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SOME MECHANICAL PROPERTIES OF WOOD IMPREGNATED WITH ENVIRONMENTALLY-FRIENDLY BORON AND COPPER BASED CHEMICALS

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ABSTRACT

The aim of this study was made to determine some mechanical properties such as compression strength parallel to grain (CSPG), modulus of rupture (MOR), and modulus of elasticity (MOE) of wood treated with some boron and copper based wood preservatives. Boric acid (BA), borax (BX), and boric acid and borax mixture were used as boron compounds. Adolith- KD 5 (Ad-KD) and tanalith-e (TN-E) were used as copper based wood preservatives. Also, copper- chromium-boron (CCB) was used as boron and copper containing wood preservative. Wood specimens were prepared from Oriental beech (*Fagus orientalis* L.) and Scots pine (*Pinus sylvestris* L.). Before tests, wood specimens were treated with aqueous solutions 4 percent of chemicals according to ASTM D 1413-76.

Our results showed that CSPG, MOR, and MOE of wood specimens treated with chemicals were lower compared to untreated control specimen. Preservative treatments caused the most decrease in MOR followed by CSPG and MOE of both wood specimens, respectively. While the lowest CSPG and MOR of both wood specimens were obtained impregnated with BA, TN-E gave the best results in terms of CSPG, MOR, and MOE of both wood specimens.

KEYWORDS: Boron, copper based chemicals, wood, CSPG, MOR, MOE.

INTRODUCTION

Wood has been popularly and favourably used as a decorative material owing to its aesthetic appearance and characteristic properties (Chang and Chang 2001). Because of its strong physical strength, aesthetically pleasing characters and low processing cost, wood is the most preferred building material (Deka and Saikia 2000). However, wood is much more easily degraded by environmental agencies, including fire, biological organisms, water and light, than man-made materials (Kiguchi and Evans 1998). These problems can be partially overcome by modification or impregnation of the wood (Tomak et al. 2011). A large of preservative compounds have been introduced on to the market; however many of them not gained acceptance either because of chemical toxicity, low efficacy, high cost, or corrosiveness (Murphy 1990). Boron compounds are well known preservative chemicals for timber protection. They are recognized as cheap, easily applicable, biologically active, flame retardant and, more importantly, environmentally safe preservatives and have been used for timber preservation since the early twentieth century (Williams 1990; Lloyd 1993, Laks and Manning 1994). Boric acid (BA) and borax (BX) are the most common boron compounds which have found many application areas in the wood preservation industry in order to obtain the benefit of their biological effectiveness and fire retardancy (Hafizoglu et al. 1994, Baysal 1994). Boric acid and borax mixtures have some efficacy in retarding flame spread on wood surfaces. In addition to the usual char forming catalytic effect, they have a rather low melting point and form glassy films when exposed to high temperatures in fires (Nussbaum 1988).

Many of the alternative preservatives contain copper as their active ingredient against fungal decay. Copper compounds are very effective against numerous fungi and are the basis of numerous formulations of wood preservatives (Mourant et al. 2008). The focus on copper-based preservatives has increased following concerns about environmental effects of chromium and arsenic and resulting restrictions on the use of chromated copper arsenate (CCA) (Freeman and McIntyre 2008).

Wood strength is affected when wood is treated with preservatives or fire retardant chemicals (Winandy 1988). The relative impact of various waterborne preservative systems is directly related to the system's chemistry and the severity of its fixation/precipitation reaction (Winandy 1996). Colakoglu et al. (2003) reported that boric acid treatment had no remarkable effect on compression strength in longitudinal direction of laminated veneer lumber (LVL). Winandy (1988) noted that the effects of fire retardant treatments on mechanical properties of Douglas-fir and aspen plywood. They found that FR treatment did not affect modulus of elasticity (MOE) of both species, whereas it reduced the other mechanical properties. Winandy et al. (1988) investigated that the effects of fire retardant treatments on mechanical properties of Douglas-fir and aspen plywood. They found that copper zinc chlorite treatment had a far greater negative effect than did the other fire retardant treatments.

The aim of this study is to evaluate the effects of boron and copper based preservative treatments on CSPG, MOR, and MOE of wood.

