EFFECT OF BORIC ACID TREATMENT ON DECAY RESISTANCE AND MECHANICAL PROPERTIES OF POPLAR WOOD

Seyyed Khalil Hosseini Hashemi,[a*] Ahmad Jahan Latibari,[a] Habibolah Khademi-Eslam,[b] and Reza Faraji Alamuti [c]

This study was performed to determine the effect of boric acid treatment upon the decay resistance and mechanical properties of poplar wood. Test specimens were prepared from poplar wood (*Populus nigra* L.) to meet ASTM D 143-94 and BS 838:1961 requirements. Samples were impregnated with boric acid solution (0.5, 1, and 2% w/w in distilled water) and by a long-term (21 days) dipping technique to reach complete saturation. Impregnated specimens were exposed to rainbow white-rot fungus (*Trametes versicolor*) for 14 weeks according to BS 838:1961 as applied by the kolle-flask method. The weight loss, compression strength parallel to the grain, and Brinell hardness were determined after impregnation and exposure to white-rot fungus. The highest weight loss (28.60%) was observed for untreated control samples and the lowest (0.63%) occurred in samples treated with 2% boric acid solution. The highest compression strength parallel to the grain was noted in samples treated with 0.5% boric acid and decayed (22.59 MPa) and the lowest compression strength parallel to the grain was recorded in untreated decayed samples (10.42 MPa). The highest Brinell hardness on tangential surface was observed in samples treated with 1% boric acid and decayed (1.32 KN) and the lowest was noted in untreated decayed samples (0.39 KN). The highest Brinell hardness on radial surface was observed in samples treated with 1% boric acid and decayed (1.07 KN) and the lowest was found in untreated decayed samples (0.35 KN).

Keywords: Poplar wood; Boric acid; Trametes versicolor; Durability; Mechanical properties

Contact information; a: Agriculture Research Center, Islamic Azad University of Karaj Branch (KIAU), P. O. Box 331485-313, Karaj, Iran. b: Islamic Azad University of Science & Research Branch (IAU), Iran. c: Department of Wood Science and Technology, Islamic Azad University of Karaj Branch (KIAU), Iran.
[*] *Corresponding author: skh_hosseini@yahoo.com*

INTRODUCTION

Solid wood is an attractive construction material due to its mechanical, processing and aesthetic properties. These traits allow wood to be used as a substitute for many materials such as iron, plastic, and concrete in engineering materials. Depletion of our forest resources, however, is limiting the wood supply, and consequently forest products industries are faced with severe shortages of raw materials (Colakoglu et al. 2003; Kurt and Ozcifci 2009). Wood and wood products are vulnerable to decay organisms (Ruberg and Hafren 2009), and therefore require protection against fungi to increase service life and performance. Wood extractives, and to lesser extent lignin, naturally retard fungal attack in wood (Eaton and Hale 1993), Since the sapwood of all species in general contains less extractives than heartwood, heartwoods exhibits a greater degree of natural durability against microorganisms in most timber. The heartwood of some species, such as aspen (*Populus tremuloides*), red maple (*Acer rubrum*), ash (*Fraxinus excelsior*), black pine (*Pinus amara*), inubuna (*Fagus japonica*), moralillo (*Carpinus caroliniana*), cirimo (*Tilia mexicana*), true fir (*Abies sp.*), and yamahannoki (*Alnus hirsuta*), are low in resistance to decay (Scheffer and Morrell 1998). Consequently, such species must be used by impregnating to wood with an effective preservative formulation that is environmentally acceptable (Thevenon et al. 2001).

Boron compounds demonstrate several advantages for application as wood preservatives and fire-retardants, including a broad spectrum activity against insects and fungi, low mammalian toxicity, low volatility, and the absence of color and odor (Yalinkilic et al. 1999). The effects of boron treatments on mechanical, biological, and dimensional properties of wood and wood-based materials have been widely investigated (Laks et al. 1988; Dimri and Shukla 1991; Hashim et al. 1992; Dimri et al. 1992; Laks and Manning 1995; Yalinkilic et al. 1999). Solar *et al*. (2005) evaluated the decay resistance of compressed beech wood treated with boric acid (3 or 4%) applying: a; hydrothermal treatment (100°C/6h, hydro-module = 1:4) and b; ammonium hydroxide treatment (26% NH_4OH, 20°C/48h, and hydro-module = 1:4). They demonstrated that boric acid increased the decay resistance of compressed woods.

Colakoglu et al. (2003) studied the effect of boric acid treatment on mechanical properties of beech laminated veneer lumber (LVL). They indicated that compression strength in the longitudinal direction of the LVL treated with boric acid was increased about 1.4% compared with the untreated lumber. They also reported that the Brinell hardness of the LVL treated with boric acid was significantly higher than untreated lumber by almost 9% (Colakoglu et al. 2003).

