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THE EFFECTS OF SOME IMPREGNATION PARAMETERS ON MODULUS OF RUPTURE AND MODULUS OF ELASTICITY OF WOOD

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ABSTRACT

The aim of this study was to determine the effects of some impregnation parameters such as impregnation chemicals, impregnation durations, and impregnation methods on modulus of rupture (MOR) and modulus of elasticity (MOE) of Oriental beech (*Fagus orientalis* Lipsky) and Scots pine (*Pinus sylvestris* L.). Wood specimens were prepared according to TS 2470 and impregnated with chemicals for 2, 4, and 6 hours by dipping and vacuum-pressure methods. Imersol aqua, aqueous solutions of zinc chloride, and borax were used as impregnation chemicals. After impregnation, the MOR and MOE of wood specimens were determined.

Results showed that the MOR and MOE of wood specimens were the lowest for the ones impregnated with imersol aqua followed by zinc chloride and borax, respectively. There were no statistically significant differences in MOR and MOE values among all impregnation durations and methods.

KEYWORDS: Impregnation of wood, impregnation chemicals, impregnation durations, impregnation methods, modulus of elasticity, modulus of rupture.

INTRODUCTION

A rapid increasing of an aplication of chemicals to the wooden materials in order to improve their physical, mechanical, biological and fire properties appears in the present (Anderson et al. 1991, Wen-Yu 1997, Yalinkilic et al. 1999a, Brelid et al. 2000, Chao and Lee 2003). However, wood strength is affected when wood is treated with preservatives or fire retardant (FR) chemicals (Winandy 1988). Many of the metallic oxides commonly used in water-borne preservative formulations react with the cell wall components by undergoing hydrolytic reduction upon contact with wood carbohydrates. This process, known as fixation, oxidizes the wood cell wall components and may reduce wood strength (Toussaint-Douvergne et al. 2000). The relative impact of various water-borne preservative systems is directly related to the preservative chemistry and the severity of its fixation/precipitation reaction (Winandy 1996). Water-borne preservative treatments generally reduce the mechanical properties of wood more than oil-type preservative treatments, because water-borne preservative chemicals physically react with the wood cell wall material (Fruno and Gato 1978). Modulus of elasticity MOE is a measure of the stiffness of material, while modulus of rupture MOR has proved to be a more reliable measure of strength than stress at the proportional limit. This is due to the fact that the maximum load can be determined more precisely than the proportional limit (Yalinkilic et al. 1999b). MOR may be also more constant since it is less affected by previous loads applied or by conditions imposed in testing. Thus the importance of MOR is that it expresses the greatest load the wood can carry (Brown et al. 1952). Toker et al. (2009) studied the MOR and MOE values of wood impregnated with borates such as boric acid (BA), borax (BX), and sodium perborate (SP). They found that the MOR and MOE values of wood specimens were the lowest for treatments with SP followed by BX and BA, respectively. Colakoglu et al. (2003) found that MOR and MOE levels of laminated veneer lumber treated with 1 % boric acid were reduced for 3.8 and for 5.1 % respectively compared to untreated control. Yildiz et al. (2004) reported 12 % decrease in MOR of yellow pine wood specimens treated with CCA and there were no significant difference in MOE between untreated and CCA impregnated wood.

This study was designed to determine the effects of some impregnation chemicals, impregnation durations, and impregnation methods on MOR and MOE of Oriental beech (*Fagus orientalis* Lipsky) and Scots pine (*Pinus sylvestris* L.).

MATERIAL AND METHODS

Preparation of test specimens and chemicals

Specimens of both wood species were cut from the sapwood of logs having dimensions of 550 × 50 × 21 mm with rough surfaces, according to TS 2470 (1976). Accordingly, knotless, normally grown (free from reaction wood as well as insect or fungal decay) specimens were selected. Five percentile solutions of zinc- chloride and borax dissolved in distilled water were prepared. imersol aqua is a non-flammable, odourless, fluent, water based, completely water soluble, noncorrosive material with a pH value of 7 and a density of 1.03 g.cm^{-3}. It is available as ready-made solution (Atar 2008).

Impregnation method

Wood specimens were impregnated with dipping and vacuum-pressure method according to ASTM D 1413-07 (2007). For dipping method, a tank of 60 cm in diameter and 120 cm in length containing specimens was filled with the prepared impregnating solutions. The specimens were dipped under normal atmospheric conditions. For pressure method, after an 84601 Pa pre-vacuuming for 60 minutes, the impregnation solution was added to the tank and a pressure of 405.3 kPa was applied. Wood specimens were pressured for 2, 4, and 6 hours for both impregnation methods. After the impregnation process, the test specimens were conditioned at 20 ± 2 ^{0}C and 65 ± 3 % relative humidity in a conditioning room until constant mass.