MATERIAL AND METHODS

Preparation of test specimens and chemicals

Air-dried sapwood specimens of Oriental beech and Scots pine were prepared for impregnation treatment with dimensions of 20 (radial) x 20 (tangential) x 360 (longitudinal) mm for MOR and MOE tests, 20 (radial) x 20 (tangential) x 30 (longitudinal) mm for CSPG test. Aqueous solution of chemicals dissolved in distilled water to concentration of 4 percent. Wood samples were oven dried at 103±2°C before and after treatment.

Impregnation method

Wood specimens were treated with 4 percent aqueous solution of adolith-KD 5 (Ad-KD), tanalith-E (TN-E), copper chromium boron (CCB), boric acid (BA), borax (BX), and BA+BX mixture (1:1; w/w) according to ASTM D 1413 (1976). Retention was calculated from the following equation:

$$\text{Retention} = \frac{G \times C}{V} \times 10 \qquad (kg.m^{-3}) \tag{1}$$

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

Compression strength parallel to grain (CSPG)

The compression strength parallel to grain test was performed according to the TS 2595 (1977) standard. Before test, wood specimens had been conditioned at 20°C and 60 % RH for six weeks.

Modulus of rupture and modulus of elasticity (MOR and MOE)

The modulus of rupture and modulus of elasticity of wood specimens were performed according to TS 2474 (1976) and TS EN 310 (1999), respectively. Wood samples had been conditioned at 20°C and 60 % RH for six weeks prior to testing. The MOR and MOE of wood samples treated with chemicals were calculated using the following equations;

$$MOR = \frac{3 \times P \times I}{2 \times b \times h^2} \qquad (N.mm^{-2}) \tag{2}$$

$$MOE = \frac{P \times I^3}{4 \times b \times h^3 \times Y} \qquad (N.mm^{-2}) \tag{3}$$

where: P - the maximum load (N),
I - span (mm),
b - the width of specimen (mm),
h - thickness of specimen (mm),
Y - the deflection (mm).

Evaluations of tests results

Tests 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.

RESULTS AND DISCUSSION

CSPG of boron and copper based preservatives treated wood

The compression strength parallel to grain (CSPG) values of wood specimens are given in Tab. 1 and Fig. 1. The compression strength parallel to grain value of untreated beech was higher compared to untreated Scots pine. The highest CSPG values of wood specimens were recorded as 47.43 and 57.20 $N.mm^{-2}$ for untreated Scots pine and Oriental beech, respectively. The lowest CSPG of wood specimens were recorded as 42.27 and 51.49 $N.mm^{-2}$ impregnated with BA for Scots pine and Oriental beech, respectively. Our results showed that preservative treatments decreased the CSPG values of both wood specimens. While the CSPG values were the lowest for the both wood specimens impregnated with BA, the CSPG values were the highest for wood specimens treated with TN-E. Research has shown that some preservatives, especially waterborne preservatives, have a negative impact on mechanical properties of the wood that is treated to be protected (Mourant et al. 2008). Toker et al. (2008) investigated that compression strength of Calabrian pine and Oriental beech wood treated with some aqueous solutions (1, 2, 3, 4, 5, and 6 %) of borates. They noted that there was a statistical difference in compression strength parallel to grain values between untreated wood and treated with all concentrations of borates. Simsek et al. (2010) reported that borate treatments decreased 3.05–41.47 % and 7.00–22.28 % of CSPG for Oriental beech and Scots pine, respectively.

Tab. 1: The CSPG of Scots pine and Oriental beech wood treated with boron and copper based chemicals.

Wood species	Impregnation chemicals	Retention ($kg.m^{-3}$)	CSPG ($N.mm^{-2}$)			Change (%)
			Mean ± SD			
Scots pine	Control (Untreated)	-	47.43	±	2.7^{a}	-
	Ad-KD 5	26.8	44.28	±	2.5^{ab}	-6.64
	TN-E	30.4	45.83	±	3.7^{ab}	-3.37
	CCB	25.4	44.40	±	2.7^{ab}	-6.38
	BA+BX	28.8	43.69	±	5.3^{ab}	-7.88
	BX	24.6	43.43	±	4.1^{ab}	-8.43
	BA	29.5	42.27	±	3.5^{b}	-10.87
Oriental beech	Control (Untreated)	-	57.20	±	5.5^{a}	-
	Ad-KD 5	22.8	53.43	±	3.3^{ab}	-6.59
	TN-E	25.4	55.24	±	3.1^{ab}	-3.42
	CCB	28.1	54.65	±	2.0^{ab}	-4.45
	BA+BX	21.1	52.80	±	5.0^{ab}	-7.69
	BX	22.7	53.47	±	3.5^{ab}	-6.52
	BA	20.1	51.49	±	3.1^{b}	-9.98

Note: Five replications were made for each group. Small letters given as superscript over CSPG values represent homogeneity groups (HG) obtained by statistical analysis with similar letters reflecting statistical insignificance at the 95 % confidence level.