The objective of this study was to determine the effect of boric acid on decay resistance, compression strength, and Brinell hardness of poplar wood to improve its performance for applications such as construction, carrier and roof poles, pile and truss, joinery and furniture, plywood and particleboard, and box making.

EXPERIMENTAL

Materials

Poplar wood (*Populus nigra* L.) was selected according to TS 2476, as defect-free, whole, knotless, normally grown wood (without zone line, reaction wood, decay, insect or fungal infection) from a plantation in northern city of Tonekabon located on fertile lands at the elevation of 20 meters above sea level. The annual precipitation of this area is usually about 1100-1500 mm.

Preparation of Test Samples

Wood samples were randomly selected. The rough boards at 30 mm thickness were tangentially sawn and then stored at 20°C and 65% relative humidity for 2 months to reach 8% final moisture content. Dimensions of 50 x 25 x 15 mm for weight loss and Brinell hardness (BH) measurements and 60 x 20 x 20 mm (longitudinal, tangential, and radial respectively) for compression strength (CS) according to BS 838:1961 and ASTM D 143-94 were prepared.

A long-term (21 days) dipping method was applied for wood treatment. Three concentrations of boric acid (0.5, 1, and 2%) were prepared, and specimens were dipped in these solutions until saturated. Before and after impregnation, samples were kept in a drying oven at 103 ± 2^{o}C to achieve constant weight. After cooling the samples in a desicator, the oven-dry weights of the specimens were measured. The retention ratios of chemicals (R %) were calculated as follows,

$$R\ (\%) = \frac{Mdi\ -\ Md}{Md} 100 \quad (1)$$

where *Mdi* is the dry mass after impregnation (*grams*), and *Md* is the dry mass before impregnation (*grams*) (Table 4).

Decay Test

Decay tests were conducted in accordance with BS 838:1961 as applied by the kolle-flask method for 14 weeks exposure to *Trametes versicolor*. The fungus was grown and maintained on malt extract agar (MEA). The medium was sterilized for 30 min at 125^{o}C and cooled to room temperature before inoculation. Test kolle flasks were prepared with 60 ml of MEA and closed with a cotton cap. The filled kolle flasks were then loosely capped and autoclaved for 30 min. at 105 kPa and 125^{o}C. After cooling the kolle flasks, two treated poplar (*Populus nigra L.*) wood specimens (either 50 x 25 x 15 mm or 60 x 20 x 20 mm) were placed on the top of the two small glass legs in each kolle flask. Both of the small glass legs were then inoculated parallel at opposite corners with a mycelia plug. The plug was cut from the actively growing edge of a 7-day old MEA culture of white-rot fungus.

Each inoculated kolle flask was then incubated at 23^{o}C and 75% relative humidity until the specimens were heavily colonized by the test fungus. All decay tests were performed on specimens from each group of treated samples in different concentrations of boron solution. Two test specimen types (CS and BH), three concentrations of boron solution (0.5, 1, and 2%) with four replications were tested. The labeled test blocks were placed on a screen tray and conditioned at 103 ± 2^{o}C to constant weight. The samples were weighed to the nearest 0.01 g after drying, recorded as W1. The test blocks were then placed on the surface of the two small glass legs colonized by fungus, two in each kolle flask. The kolle flasks inoculated with white-rot fungus were incubated at 23^{o}C and 75% relative humidity for 14 weeks. At the end of the exposure period, the test blocks were removed from the kolle flasks and their surfaces carefully brushed. The blocks were then dried to constant weight at 103 ± 2^{o}C. The blocks were weighed to the nearest 0.01 g to determine the decayed weight (W2). Weight loss was calculated as percentage of the initial sample weight (weight loss (%) = [(W1 – W2)/W1] x 100).

Mechanical Testing

Compression strength (CS) and Brinell hardness (BH) were determined according to ASTM D 143-94 (2000)^{e1} using an Instron Universal Testing machine.

Statistical Procedure

To evaluate changes in decay resistance and mechanical properties of untreated decayed, treated decayed, and untreated (un-decayed or control) poplar samples, one-way ANOVA analyses of variance were used. The effects of different concentrations of boric acid solution on decay resistance, compression strength, and Brinell hardness of the prepared samples were determined. Duncan's test was used to determine whether there was a significant difference between the groups (Table 1, 3, and 4).

RESULTS AND DISCUSSION

The results from decay resistance and mechanical properties measurements are summarized in Table 1. Each value in Table 1 is the average of four replications. The average and standard deviation of decay resistance and mechanical properties were also calculated and are summarized in Table 1.

The mean values of the variation sources that were found to be significant were compared using Duncan's test and the results are summarized in Table 2.

