [4].

The results indicated that the oil treated beech specimens absorbed much more water than the oil treated pine specimens. The probable reason for this might be the lower oil uptake of the beech specimens. The retention of boron compounds and oils are reported in Part 1 of this series. Oil impregnation as a second step of the treatment process clearly reduced the WA and improved the WRE of the specimens, most probably due to water repellent effect of

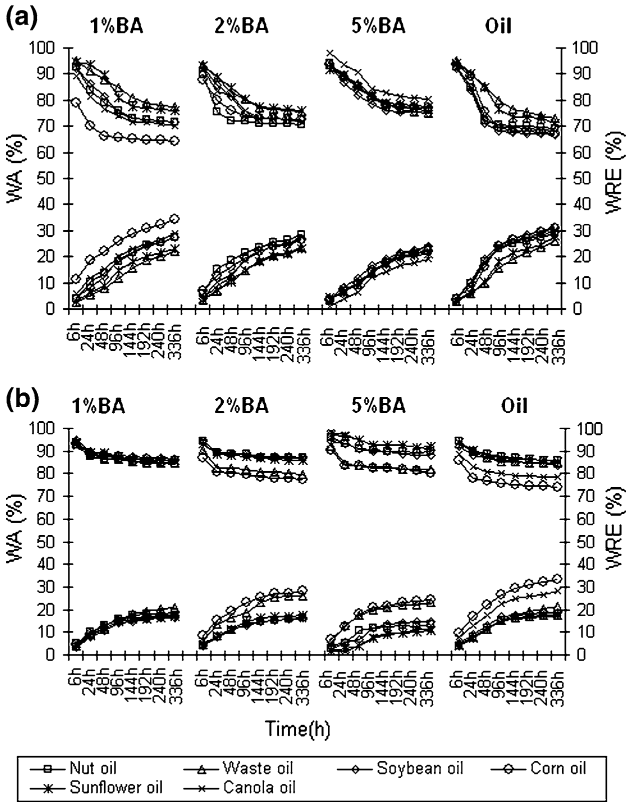

Fig. 1 Water absorption and water repellent efficiency of BA + oil and only oil treated specimens (%) (**a** Beech specimens, **b** Scots pine specimens)

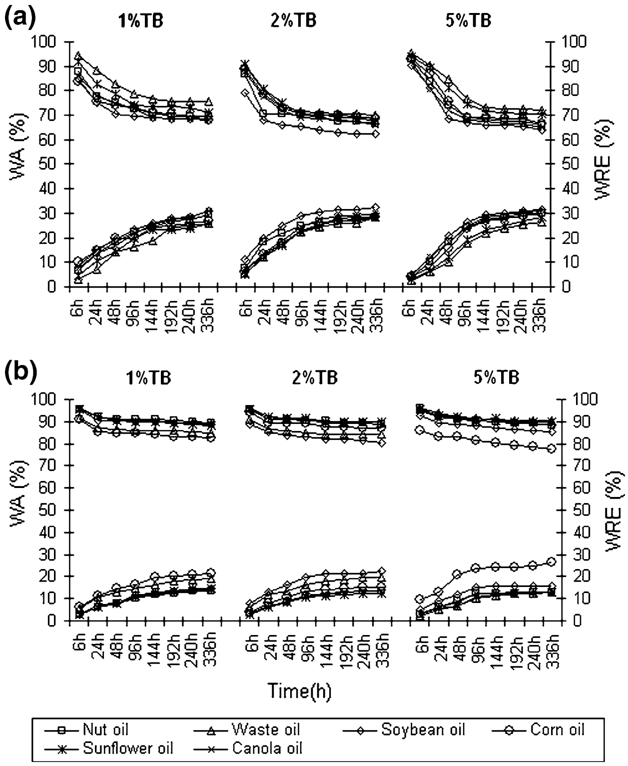

Fig. 2 Water absorption and water repellent efficiency of TB + oil treated specimens (%) (**a** Beech specimens, **b** Scots pine specimens)