SD: Standard deviation.

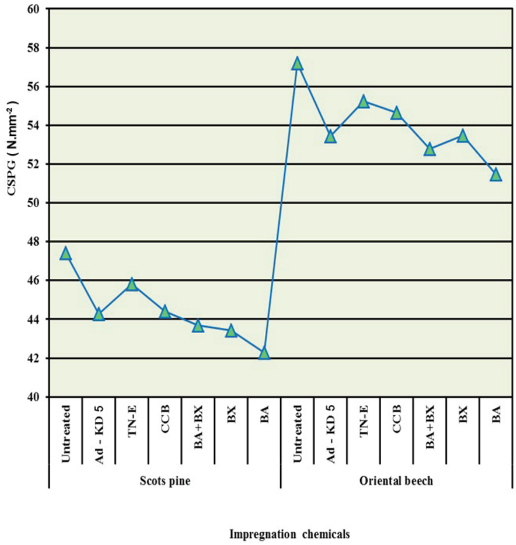

Fig. 1: The CSPG of Scots pine and Oriental beech impregnated with boron and copper based chemicals.

Bal (2006) investigated that CSPG of Scots pine impregnated with copper based wood preservative such as ACQ. He found that ACQ treatments decreased 1-3 % of CSPG of Scots pine. But, there was no significant difference between untreated and ACQ treated wood specimens. Our results showed that all treated wood species have less CSPG values compared to untreated control. In our study, preservative treatments decreased 3.37-10.87 % and 3.42-9.98 % of CSPG for Scots pine and Oriental beech, respectively. However, with the exception of BA treated both wood specimens, there were no statistical differences between treated and untreated wood.

MOR and MOE of boron and copper based preservatives treated wood

The MOR and MOE values of Scots pine and Oriental beech are given in Tab. 2. The MOR and MOE values of untreated both wood specimens were higher compared to treated both wood specimens. The highest MOR and MOE values were recorded as 83.83 and 132.07; and 8081 and 10267 $N.mm^{-2}$ for untreated Scots pine and Oriental beech, respectively. The lowest MOR values were recorded as 71.64 and 109.20 $N.mm^{-2}$ for Scots pine and Oriental beech treated with BA, respectively (Fig. 2). The lowest MOE values were recorded as 7502 and 9025 $N.mm^{-2}$ treated with CCB for Scots pine and impregnated with BX for Oriental beech, respectively (Fig. 3). Our results showed that preservative treatments decreased the MOR of both wood specimens. In our study, preservative treatments decreased 0.45-14.54 % of MOR for Scots pine. However, with the exception of BA treated both wood specimens, there were no statistical differences between Scots pine treated and Scots pine untreated wood. Also, preservative treatments decreased 1.25-17.31 % of MOR for Oriental beech. With the exception of TN-E treated Oriental beech wood specimens, there were statistical differences between Oriental beech treated and Oriental beech untreated wood specimens. Ayrilmis et al. (2005) found that MOR values of OSB panels impregnated with 2, 4, and 6 % of boric acid treatments were significantly decreased when compared to untreated control specimens. Toker et al. (2009) investigated MOR levels

Tab. 2: The MOR and MOE of Scots pine and Oriental beech wood treated with boron and copper based chemicals.

