WOOD RESEARCH
54 (2): 2009
117-126

THE EFFECT OF TREATMENT TIME ON DIMENSIONALLY STABILITY, MOISTURE CONTENT AND MECHANICAL PROPERTIES OF HEAT TREATED ANATOLIAN CHESTNUT (*CASTANEA SATIVA* MILL.) WOOD

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ABSTRACT

In this study, the effect of treatment time on dimensional stability, moisture content, and mechanical properties of heat-treated Anatolian chestnut (*Castanea sativa* Mill.) were investigated. Test specimens were subjected to a temperature of 180°C at atmospheric pressure for five different treatment times (2, 4, 6, 8, and 12 hours). After the heat treatment of the specimens was completed, their moisture contents at relative humidity (RH) conditions of 45, 55, 65, 80, and 95%, their dimensional stabilities, their mechanical properties, e.g., bending strength, modulus of elasticity, and compression strength, were determined. The data obtained were analyzed using variance analysis, and then the statistical analysis of Tukey's test was conducted. The results showed that heat treatment resulted in decreased (i.e., improved) moisture content, enhanced dimensional stability, and reductions of the mechanical properties. The decrease of mechanical properties that resulted from the 12-hour test was greater than the reductions observed for the tests that lasted 2, 4, 6, and 8 hours.

KEY WORDS: treatment time, anatolian chestnut, mechanical properties, moisture content

INTRODUCTION

Heat treatment of wood is known to improve wood properties by reducing hygroscopicity, improving dimensional stability, and enhancing the resistance against biological attack. Nowadays, in Europe, the heat treatment of wood is conducted successfully on an industrial scale using steam, nitrogen, or oil as the heat-transfer and oxygen-excluding medium (Boonstra et al. 1998, Militz 2002). Another important aspect of heat-treated wood is strength reduction. According to Viitaniemi (1997), the effects of heat treatment of wood at temperatures between 185°C and 250°C are reduction of moisture content (MC) by 43 – 60%, reduction of shrinkage and swelling by 30 – 80%, and reduction of bending strength by 5 – 25%.

Wood material is heated to approximately 120°C with steam in conventional drying. During conventional drying, no structural changes take place in the wood, and water is removed from the wood only by evaporation. Generally, the aims of conventional drying are to prevent biological degradation of the wood and to prevent undesirable biochemical reactions that may result from the absence of moisture in the wood. In high-temperature drying, the wood is heated slowly up to 180–250°C. This high-temperature treatment decreases the hydrophilic behavior of the wood by changing the chemical structure of its components. These chemical changes lower the re-absorption of moisture, and they also improve the dimensional stability of the wood and its resistance to decay. When wood is heat treated, its hydrophilic OH groups are replaced by hydrophilic O–acetyl groups (Hinterstoisser et al. 2003), creating cross-links between wood fibers and thereby decreasing the ability of water to penetrate into the wood (Homan et al. 2000). As a consequence of the reduced number of OH groups, swelling and shrinkage are reduced. In addition to better durability, the advantages of heat-treated wood are reduced hygroscopicity and improved dimensional stability. It stabilizes with moisture content around 4 – 5% instead of 10 – 12% (Inoue et al. 1993).

Heat-treated wood becomes more stable dimensionally than untreated wood. Elimination of hydroxyl groups also reduces the number of potential anchor points for fungi. Wood becomes more rigid and fragile, and the mechanical resistance decreases (Vitanemi 2000). Heat treatment decreased the water absorption of uludag fir, as was predicted. Therefore, the reduction of the equilibrium moisture content of uludag fir strongly depends on the heat-treatment temperature. The higher the heat-treatment temperature, the lower the levels of absorbed moisture and equilibrium moisture contents (EMC) (Gündüz et al. 2007, Aydemir 2007). It known that the specific gravity and EMC of wood are reduced after heat treatment. This result is the degradation of mechanical properties, but dimensional stability is improved (Aydemir 2007).

Santos (2000) determined that strength properties were slightly affected. The apparent modulus of elasticity was slightly higher for treated wood than for untreated wood, despite a 26% reduction in transverse tensile strength. Similar results were presented by Kobojima et al. (2000) with treatments performed in air and nitrogen atmospheres. One difference is that Kobojima et al. (2000) used a constant treatment temperature of 160°C and noted an increase in bending strength when the duration of treatment was less than four hours.

According to Bengtsson et al. (2002), a reduction of approximately 50% in bending strength was found in tests of heat-treated spruce and pine. With heat treatment, the least affected property is modulus of elasticity, while the most affected properties are impact strength and static bending strength. In a study of the effect of heat treatment using pine sapwood heated at 110, 130, 150, and 180 °C, it was found that compression strength decreased by 5% (Schneider 1973).

