Construction and Building Materials 24 (2010) 2279–2284

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Some mechanical properties and decay resistance of wood impregnated with environmentally-friendly borates

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ARTICLE INFO

Article history:
Received 23 September 2009
Received in revised form 15 March 2010
Accepted 1 April 2010
Available online 27 April 2010

Keywords:
Compression strength parallel to grain
Modulus of rupture
Decay resistance
Borates
Wood
Environmentally-friendly
Impregnation

ABSTRACT

This study was made to determine some mechanical properties such as compression strength parallel to grain, modulus of rupture, and decay resistance of wood treated with some environmentally-friendly borates. Sodium tetrafluoroborate (SFB), ammonium tetrafluoroborate, (AFB), and ammonium pentaborate octahydrate (APB) were used as borates. Wood specimens were prepared from Oriental beech (*Fagus orientalis* L.) and Scots pine (*Pinus sylvestris* L.). Before tests, wood specimens were impregnated with aqueous solutions (0.25%, 0.50%, 1.50%, and 3.00%) of borates according to ASTM D 1413-76.

Results showed that compression strength parallel to grain (CSPG) and modulus of rupture (MOR) of wood specimens treated with borates were lower compared to untreated control specimen. In general, our results showed that the higher concentration levels of borates, the lower mechanical properties of wood resulted. Borate treated wood showed considerable resistance to the decay fungus compared to that of untreated control specimen.

1. Introduction

Among the construction materials which are used by people wood holds a special place because of its impressive range of attractive properties, including low thermal extension, low density and high enough mechanical strength [1]. With an increased demand for timber worldwide and moves towards fast-grown plantation species, the need to impart additional protection, usually in the form of chemical treatment, has become necessary to confer long-term performance in these wood products [2]. In recent years, there has been a rapid increase in the application of chemicals to wooden materials in order to improve their physical, mechanical, biological, and fire properties [3,4]. However, many of the effective poisonous chemicals were also questionable. Increased public concern on the environmental effect of many wood preservatives has rendered a special importance to borates as an environmentally-friendly agent [5]. Borates have several advantages as wood preservative in addition to imparting flame retardancy, providing sufficient protection against wood destroying organisms, having a low mammalian toxicity and low volatility. Moreover, they are colorless and odorless [6,7]. However, they are generally leachable from treated wood in ground contact under rainfall [8,9]. Many attempts have already been made to reduce leaching of borates from treated wood through chemical fixation of boron. To achieve a longlasting boron effect in wood, one practical approach is the chemical complexion of boron with a fixing agent capable of forming water-insoluble complexes upon dehydration in wood [10]. Lloyd et al. [11] reported that addition of polyols to borate solutions greatly increased the boron stability through borate/polyol chelate complexion. Another practical approach is to physically restrict water access in wood by impregnating by hydrophobic agents to limit boron mobility without interfering with its bioactive structure [5].

Hygroscopic nature of some boron salts may have adverse effect on dimensional stability of wood under humid service conditions and can cause strength losses at elevated temperatures at high retention levels [12,13]. Yildiz et al. [14] determined the effects of wood preservatives on MOR. There were no significant differences in MOR values between untreated (control) and Wolmanit CX-8, Tanalith-3491 impregnated wood. However, there was significant difference in MOR levels between untreated wood and ACQ-2200 and CCA impregnated wood.

Biodegradability of wood material is another criterion of wood treatment for longer serviceability. Borates provide protection against all forms of wood destroying organisms, including decay fungi (such as wet and dry rot), wood boring beetles (such as the common furniture beetle, the house longhorn beetle and powder post beetles) and termites (including dry wood and subterranean termites [15]. Temiz et al. [16] investigated decay resistance of

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0950-0618/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.conbuildmat.2010.04.028

Scots pine treated with 4-methoxytrityl tetrafluoborate (MTFB). Decay resistance tests of unleached samples showed that 2%, 1.5%, and 1% concentrations of MTFB gave less than 2% decay of *Coniophora puteana*. Kose et al. [17] investigated that the relative ability of various combinations of copper sulfate with either boric acid or calcium-precipitating agent, N′-N-(1,8-naphthalyl) hydroxylamine (NHA-Na), to inhibit fungal degradation. They found that increased efficacy of copper sulfate against the brown-rot fungus *Tyromyces palustris* was observed when either boric acid or NHA-Na was added.

This study was performed to determine CSPG, MOR, and decay resistance of wood impregnated with aqueous solutions (0.25%, 0.50%, 1.50%, and 3.00%) of sodium tetrafluoroborate (SFB) ammonium tetrafluoroborate, (AFB), and ammonium pentaborate octahydrate (APB).

2. Materials and methods

2.1. Preparation of test specimens and chemicals

Wood specimens measuring 20 (radial) × 20 (tangential) × 360 (longitudinal) mm, and 20 (radial) × 20 (tangential) × 30 (longitudinal) mm were prepared from air-dried sapwood of Oriental beech (*Fagus orientalis* L.) and Scots pine (*Pinus sylvestris* L.) for modulus of rupture and compression parallel to grain tests, respectively. For decay test, wood specimens measuring 15 (radial) × 25 (tangential) × 50 (longitudinal) mm were prepared from air-dried sapwood of Oriental beech (*F. orientalis* L.) and Scots pine (*P. sylvestris* L.). Fungal decay test was made using a white rot fungus, *Coriolus versicolor* (COV) (L. ex Fr.) Quel [FFPRI 1030]. Aqueous solutions of sodium tetrafluoroborate (SFB) ammonium tetrafluoroborate, (AFB), and ammonium pentaborate octahydrate (APB) dissolved in distilled water to concentrations of 0.25%, 0.50%, 1.50%, and 3.00%. Wood specimens were oven dried at 103 ± 2 °C before and after treatment.