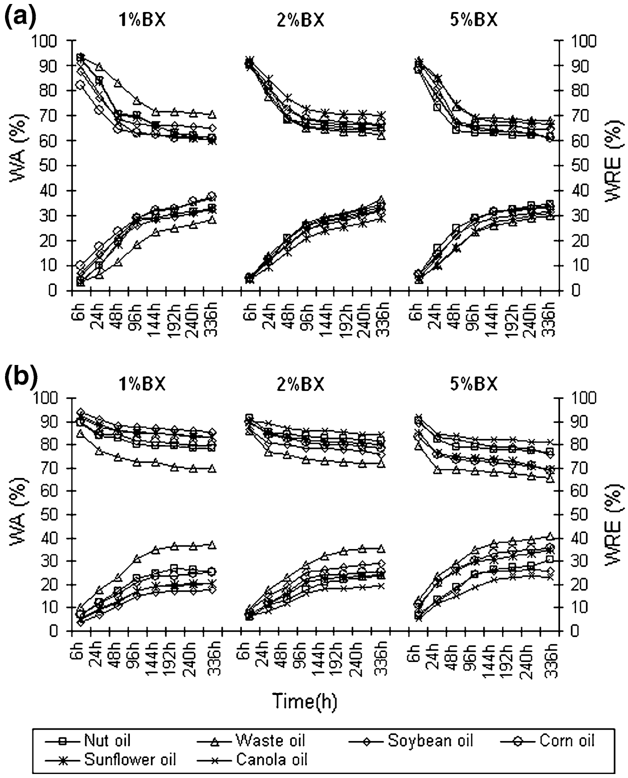

Fig. 3 Water absorption and water repellent efficiency of BX + oil treated specimens (%) (**a** Beech specimens, **b** Scots pine specimens)

the oils. Temiz et al. [16] impregnated wood specimens with pyrolysis oils and found lower water absorption values than that of the controls along with an anti-swelling efficiency of 60–90%. As can be seen from Fig. 1a and b, BA + oil treated specimens showed good performance with WA levels and WRE at around 20 and 80–90% for pine and 20–30 and 70–80% for beech, respectively. WA values decreased with increasing boric acid concentration in the BA + oil treated specimens. The original color of the wood specimens treated with 5%BA + oil changed and turned almost black, looking like char formation on the surface. The high concentration of boric acid probably catalyzed the dehydration of the wood specimens during oil heat treatment at 160 °C. The penetration of water into the wood might be inhibited by the char layer formed on the surface of the 5%BA + oil treated specimens, since these specimens displayed lower water absorption and a better WRE than wood treated with other concentrations of boric acid. After torrefaction the wood possesses new properties: reduced hygroscopicity, improved dimensional stability and durability [17]. The WA level and WRE of TB + oil treated specimens were 10–20 and 80–90% for pine and 30 and 60–70% for beech (Fig. 2a, b). Due to the high oil uptake of wood, WA was reduced because of the filling of the lumen with oil. Similar behavior was noted by Temiz et al. [18] in wood treated with a combination of vegetable oils and fungicide. The WA and WRE were found to be 20–40 and 70–85% for BX + oil treated pine and 30–40 and 60–70% for beech specimens, respectively (Fig. 3a, b). Compared to the other two boron compounds, borax pretreated samples showed lower water repellent efficiency. This might be due to the different chemical composition of the chemicals. Toker [19] reported that borax treated wood exhibited greater hygroscopicity than boric acid treated material.

Water repellents considerably reduce hygroscopicity, water absorption, and shrinkage as well as increasing the water repellent efficiency and anti-swelling efficiency of wood treated with boron compounds [4, 20].

The effect of the water repellents in reducing water absorption levels in treated wood were much more pronounced during the early part of leaching, especially within 6 and 24 h. This finding is consistent with that of previously reported study [4]. These results may be due to high water uptake into available empty pores in wood at the beginning of soaking and the reduction of those wood spaces over time [4]. With the exception of boric acid, the concentration of boron in the other boron compounds seemed no effect on water uptake in the boron + oil treated specimens. There were no apparent differences between the oil types, with the exception of corn oil which showed a greater tendency to water uptake in the treated samples. Limiting water-boron contact through low WA is expected to slow down boron leaching [2]. The fact that boron impregnation before oil treatment did not have any significant effect on the WA of the treated wood could indicate delayed leaching of boron.