Wood species	Impregnation chemicals	Retention ($kg.m^{-3}$)	MOR ($N.mm^{-2}$) Mean ± SD			Change (%)	MOE ($N.mm^{-2}$) Mean ± SD			Change (%)
Scots pine	Control (Untreated)	-	83.83	±	9.4[a]	-	8081	±	1125[a]	-
	Ad-KD 5	23.6	76.05	±	8.8[ab]	-9.28	7540	±	247[a]	-6.69
	TN-E	25.5	83.45	±	9.4[a]	-0.45	7942	±	379[a]	-1.75
	CCB	26.1	74.89	±	6.3[ab]	-10.66	7502	±	261[a]	-7.16
	BA+BX	29.4	73.61	±	4.8[ab]	-12.19	7726	±	549[a]	-4.39
	BX	26.6	74.05	±	6.8[ab]	-11.66	7661	±	507[a]	-5.19
	BA	24.9	71.64	±	3.4[b]	-14.54	7524	±	213[a]	-6.89
Oriental beech	Control (Untreated)	-	132.07	±	8.6[a]	-	10267	±	1784[a]	-
	Ad-KD 5	20.4	112.66	±	9.8[c]	-14.69	9220	±	407[a]	-10.20
	TN-E	23.1	130.41	±	7.9[ab]	-1.25	9834	±	1158[a]	-4.22
	CCB	20.4	120.45	±	11.5[bc]	-8.79	9468	±	2395[a]	-7.79
	BA+BX	23.4	110.64	±	7.8[c]	-16.22	9182	±	137[a]	-10.57
	BX	24.3	112.27	±	9.1[c]	-14.99	9025	±	486[a]	-12.10
	BA	22.5	109.20	±	6.7[c]	-17.31	9065	±	670[a]	-11.71

Note: Five replications were made for each group. Small letters given as superscript over MOR and MOE values represent homogeneity groups (HG) obtained by statistical analysis with similar letters reflecting statistical insignificance at the 95% confidence level.

SD: Standard deviation.

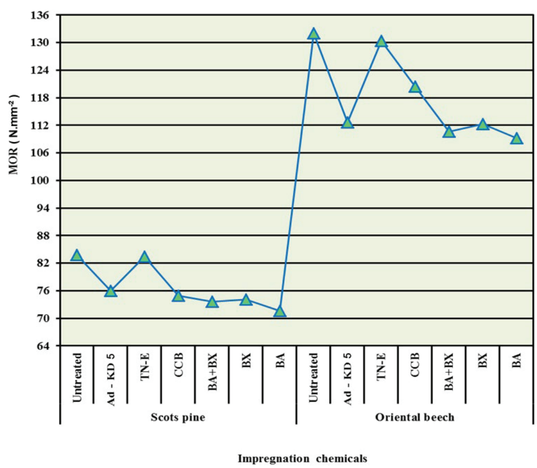

Fig. 2: The MOR of Scots pine and Oriental beech impregnated with boron and copper based chemicals.

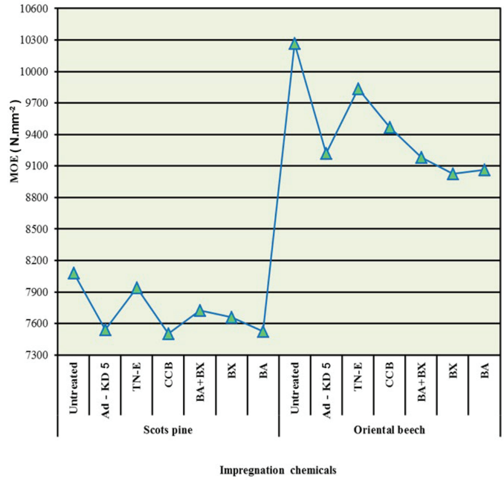

Fig. 3: The MOE of Scots pine and Oriental beech impregnated with boron and copper based chemicals.

of Scots pine and Oriental beech wood impregnated with some aqueous solutions of boric acid, borax, and sodium perborate. They reported that MOR levels of borate treated both wood specimens were lower compared to untreated both wood specimens. Our results are in good agreement with data from Ayrilmis et al. (2005) and Toker et al. (2009). According to our results, the MOE values of untreated both wood specimens were higher than that treated both wood specimens. But, there were no statistical differences between treated and untreated both wood specimens. Colakoglu et al. (2003) found that MOE values of laminated veneer lumber impregnated with 5 % boric acid were reduced 3.8 % compared to untreated control specimen. But, these reductions are of little practical consequence. Yildiz et al. (2004) studied the effects of some copper based wood preservatives on MOE. They found that there were no significant differences in MOE values between untreated and ACQ, CCA and Tanalith E 3491 treated wood. Winandy et al. (1985) reported that air – drying of small clear specimens of CCA-treated 0.25 to 1.0 pcf southern pine had no significant effect on MOE. Our results are consistent with the findings of the aforementioned studies.