Table 1. The average and Standard Deviation Values for Decay Resistance and Mechanical Test Results of Poplar Wood Samples

Test Samples	Weight Loss (%)	Brinell Hardness (KN)		Compression Strength (MPa)
		Tangential	Radial	
Untreated and Un-decayed) (Control)	-	1.84 ± 0.34^{d}	1.10 ± 0.12^{c}	25.46 ± 0.02^{d}
Decayed (Untreated)	$28.59 \pm 4.92^{a*}$	0.39 ± 0.20^{a}	0.35 ± 0.04^{a}	10.42 ± 3.22^{a}
Decayed (Treated 0.5%)	1.20 ± 0.31^{b}	0.94 ± 0.11^{b}	0.83 ± 0.17^{b}	22.59 ± 0.33^{cd}
Decayed (Treated 1%)	0.68 ± 0.42^{b}	1.32 ± 0.22^{c}	1.07 ± 0.16^{c}	20.58 ± 3.04^{bc}
Decayed (Treated 2%)	0.63 ± 0.29^{b}	1.08 ± 0.18^{bc}	0.96 ± 0.14^{bc}	19.01 ± 1.11^{b}

* Superscripts in the table indicate statistically significant differences and Duncan ranking of the average value of measured property.

Table 2. One-way ANOVA Test for Decay resistance and Mechanical Tests Results of Poplar Wood Samples

(Untreated and Treated) and Decayed Test Samples	Variation Sources	Sum of Squares	df	Mean Squares	F	Sig.
Weight loss	Between Groups	2311.54	3	770.51	125.71	0.000
	Within Groups	73.55	12	6.13	-	-
	Total	2385.09	15	-	-	-
Compression strength Parallel to the grain	Between Groups	344.56	3	114.85	21.89	0.000
	Within Groups	62.97	12	5.25	-	-
	Total	407.53	15	-	-	-
Brinell hardness perpendicular to tangential surface	Between Groups	1.86	3	0.62	18.33	0.000
	Within Groups	0.41	12	0.03		
	Total	2.27	15	-	-	-
Brinell hardness perpendicular to radial surface	Between Groups	1.22	3	0.40	21.21	0.000
	Within Groups	0.23	12	0.02	-	-
	Total	1.44	15	-	-	-

Table 3. The average and Standard Deviation Values for Dry Specific Gravity Measurements of Poplar Wood Samples.

Test Samples	Weight Loss or Brinell Hardness Test Samples (gr/cm^3)		Compression Strength Test Samples (gr/cm^3)	
	Before Treatment	After Treatment	Before Treatment	After Treatment
Untreated and un-decayed (Control)	0.337 ± 0.03[d*]	-	0.35 ± 0.01[ab]	-
Decayed (Untreated)	0.322 ± 0.03[cd]	-	0.357 ± 0.03[b]	-
Decayed (Treated 0.5%)	0.297 ± 0.02[bc]	0.257 ± 0.02[a]	0.302 ± 0.03[a]	0.372 ± 0.03[bc]
Decayed (Treated 1%)	0.320 ± 0.04[cd]	0.277 ± 0.02[ab]	0.305 ± 0.03[a]	0.375 ± 0.03[bc]
Decayed (Treated 2%)	0.315 ± 0.02[cd]	0.260 ± 0.01[a]	0.332 ± 0.04[ab]	0.412 ± 0.05[c]

*Superscripts in the table indicate statistically significant differences and Duncan ranking of the average value of measured property

Table 4. The average and Standard Deviation Values for Retention Measurements of Poplar Wood Samples

Test Samples	Retention Ratio (%)	
	Weight Loss or Brinell Hardness Test Samples	Compression Strength Test Samples
Decayed (Treated 0.5%)	1.73 ± 0.31[b*]	2.02 ± 0.49[b]
Decayed (Treated 1%)	1.16 ± 0.46[ab]	1.86 ± 0.27[b]
Decayed (Treated 2%)	1.08 ± 0.38[a]	0.81 ± 0.55[a]

*Superscripts in the table indicate statistically significant differences and Duncan ranking of the average value of measured property.

The mean weight loss values obtained from the decay test were 28.60% for untreated samples and 1.20%, 0.68%, and 0.63% for treated poplar wood samples impregnated with 0.5%, 1%, and 2% boric acid solutions, respectively (Table 1).

According to the one-way ANOVA test (Table 2), the effect of boric acid on weight loss was statistically significant, but no significance was observed between poplar samples treated with any of the 3 concentrations of boric acid (0.5, 1, and 2%).

The Duncan test revealed that the mean values of compression strength parallel to the grain of the untreated decayed samples was calculated as 10.42 MPa, and the samples of poplar treated with boric acid (0.5, 1, and 2%) and decayed were calculated at 22.59 MPa, 20.58 MPa, and 19.01 MPa, respectively (Table 1). Boric acid treatment exhibited a significant effect on compression strength parallel to the grain in decayed samples, but when compared with the untreated (un-decayed or control) samples (25.46 MPa), a negative effect on compression strength parallel to grain was demonstrated. Statistically significant difference was observed between the treated decayed and the untreated (un-decayed or control) poplar wood samples.