Compression strength parallel to grain

As may be observed from Table 1, oil heat treatment after boron impregnation did not adversely affect compression strength parallel to grain (CSPG); indeed CSPG appeared to increase in the case of TB + oil treatment compared to the controls.

In both species, oil treatment alone did not affect CSPG. Some decreases in compression strength were expected due to the thermal treatment as it has been reported that certain mechanical properties decrease following heat treatment [21, 22]. However, increased density levels of oil treated specimens probably caused no reduction in CSPG. It is fairly certain that the compression strength increases as a result of high density values. It was reported that the gross wood probably fails in compression due to the buckling of relatively thin cell walls because of a long-column type of instability [23]. High oil uptake in the specimens might fill the lumena and coat on the walls which thickens them greatly increasing their lateral stability. Boron compounds cause little changes in the mechanical properties of wood except at very high boron loadings. CSPG was 67 and 49 N/mm^2 for untreated beech and pine specimens, respectively. There were slight decrease in the CSPG of BA + oil treated specimens with increasing boric acid concentration. Kartal et al. [21] found that bending strength decreased by between 10 and 30%, depending on the wood species and process parameters during the thermal treatment of boric acid pretreated specimens. Similar decreases in the CSPG of wood specimens treated with boric acid followed by heat treatment were also reported by Tomak et al. [24]. The results also showed that the highest value in compression strength was obtained in the 5%TB + oil and 5%BX + oil treated beech specimens. It would be advisable to take into consideration the concentration of boron compounds in double treated specimens in applications requiring high strength. The type of the oil used did not result in any notable differences in

Table 1 Compression strength parallel to grain of wood specimens (N/mm^2)

Treatment groups		Compression strength parallel to grain (N/mm^2)						
		Boron	Nut oil	Waste oil	Soybean oil	Corn oil	Sunflower oil	Canola oil
1%BA	Pine	42.9(1.8)	41.54(2.5)	43.12(5.5)	44.18(4.6)	42.36(1.7)	39.92(3.9)	45.32(4.8)
	Beech	70.2(3.2)	68.56(2.4)	70.74(3.3)	70.04(2.3)	69.30(2.8)	69.94(1.7)	68.72(2.2)
2%BA	Pine	40.3(3.6)	38.66(2.2)	44.06(2.7)	49.66(3.4)	43.47(4.4)	42.7(3.9)	45.35(4.8)
	Beech	68.4(1.4)	66.82(2.1)	66.08(3.8)	64.30(3.5)	64.14(2.9)	62.44(3.5)	66.63(1.7)
5%BA	Pine	38.4(3.9)	40.04(4.0)	47.93(4.9)	41.08(3.3)	45.35(1.2)	50.88(3.7)	49.1(3.1)
	Beech	65.4(1.4)	63.38(5.3)	65.72(5.2)	67.58(4.4)	68.32(2.8)	69.73(2.2)	65.30(3.7)
1%TB	Pine	47.4(6.7)	58.82(0.8)	59.75(2.3)	53.25(6.7)	44.35(8.1)	59.15(4.0)	55.47(2.0)
	Beech	70.4(2.9)	62.72(4.9)	62.90(3.5)	60.50(3.03)	63.02(6.5)	58.58(3.1)	63.7(2.05)
2%TB	Pine	45.6(2)	62.6(0.6)	62.12(2.0)	55.83(2.6)	60.97(0.8)	60.9(2.1)	60.78(1.3)
	Beech	73.5(3.5)	62.94(3.5)	65.32(1.6)	64.52(2.3)	63.28(4.7)	59.80(4.4)	66.25(4.0)
5%TB	Pine	46.3(7.9)	56.45(3.7)	60.56(5.2)	56.06(3.3)	54.3(2.5)	57.66(2.2)	58.68(3.0)
	Beech	73.5(3.2)	72.36(3.1)	73.98(2.3)	68.48(4.1)	69.82(4.2)	71.65(4.6)	70.9(4.06)
1%BX	Pine	46.6(2.2)	47.62(3.5)	48.8(4.6)	49.38(1.1)	49.38(1.1)	46.1(0.4)	50.96(2)
	Beech	71.4(1.4)	65.15(5.4)	67.98(3.9)	62.8(3.48)	68.45(0.7)	63.54(3.91)	67.92(1.5)
2%BX	Pine	44.3(2.8)	51.17(4.2)	50.58(2.6)	50.88(3.3)	49.8(2.5)	50.06(1.2)	49.76(0.7)
	Beech	73.7(2.5)	67.64(2.7)	68.48(7.0)	69.54(5.0)	70.96(2.4)	70.98(2.8)	69.6(2.8)
5%BX	Pine	48.7(3.9)	52.96(4.1)	52.13(5.2)	53.28(1.1)	49.97(4.1)	47.96(5.1)	51.88(3.2)
	Beech	72.8(2.3)	75.22(3.5)	73.35(4.6)	73.06(2.26)	75.48(3.5)	73.6(4.55)	71.72(1.5)
	Pine		49.7(2.8)	48.76(4.6)	45.86(2.04)	50.3(1.35)	49.42(3.7)	47.4(4.05)
	Beech		67.85(4.7)	65.57(4.7)	68.17(2.4)	66.9(2.95)	66(1.85)	68.2(3.56)
Controls								
	Pine	48.6 (3.1)						
	Beech	66.51(1.76)						