MOE is a measure of the stiffness of a material while MOR has proved to be a more reliable measure of strength than stress at the proportional limit. This is due largely to the fact that the maximum load can be determined more precisely than the proportional limit (Brown et al. 1952). Therefore, MOR and MOE values have crucial importance for designing wood constructions (Yildiz et al. 2004).

CONCLUSIONS

This study was performed to determine some mechanical properties such as CSPG, MOR, and MOE of Scots pine and Oriental beech impregnated with environmentally-friendly boron and copper based wood preservatives.

In our study, waterborne type preservatives such as boron and copper based chemicals were used. Waterborne preservative formulations do react with the cell wall components and can cause cell wall hydrolysis, and this reaction causes strength reduction (Winandy 1988). Our results showed that preservative treatments contributed to lower CSPG, MOR and MOE of both wood specimens. The CSPG and MOR values were the lowest for both wood specimens impregnated with BA. In impregnation chemicals, TN-E gave the best results in terms of CSPG, MOR and MOE of both wood specimens. The National Design Specification for Wood Construction requires a 10–20 % reduction in allowable design stress, depending on mechanical property under consideration (NFPA 1986). Our results showed that preservative treatments decreased 3.37-10.87 % and 3.42-9.98 of CSPG for Scots pine and Oriental beech, respectively. It decreased 0.45–14.54 % and 1.25–17.31 % of MOR for Scots pine and Oriental beech, respectively. Also, it decreased 1.75–6.89 % and 4.22–12.10 % of MOE for Scots pine and Oriental beech, respectively. Therefore, our results met the NFPA requirements for design purposes.

In conclusion, the variety of copper-based wood preservatives has increased in recent years since copper exhibits good biocidal activity and environmental effects of chromium and arsenic and resulting restrictions on the use of chromated copper arsenate (CCA) (Freeman and McIntyre 2008). Also, boron compounds can be considered as safe and environmentally friendly fire retardant chemicals and wood preservatives (Wen-Yu 1997). Thus, boron and copper based wood preservatives treated wood may be of advantage in fire resistance as well as decay resistance in wood constructions.

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REFERENCES

1. ASTM D 1413, 1976: Standard test method of testing wood preservatives by laboratory soil block cultures.
2. Ayrilmis, N., Kartal, S.N., Laufenberg, T.L., Winandy, J.E., White, R.H., 2005: Physical and mechanical properties and fire, decay, and termite resistance of treated oriented strand board. Forest Prod. J. 55(5): 74-81.
3. Bal, B.C., 2006: Investigation of some physical and mechanical properties of Scots pine (*Pinus sylvestris* L.) wood treated with ammonical copper quat (ACQ). Department of Forest Industrial Engineering, M.Sc. Thesis, Kahramanmaras Sutcu Imam University, 73 pp.
4. Baysal, E., 1994: Some physical properties of Calabrian pine wood treated with borates and water repellents. M.Sc. Thesis, Karadeniz Technical University, 114 pp.
5. Brown, H.P., Panshin, A.J., Forsaith, C.C., 1952: Textbook of Wood Technology. Vol. II. The physical, mechanical, and chemical properties of the commercial woods of the United States.1st ed. McGraw-Hill Book Company, Inc., New York, 783 pp.
6. Chang, H.T., Chang, S.T., 2001: Correlation between softwood discoloration induced by accelerated lightfastness testing and by indoor exposure. Polymer Degradation and Stability 72(2): 361-365.
7. Colakoglu, G., Colak, S., Aydin, I., Yildiz, U.C., Yildiz, S., 2003: Effects of boric acid treatment on mechanical properties of laminated beech veneer lumber. Silva Fennica 37(4): 505-510.