The Brinell hardness values perpendicular to the tangential surface and Brinell hardness values perpendicular to radial surface were compared. The mean value of Brinell hardness perpendicular to tangential surface for samples treated with boric acid and decayed poplar wood samples 0.94 KN, 1.32 KN, and 1.08 KN respectively was higher than that of untreated decayed wood samples (0.39 KN). According to the results of a one-way ANOVA test (Table 2) applied to this variable, the significance level obtained for four average values (0.000) was found to be lower than the selected significance level (0.01). Boric acid treatment had a significant effect on Brinell hardness perpendicular to the tangential surface of decayed samples, but when compared with the untreated (un-decayed or control) samples (1.84 KN), had negative effect on Brinell hardness perpendicular to tangential surface. A statistically significant difference was found however between the treated decayed and the untreated (un-decayed or control) poplar wood samples.

The mean value of Brinell hardness perpendicular to the radial surface for samples the treated with boric acid and decayed poplar wood samples (0.83 KN, 1.07 KN and 0.96 KN respectively) was higher than that for the untreated decayed wood samples (0.35 KN) (Table 1). According to the results of the one-way ANOVA test (Table 2) applied to this variable, the significance level obtained for four average values (0.000) was lower than the chosen significance level (0.01). Boric acid treatment had a significant effect on Brinell hardness perpendicular to radial surface of decayed samples, but compared with the untreated (un-decayed or control) samples (1.10 KN) had a negative effect on Brinell hardness perpendicular to radial surface. No statistically significant difference was found however between the treated decayed and the untreated (un-decayed or control) poplar samples.

The Brinell hardness perpendicular to the tangential surface was higher than that for perpendicular to the radial surface in treated decayed, untreated decayed, and untreated (un-decayed or control) wood samples, and statistically significant difference was found between poplar wood samples.

Weight loss of poplar wood samples initiated by white-rot fungus was directly related to boric acid concentration. Decay by the white-rot fungus was evident for poplar samples untreated and treated with 3 concentrations of boric acid. The penetration of boric acid into treated poplar wood samples provided suitable protection against white-rot fungus, even at 0.5% concentration.

The Willitner scale showed distinct evidence of fungal colonization (100%) on the wood samples surface (Willitner 1984). However, boric acid treatment of poplar samples effectively prevented fungal growth (0%). Fungal resistance was further enhanced by an increase of boric acid concentration. This can be attributed to the suitable anti-fungal characteristics of boric acid (Yalincilic et al. 1999) and the further acidification of wood samples treated with boric acid (Yamaguchi 2001). In this study, the effect of boric acid on reduction of poplar wood samples weight loss was maximized by using boric acid at a 2% concentration. Conversely, when a treated and an untreated sample were placed in the same kolle flask, the treated sample showed little weight loss. It can be postulated that boric acid is transported through the gas phase within the kolle flask.

The compression strength parallel to the grain decreased with increasing boric acid concentration. The compression strength parallel to the grain of wood treated with boric acid at 0.5% concentration and decayed increased 53% compared with the untreated wood samples. However when the treatment was with 2% concentration of boric acid, such increase was 45%. The compression strength parallel to the grain of the poplar wood treated with boric acid at 0.5% and 2% concentration and decayed decreased by 11%, and 25%, respectively, compared with the untreated (un-decayed or control) wood samples.

CONCLUSIONS

1. Decay increased water absorption in poplar wood, affecting its mechanical properties. The severity of decay was decreased with increasing boric acid concentration.

2. Compression strength parallel to the grain is thus expected to be increased by treatment. However, the compression strength parallel to the grain was reduced compared with untreated (un-decayed or control) samples.

3. The Brinell hardness perpendicular to tangential and radial surfaces of the poplar samples treated with boric acid were significantly higher than those of the untreated wood samples. Brinell hardness perpendicular to the tangential surface of the poplar samples treated with boric acid at 0.5% concentration and decayed increased 141%, and at 1% concentration increased 238% as compared with the untreated wood samples. The Brinell hardness perpendicular to tangential surface of the poplar wood treated with boric acid at 0.5% concentration and decayed decreased 48%, and at 1% concentration decreased 28% as compared with the untreated (un-decayed or control) samples.

4. Increase in Brinell hardness perpendicular to the radial surface of the poplar wood treated with boric acid at 0.5% concentration and decayed increased 137% and at 1% concentration increased 205% compared with the untreated samples. The Brinell hardness perpendicular to the radial surface of the poplar wood treated with boric acid at 0.5% concentration and decayed decreased 18%, and at 1% concentration increased 6% as compared with the untreated (un-decayed or control) samples.

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