Values in parentheses are standard deviations compression strength between the variations but in general waste, sunflower and canola oils seemed to be the best treatment agents.

Color changes of specimens

Color changes occurring in the specimens following treatment are shown in Table 2.

Boron treatment alone caused only minor color changes (ΔE^*) due it being colorless. However, ΔE^* increased with increasing boron concentration. Boron crystals could be seen on the surface of the specimens at high boron loadings. The highest ΔE^* was observed in the 5%BA + oil treated pine specimens and it was possible to see the color change with the naked eye. As mentioned above, in both wood species, the surfaces of the 5%BA + oil treated wood turned almost black with what appeared to be char formation clearly visible on the surface. Some chemical interactions might have taken place between the boric acid on the surface of wood, during heat treatment. This is an important aspect to consider in applications where the esthetic properties are of importance. A greater ΔE^* was observed in the oil treated samples that had been first treated with 2 and 5% boron compounds than samples treated with oil alone. More noticeable color changes were observed in the pine specimens than in the beech specimens.

Decay resistance of specimens

The results of the decay tests are given in Table 3. The decay test was carried out on 5% boric acid treated wood and in combination with the different oils. The purpose was to determine the best oil type for this application. The mass losses of the virulence controls were 52 and 56% for unleached and leached pine specimens, respectively, exposed to *C. puteana* attack. In the case of beech, the mass losses of the virulence controls were found to be 30 and 28% for unleached and leached specimens, respectively, exposed to *C. versicolor*. These results verified that the decay test was valid.

Unleached specimens treated with 5%BA alone showed less than 1% mass loss for both decay fungi. However, after leaching for a total of 14 days, the mass loss observed in both wood species was nearly equal to that of the untreated controls, showing that nearly all the boron had been leached out from the wood.

Pine specimens treated with only vegetable oils exhibited mass losses in the range 7–13%, but after leaching the mass loss increased to 10–16%. The difference between the mass loss of the unleached and the leached beech specimens was in the range of 7–14 and 10–20%, respectively. In general, the waste and sunflower oil seemed to be the best protection agents. The efficiency of the vegetable oils