Modulus of rupture and modulus of elasticity

The modulus of rupture (MOR) and modulus of elasticity (MOE) of wood specimens were determined according to TS 2474 (1976) and TS EN 310 (1999), respectively. Wood specimens were conditioned at 20 °C and 65 ± 3 % RH for 6 weeks prior to testing. The MOE and MOR of wood specimens impregnated with impregnation chemicals were calculated according to formulas (2) and (3):

$$MOR = \frac{3xPxI}{2xbxh^2} \quad (N.mm^{-2}) \tag{1}$$

$$MOE = \frac{dPxI^3}{4xbxh^3xdY} \quad (N.mm^{-2}) \tag{2}$$

where: P is the maximum load (N), I is span (mm), b is width of specimen (mm), h is thickness of specimen (mm), dP is load to proportional limit (mm), and dY is deflection (mm).

RESULTS AND DISCUSSION

MOR of Scots pine and Oriental beech wood

MOR of untreated Oriental beech was higher than of untreated Scots pine. The highest MOR of 123.90 $N.mm^{-2}$ was obtained for Oriental beech treated with zinc-chloride for two hours dipping method. The highest MOR of 81.50 $N.mm^{-2}$ was obtained for Scots pine treated with borax for two hours by dipping method. In general, Oriental beech had higher MOR than Scots pine. MOR was the lowest for wood specimens treated with imersol aqua followed by zinc-chloride and borax, respectively. In order to determine the effects of impregnation chemicals, impregnation durations and impregnation methods on MOR, ANOVA tests were made and homogeneity groups were tested using SPSS 15.0 statistical software package. No significant differences were found in MOR between untreated wood and wood treated with borax and zinc-chloride for both wood species. However, there was a significant difference in MOR between control and imersol aqua treated wood. In the same time, there were no significant differences in MOR values among all impregnation durations and methods (Tabs. 1, 2, 3, 4).

Ayrilmis et al. (2005) reported that MOR of OSB panels treated with 2, 4, and 6 percent water solutions of boric acid were significantly lower compared to untreated control specimen. Yildiz et al. (2004) studied the effects of wood preservatives on MOR. They reported no significant differences in MOR between untreated and wood impregnated with Wolmanit CX-8 and Tanalith-3491. However, there was a significant difference in MOR levels between untreated wood and ACQ-1900, ACQ-2200, and CCA impregnated wood. Hesp and Watson (1964) determined the mechanical properties of Scots pine impregnated with CCA. They found some reductions in MOR of Scots pine, but these reductions have little practical importance.

In this study, MOR of wood specimens treated with impregnation chemicals was lower than of untreated control. However, only imersol aqua treatment significantly decreased MOR compared to untreated control specimen

Tab. 1: The MOR and MOE values of Scots pine and Oriental beech[a]

Wood species	Periods	Methods	Impregnation solutions	MOR[a] ($N.mm^{-2}$)	MOE[a] ($N.mm^{-2}$)
Scots pine			Control	77.93	9272.88
	2 hours	Dipping	Imersol aqua	75.63	9053.64
			Borax	81.50	9734.86
			Zinc-chloride	75.68	8672.06
		Pressure	Imersol aqua	75.04	8748.54
			Borax	80.84	9302.4
			Zinc-chloride	75.24	9538.34
	4 hours	Dipping	Imersol aqua	74.55	8579.35
			Borax	78.92	9682.93
			Zinc-chloride	74.8	9044.49
		Pressure	Imersol aqua	74.95	9644.71
			Borax	81.11	10415.87
			Zinc-chloride	76.13	9145.6
	6 hours	Dipping	Imersol aqua	79.51	9409.94
			Borax	77.88	9699.68
			Zinc-chloride	75.23	8915.07
		Pressure	Imersol aqua	74.55	8960.58
			Borax	74.21	9522.11
			Zinc-chloride	78.07	9637.04
Oriental beech			Control	121.25	13002.49
	2 hours	Dipping	Imersol aqua	105.68	11270.52
			Borax	109.49	11873.09
			Zinc-chloride	123.90	12777.12
		Pressure	Imersol aqua	105.43	11855.88
			Borax	115.86	13283.06
			Zinc-chloride	115.01	12617.26
	4 hours	Dipping	Imersol aqua	123.54	12950.39
			Borax	114.05	13623.75
			Zinc-chloride	115.39	13139.32
		Pressure	Imersol aqua	105.34	12132.98
			Borax	119.74	12869.28
			Zinc-chloride	105.41	12020.11
	6 hours	Dipping	Imersol aqua	123.31	13326.06
			Borax	116.35	12238.81
			Zinc-chloride	114.34	12148.68
		Pressure	Imersol aqua	95.89	11150.94
			Borax	116.89	13053.1
			Zinc-chloride	118.83	12897.31

[a]Results reflect observations of ten wood specimens

Tab. 2: Duncan test results of effects of impregnation chemicals on MOR ($N.mm^{-2}$)

Chemicals	Mean	Homogeneity groups*
Control (Untreated)	99.59	A
Borax	97.24	A B
Zinc-chloride	95.67	A B
Imersol aqua	92.78	B

* Similar letters reflecting statistical insignificance at the 95 % confidence level.