8. Deka, M., Saikia, C.N., 2000: Chemical modification of wood with thermosetting resin: Effect on dimensional stability and strength property. Bioresource Technology 73(2): 179-181.
9 Freeman, M.H., McIntyre, C.R., 2008: A comprehensive review of copper based wood preservatives: With a focus on new micronized or dispersed copper systems. Forest Prod. J. 58(11): 6-27.
10. Hafizoglu, H., Yalinkilic, M.K., Yildiz, U.C., Baysal, E., Demirci, Z., Peker, H., 1994: Utilizations of Turkey's boron reserves in wood preservation industry. Project of the Scientific and Technical Research Council of Turkey, No: TOAG-875, 377 pp (in Turkish).
11. Kiguchi, M., Evans, P.D., 1998: Photostabilization of wood surface using a grafted benzophenone UV absorber. Polymer Degradation and Stability 61(1): 33-45.
12. Laks, P.E., Manning, J.D., 1994: Inorganic borates as preservative systems for wood composites. In: Proceedings of the 2nd Pacific Rim Bio-based symposium, Vancouver, Canada. Pp 236-244.
13. Lloyd, J.D., 1993: The mechanisms of action boron-containing wood preservatives. Ph.D. Thesis. Imperial College of Science, London, 352 pp.
14. Mourant, D., Yang, D.Q., Riedl, B., Roy, C., 2008: Mechanical properties of wood treated with PF-pyrolytic oil resins. Holz als Roh- und Werkstoff 66(3): 163-171.
15. Murphy, R.J., 1990: Historical perspective in Europa. Proceedings of the first international conference on wood protection with diffusible preservatives, Ed. M. Hamel, 28-30 Nov. Nashville, Tennessee. Pp 9-13.
16. NFPA, 1986: National design specification for wood construction. Washington (DC): National Forest Products Association.
17. Nussbaum, R.M., 1988: The effect of low concentration fire retardant impregnations on wood charring rate and char yield. J. Fire Sci. 6(4): 290-307.
18. Simsek, H., Baysal, E., Peker, H., 2010: Some mechanical properties and decay resistance of wood impregnated with environmentally-friendly borates. Constr. Build. Mater. 24(11): 2279-2284.
19. Toker, H., Baysal, E., Ozcifci, A., Altinok, M., Sonmez, A., Yapici, F., Altun, S., 2008: An investigation on compression parallel to grain values of wood impregnated with some boron compounds. Wood Research 53(4): 59-68.
20. Toker, H., Baysal, E., Simsek, H., Senel, A., Sonmez, A., Altinok, M., Ozcifci, A., Yapici, F., 2009: Effects of some environmentally-friendly fire-retardant boron compounds on modulus of rupture and modulus of elasticity of wood. Wood Research 54(1): 77-88.
21. Tomak, E.D., Viitanen, H., Yildiz, U.C., Hughes, M., 2011: 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. J. Mater. Sci. 46(3): 608-615.
22. TS 2474, 1976: Wood-determination of ultimate strength in static bending.
23. TS 2595, 1977: Wood-testing in compression parallel to grain.
24. TS EN 310, 1999: Wood based panels. The determination of static bending strength and modulus of elasticity.
25. Wen-Yu Su, 1997: Development of fire-retardant wood composites using boron compounds and their evaluation methods. Ph.D. Thesis, Kyoto University, Kyoto, Japan.
26. Williams, L.H., 1990: Potential benefits of diffusible preservatives for wood protection: An analysis with emphasis on building protection. In: 1st international conference on wood protection with diffusible preservatives, 28–30 Nov. TN, USA, Proceedings 47355. Pp 29-34.

27. Winandy, J.E., Boone, R.S., Bendsten, B.A., 1985: The interaction of CCA preservative treatment and redrying: Effects on the mechanical properties of southern pine. Forest Prod. J. 35(10): 62-68.
28. Winandy, J.E., 1988: Effects of treatment and redrying on mechanical properties of wood. In: Proc. of conf. on wood protection and the use of treated wood in construction. M. Hamel, ed. Memphis, TN, Oct 28-30, 1987 by Forest Prod. Res. Soc., Madison, WI. Pp 54-62.
29. Winandy, J.E., LeVan, S.L., Schaffer, E.L., Lee, P.W., 1988: Effect of fire-retardant treatment and redrying on the mechanical properties of Douglas- fir and aspen plywood. Res. Pap. FPL-RP-485. Madison WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, 20 pp.
30. Winandy, J.E., 1996: Effects of treatment, incising, and drying on mechanical properties of timber. In: Proceedings, National conference on wood transportation structures-new wood treatments; 1996 October 23-25; Ritter, Michael A.; Duwadi, Shella Rimal; Lee, Paula D. Hilbrich, eds., Madison, WI. Madison, WI: USDA Forest Service, Forest Products Laboratory. Gen. Tech. Rep. FPL-GTR 94: 371-378.
31. Yildiz, U.C., Temiz, A., Gezer, E.D., Yildiz, S., 2004: Effects of wood preservatives on mechanical properties of yellow pine (*Pinus sylvestris* L.) wood. Building and Environment 39(9): 1071-1075.

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