Table 2 Total color changes of specimens

Treatment groups		Color changes (ΔE)						
		Boron	Nut oil	Waste oil	Soybean oil	Corn oil	Sunflower oil	Canola oil
1%BA	Pine	2.29(1.1)	25.37(3.3)	26.73(3.1)	23.78(3.4)	26.34(4.5)	23.45(5.7)	24.06(2.3)
	Beech	2.32(1.9)	22.29(0.8)	23.91(2.3)	23.96(1.0)	24.41(2.1)	22.16(2.6)	20.71(1.5)
2%BA	Pine	2.41(1.3)	29.67(5)	29.07(4.4)	29.61(1.07)	29.01(5.2)	27.17(5.1)	29.36(5.3)
	Beech	2.59(0.8)	26.39(1.2)	27.12(1.6)	25.89(3.1)	24.20(1.9)	24.39(2.1)	24.6(2.07)
5%BA	Pine	3.48(1.6)	40.67(2.5)	39.09(1.3)	37.84(3.8)	35.2(2.04)	36.199(1.15)	36.45(3.5)
	Beech	4.94(0.6)	30.57(1.6)	29.2(0.9)	27.65(1.7)	27.36(1.6)	27.50(1.4)	28.94(4.2)
1%TB	Pine	4.66(3.1)	26.76(1.9)	23.71(4.6)	25.83(2.6)	26.58(4.1)	26.98(3.7)	23.99(4.1)
	Beech	3.76(1.3)	22.05(0.9)	22.14(3.2)	21.10(0.9)	22.6(2.05)	21.94(2.1)	21.90(2.5)
2%TB	Pine	5.37(3.9)	29.08(2.5)	25.41(2.4)	27.11(2.3)	29.25(1.7)	29.88(4.2)	30.91(1.5)
	Beech	3.80(1.1)	25.95(2.6)	24.48(2.4)	24.32(1.05)	24.72(1.7)	25.20(2.2)	25.34(2.3)
5%TB	Pine	5.47(2.8)	34.93(4.2)	33.83(3.9)	35.02(4.2)	34.0(4.2)	33.53(3.1)	34.46(1.3)
	Beech	4.32(1.2)	29.05(1.4)	25.33(1.4)	24.72(0.7)	28.24(0.8)	28.06(0.8)	26.30(1.1)
1%BX	Pine	5.24(1.7)	23.8(3.07)	24.51(2.5)	25.21(2.7)	22.32(1.1)	23.42(1.8)	25.42(2.7)
	Beech	2.87(1.8)	23.93(2.5)	23.78(1.9)	24.73(2.05)	24.61(2.1)	22.64(3.2)	23.17(1.9)
2%BX	Pine	5.66(1.8)	26.82(4.3)	25.85(3.1)	28.27(3.3)	26.16(3.1)	25.43(3.7)	24.3(4.06)
	Beech	2.98(0.5)	25.28(3.5)	26.23(2.7)	26.50(1.3)	26.91(1.7)	26.91(2.05)	23.48(1.4)
5%BX	Pine	7.71(1.2)	33.3(2.08)	31(2.5)	32.72(2.9)	31.43(1.3)	31.74(3.01)	32.72(1.9)
	Beech	4.23(0.7)	29.60(1.8)	29.06(1.9)	30.31(1.4)	28.18(1.8)	27.06(0.9)	25.71(1.5)
	Pine		23.15(4.4)	22.27(1.9)	23.73(1.1)	21.48(1.2)	23.71(2.9)	21.58(2.6)
	Beech		23.78(2.7)	22.93(1.7)	22.23(1.8)	21.8(1.04)	20.49(2.4)	21.8(1.9)

Table 3 Mass loss (%) of beech and pine specimens exposed to *C. versicolor* and *C. puteana* attack