2.2. Impregnation method

Wood specimens were impregnated with aqueous solutions of borates according to ASTM D 1413-76 [18]. Treatment solutions were prepared the day before the impregnation for homogenizing. A vacuum desiccator used for the impregnation process was connected to a vacuum pump through a vacuum trap. Vacuum was applied for 60 min at 760 m Hg^{-1} before supplying the solution into the chamber followed by another 60 min at 760 mm Hg^{-1} diffusion period under vacuum. Retention of boron was calculated from the following equation:

$$\text{Retention } (\text{kg/m}^3) = \frac{G \times C}{V} \times 10 \quad (1)$$

where G is the amount of solution absorbed by wood that is calculated by $T_2 - T_1$; where T_2 is weight of wood after impregnation and T_1 is weight of wood before impregnation, C is solution concentration as percentage, and V is the volume of the specimen as cm^3.

2.3. Compression strength parallel to grain

The compression strength parallel to grain test was determined according to the TS 2595 [19] standard by using a 4000-kp capacity universal test machine, and applying 6 mm/min loading time. Before tests, wood specimens had been conditioned at 20 °C and 60% RH for 6 weeks.

2.4. Modulus of rupture

The modulus of rupture (MOR) of wood specimens was determined according to TS 2474 [20]. Wood specimens had been conditioned at 20 °C and 60% RH for 6 weeks prior to testing. The MOR of wood specimens was calculated using the following formula;

$$\text{MOR} = \frac{3 \times P \times I}{2 \times b \times h^2} \text{ Nt/mm}^2 \quad (2)$$

where P is the maximum load (Nt), I is span (mm), b is width of specimen (mm), h is thickness of specimen (mm).

2.5. Decay test

Wood specimens measuring 15 (radial) × 25 (tangential) × 50 (longitudinal) mm were prepared for decay test, from air-dried sapwood of Oriental beech (*F. orientalis* L.) and Scots pine (*P. sylvestris* L.). Fungal decay test was made according to JIS A-9201 [21] using a white rot fungus, *C. versicolor* (COV) (L. ex Fr.) Quel [FFPRI 1030]. Wood specimens were sterilized with gaseous ethylene oxide after measuring the initial dry weights. The wood specimens of the same treatment were placed in a glass jar which contained medium of 250 g quartz sand + 80 ml nutrient solution was composed of 3 g $MgSO_4 \cdot 7H_2O$, 2 g KH_2PO_4, 10 g malt extract, and 5 g peptone per 1000 ml distilled water with fungal mycelia grew on it. Then, they were incubated at 26 °C for 12 weeks. Test results were expressed as percentage of mass losses of wood specimens due to fungal attacks after decay test. Ten replicates were used for each treatment groups.

2.6. Evaluations of test results

Mechanical and decay test results were evaluated by a computerized statistical program composed of analysis of variance and following Duncan tests at the 95% confidence level. Statistical evaluations were made on homogeneity groups (HG), of which different letters reflected statistical significance.

3. Results and discussion

3.1. Compression strength parallel to grain (CSPG)

The CSPG values of wood specimens are given in Table 1 and Fig. 1. The CSPG of untreated Oriental beech was higher compared to untreated Scots pine. The highest CSPG values of wood specimens were obtained as 72.70 and 61.46 Nt/mm^2 for untreated Oriental beech and Scots pine, respectively. The lowest CSPG values

Table 1
The CSPG of Oriental beech and Scots pine impregnated with borates.

Chemicals	Concentrations (%)	Oriental beech				Scots pine			
		Retention (kg/m^3)	CSPG[A] (N/mm^2)		Change (%)	Retention (kg/m^3)	CSPG[A] (N/mm^2)		Change (%)
			Mean	SD			Mean	SD	
Control	–	–	72.70^a	4.72	–	–	61.46^a	7.54	–
SFB	0.25	1.23	56.74^b	9.70	−21.96	1.06	57.16^b	8.30	−7.00
	0.50	2.69	57.81^b	8.63	−20.49	2.63	56.49^b	5.39	−8.09
	1.50	7.64	52.39^{bc}	6.72	−27.94	8.43	53.09^c	6.24	−13.62
	3.00	17.42	46.73^{cd}	8.23	−35.72	15.98	48.74^d	7.26	−20.69
AFB	0.25	1.42	65.65^a	3.44	−9.70	1.09	57.27^b	9.66	−6.82
	0.50	2.57	65.52^a	2.59	−9.88	2.58	52.26^c	9.71	−14.97
	1.50	8.22	54.37^b	9.76	−25.21	8.17	49.91^d	3.97	−18.80
	3.00	14.79	42.55^d	9.55	−41.47	11.48	47.77^d	6.69	−22.28
APB	0.25	1.40	70.48^a	1.60	−3.05	0.98	55.35^b	2.06	−9.94
	0.50	2.44	68.97^a	1.79	−5.13	2.44	55.49^b	5.23	−9.72
	1.50	7.00	55.25^b	9.03	−24.01	7.14	48.45^d	8.51	−21.17
	3.00	16.04	56.82^b	10.74	−21.85	9.89	52.87c	4.13	−13.98

Note: Small letters given as superscript over CSPG values represent HG obtained by statistical analysis with similar letters reflecting statistical insignificance at the 95% confidence level.
[A] Results reflect observations of 10 wood specimens, SD: Standard deviation.