Tab. 3: Duncan test results of effects of impregnation durations on MOR (N.mm^{-2})

Chemicals	Mean	Homogeneity groups
Control (Untreated)	99.59	A
2 hours	95.42	A
4 hours	95.33	A
6 hours	94.94	A

* Similar letters reflecting statistical insignificance at the 95 % confidence level.

Tab. 4: Duncan test results of effects of impregnation methods on MOR (N.mm^{-2})

Chemicals	Mean	Homogeneity groups
Control (Untreated)	99.59	A
Dipping method	96.65	A
Pressure method	93.81	A

* Similar letters reflecting statistical insignificance at the 95 % confidence level.

MOE of Scots pine and Oriental beech wood

The MOE of untreated Oriental beech was higher than the MOE of untreated Scots pine. MOE of untreated Scots pine was 9272.88 N.mm^{-2} while untreated Oriental beech had MOE of 13002.49 N.mm^{-2}. The highest MOE of 13623.75 N.mm^{-2} was obtained for Oriental beech when treated with borax for four hours by dipping method. The highest MOE of 10415.87 N.mm^{-2} was obtained for Scots pine when treated with borax for four hours by vacuum-pressure method. The MOE were the lowest for specimens treated with imersol aqua followed by zinc-chloride and borax, respectively (Tab. 5).

In order to determine the effects of impregnation chemicals, impregnation durations, and impregnation methods on MOE values, ANOVA tests were made and homogeneity of groups was tested using the same statistical software. No significant differences were found in MOE between untreated and wood treated with borax and zinc-chloride. However, there was a significant difference in MOE between untreated control specimen and imersol aqua treated wood for both wood species (Tab. 5).

Tab. 5: Duncan test results of effects of impregnation chemicals on MOE (N.mm^{-2})

Chemicals	Mean	Homogeneity groups
Control (Untreated)	11274.91	A
Borax	11137.69	A B
Zinc-chloride	10879.37	A
Imersol aqua	10590.29	B

* Similar letters reflecting statistical insignificance at the 95 % confidence level.

There were no significant differences in MOE among all impregnation durations and methods of both wood species (Tabs. 6, 7).

Tab. 6: Duncan test results of effects of impregnation durations on MOE (N.mm^{-2})

Chemicals	Mean	Homogeneity groups
Control (Untreated)	11137.69	A
2 hours	10727.23	A B
4 hours	11104.06	A
6 hours	10913.28	B

* Similar letters reflecting statistical insignificance at the 95 % confidence level.

Tab. 7: Duncan test results of effects of impregnation methods on MOE (N.mm^{-2})

Chemicals	Mean	Homogeneity groups
Control (Untreated)	11137.69	A
Dipping method	10896.65	A
Pressure method	10922.06	A

* Similar letters reflecting statistical insignificance at the 95 % confidence level.

Wu et al. (2002) reported that the specific modulus of elasticity of borate-modified oriented strain board was affected a little at room condition by borate up to the 3.5 % boric acid equivalent (BAE) level. Colakoglu et al. (2003) reported that MOE values of laminated veneer lumber treated with 1 % boric acid were reduced for 5.1 % compared to untreated control specimen. Gerhards (1970) found that fire retardant chemical treatment and kiln-drying reduce the MOE of wood for 5 % in average.

Results of this research showed that all impregnation chemicals cause decrease in MOE of both wood species. However, only imersol aqua treatment significantly decreased MOE of both wood species compared to untreated control specimen.

Increased public concern on the environmental effects of many wood preservatives has rendered special importance to boron compounds as an environmentally friendly agent. As boron containing wood preservative, borax is one of the most common compounds that has found many application areas in the wood preservation industry. Additionally, it has biocide properties against all forms of wood destroying organisms and carries fire retardancy properties (Hafızoglu et al. 1994, Baysal 1994).

CONCLUSIONS

The modulus of rupture and modulus of elasticity of untreated wood specimens were higher than of treated ones. The modulus of rupture and modulus of elasticity of wood specimens were the lowest when impregnated with imersol aqua, followed by zinc-chloride and borax, respectively. The results showed that only imersol aqua treatment significantly decreased the modulus of rupture and modulus of elasticity of wood specimens compared to untreated control specimen. No significant differences were observed in modulus of rupture and modulus of elasticity among all impregnation durations and methods. Among the impregnation chemicals: borax, boron containing wood preservative, gave the highest modulus of rupture and modulus of elasticity of both wood species.

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