Treatment groups	Beech specimens				Pine specimens			
	Test UL	Control UL	Test L	Control L	Test UL	Control UL	Test L	Control L
Nut + 5%BA	0.44 (0.29)	37.71 (4.96)	7.54 (1.75)	27.28 (2.29)	0.82 (0.42)	53.12 (4.24)	1.29 (1.0)	45.82 (5.44)
Waste + 5%BA	0.88 (0.57)	30.78 (3.06)	5.33 (2.12)	27.48 (2.18)	1.28 (0.85)	51.99 (4.11)	3.20 (1.57)	43.62 (6.09)
Soybean + 5%BA	0.95 (0.51)	30.33 (5.16)	10.66 (2.69)	27.45 (4.16)	1.00 (0.33)	53.45 (1.83)	2.25 (1.88)	35.39 (8.59)
Corn + 5%BA	0.95 (0.55)	36.81 (5.72)	13.28 (4.34)	25.61 (1.87)	1.83 (0.65)	54.80 (3.75)	2.68 (1.33)	43.68 (7.98)
Sunflower + 5%BA	0.36 (0.29)	28.70 (3.82)	5.32 (1.72)	24.14 (6.24)	1.51 (0.2)	50.72 (2.72)	3.89 (0.86)	38.30 (6.99)
Canola + 5%BA	1.34 (0.63)	32.81 (3.7)	4.67 (2.91)	28.95 (4.51)	1.72 (0.8)	53.43 (4.03)	4.05 (2.18)	32.71 (3.36)
5%BA	0.51 (0.24)	31.40 (2.21)	28.49 (7.34)	27.60 (4.51)	0.59 (0.37)	55.88 (4.22)	45.98 (3.34)	48.80 (6.86)
Nut oil	7.28 (2.89)	34.51 (6.1)	13.48 (4.29)	28.08 (0.9)	12.90 (1.96)	52.92 (3.03)	14.54 (2.52)	47.64 (8.74)
Waste oil	8.46 (1.03)	34.78 (4.02)	10.39 (1.87)	24.33 (6.62)	7.15 (1.14)	52.55 (3.41)	12.54 (4.47)	46.60 (7.57)
Soybean oil	14.02 (2.02)	30.36 (4.38)	20.12 (1.44)	28.20 (3.44)	11.68 (2.83)	55.90 (4.02)	11.53 (2.3)	54.65 (4.22)
Corn oil	10.82 (2.81)	32.67 (4.46)	16.77 (1.94)	26.84 (3.66)	10.0 (1.43)	51.82 (3.45)	12.56 (2.5)	44.64 (7.63)
Sunflower oil	14.19 (2.07)	33.89 (5.94)	14.93 (2.77)	30.45 (3.67)	7.08 (2.99)	51.53 (3.69)	9.567 (1.70)	46.09 (4.64)
Canola oil	9.74 (3.24)	32.95 (3.34)	14.31 (5.62)	26.63 (4.77)	11.43 (2.83)	54.41 (3.62)	15.57 (4.48)	42.35 (8.37)

UL unleached specimens, *L* leached specimens

might be related to the chemical composition of oils, their drying properties and the barrier properties of the dry film. Oil treatment was observed to result in reduced mass losses compared to the controls, but was unable to protect the whole wood against decay fungi due to its non-toxic properties. Similar observations have also been reported for the termite and fungal resistance of oil treated specimens by Lyon et al. [9] and Temiz et al. [25]. The biological performance of oil treated wood could be attributed to the fact that the oils simply fill the lumen and thus provide only a physical protection by acting as water repellents that inhibited the catalytic action of the fungal enzymes [25].

As shown in Table 3, double treatment with 5% boric acid and vegetable oils displayed a potentially synergetic effect in protecting the specimens against both fungal types: the mass losses were lower than that of the specimens having been treated with either the boron compounds or oils alone. Double treated pine displayed mass losses of between 0.8 and 1.83% for the unleached specimens and between 1.29 and 4.05% for the leached specimens. For beech, the values were, respectively, 0.36 to 1.34% for the unleached material and from 4.6 to 13% for the leached specimens. The mass losses in the double treatment were less than 3% for all oils, and within the range of the efficiency needed for a wood preservative for unleached specimens. 5%BA pretreatment followed by nut, waste, soybean, and corn oil treatment seemed to display the greatest efficacy against *C. puteana* showing less than 3% mass loss for the leached pine specimens.

In some cases, especially in the oil treatments, the sterile control specimens showed high mass losses caused reasons other than fungal attack during the test. This may have been caused by the high oil loadings, with oil leaching out from the wood at high moisture contents into the vermiculite and by the drying of the specimens before and/or after the test. More studies are needed to investigate the biological degradation at the lower loadings of oil and their combinations with boron compound concentrations below 5%.

Conclusions

Combinations of vegetable oils and boron compounds seem to have the potential for engendering a synergetic effect against fungal attack yielding mass losses of less than 3% against both decay fungi. Improved water repellent efficiencies may be connected with the increased hydrophobicity of the surfaces. Waste oil showed similar, or better, performance to the other oils in relation to the wood properties investigated in this study. Therefore, it has a potential as a wood protection agent like other oils have been used in wood protection for many years.

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