The aims of this article can be summarized by the following points:

- To learn more about changes in the moisture content, dimensional stability and mechanical properties that occur in wood after heat treatment and to determine how these changes affect heat treated wood
- To understand the effect of treatment time on the physical and mechanical properties of heat-treated wood. To accomplish this aim, this study was conducted at a temperature at 180°C and at treatment times of 2, 4, 6, 8, and 12 hours.

MATERIAL AND METHODS

Material

Preparation of Specimens: The experimental samples were dried in a drying oven at 103±2°C until they reached an equilibrium point where there was no additional weight loss. The weights were measured with a scale having a sensitivity of 0.001 g, and the dimensions of the samples were measured with a digital caliper having a sensitivity of 0.01 mm. Thus, their dry weight dimensions and volumes were determined. After the measurements, the samples were placed in a climatic chamber at 65% relative humidity and a temperature of 20°C until they reached the equilibrium moisture content of 12%.

Heat Treatment Process: The heat-treatment process was carried out in a drying oven having a sensitivity of 1°C at atmospheric pressure and in the presence of air and water vapor. The treatment temperature was 180°C, and the durations were 2, 4, 6, 8, and 12 hours. After treatment, the samples were removed from the oven, and their dimensions and weights were measured again. Then, the samples were placed in a conditioning chamber where they remained for seven days. Afterwards, they were put in a drying oven at a temperature of 103±2°C, and their dry weights and dimensions were measured for the third time. The samples were conditioned afterwards until they reached their equilibrium moisture content of 12%.

Method

Anatolian Chestnut (*Castanea sativa* Mill.) lumber was planed in a local mill and small, transparent clear specimens were obtained. Tests of moisture content (%45, %55, %65, %80 and %95), and dimensional stability (Swelling and Shrinkage) were conducted on samples that had dimensions of 2 x 2 x 3 cm. The three specified tests were carried out based on Turkish Standards (TS) TS 2471, and TS 4084, respectively.

Specimens were prepared for conducting mechanical tests as follows: compression strength parallel to grain (2 x 2 x 3 cm); bending strength (2 x 2 x 36 cm); and modulus of elasticity in bending (2 x 2 x 36 cm) according to the protocols of TS 2595, TS 2474, and TS 2478, respectively. Measurements were conducted for both heat-treated and control (untreated) specimens.

After the strength test, the moisture content of samples was measured and strength values were transformed to 12% MC. For all parameters, all multiple comparisons were first subjected to an analysis of variance (ANOVA) and significant differences between mean values of control and treated samples were determined using Duncan's multiple-range test.

RESULTS AND DISCUSSION

In this study, Castanea wood was treated thermally at 180 °C for 2, 4, 6, 8, and 12 hours to determine the effect of treatment times on the properties of the wood.

The effects of treatment time on moisture content and dimensional stability of heat-treat Castanea wood: Heat treatment at 180°C for 2, 4, 6, 8, and 12 hours significantly reduces tangential, radial, and longitudinal swelling. The effects of heat treatment in terms of reduced swelling and shrinkage of wood are clearly shown in Tab. 1.

Tab. 1: The effect of treatment times on the swelling and shrinking (dimension stability – DS) at three different sections (Anatomical direction)

Treatment Time (h)	Statistical* Values	Swelling (%)			Shrinking (%)		
		Tangential	Radial	Cross-Section	Tangential	Radial	Cross-Section
Control	X	**5.36**	**3.65**	**1.31**	**5.09**	**3.13**	**1.11**
	±s	0.34	0.43	0.17	0.31	0.44	0.18
	v (%)	6.40	11.79	13.12	6.04	14.04	16.14
2	X	**4.38**	**2.62**	**0.60**	**4.20**	**2.53**	**0.56**
	±s	0.14	0.15	0.09	0.11	0.18	0.06
	v (%)	3.28	5.84	15.56	2.65	7.16	10.64
4	X	**4.43**	**2.63**	**0.55**	**4.13**	**2.50**	**0.51**
	±s	0.05	036	0.10	0.14	0.27	0.06
	v (%)	1.07	13.52	17.68	3.47	10.77	11.74
6	X	**4.43**	**2.56**	**0.47**	**4.10**	**2.47**	**0.49**
	±s	0.63	0.26	0.08	0.80	0.29	0.07
	v (%)	14.23	10.25	16.68	19.51	11.86	14.42
8	X	**4.02**	**2.50**	**0.41**	**3.76**	**2.44**	**0.39**
	±s	0.47	0.40	0.06	0.51	0.31	0.04
	v (%)	11.66	16.10	13.75	13.56	12.73	10.35
12	X	**3.80**	**2.30**	**0.31**	**3.49**	**2.19**	**0.33**
	±s	0.47	0.11	0.01	0.54	0.25	0.06
	v (%)	12.36	4.73	3.63	15.47	11.39	18.39

*x, average; ±s, standard deviation; v (%), variance coefficient

The swelling and shrinking reductions were found to be independent of relative humidity. The swelling or shrinking reductions, expressed in the MC values of the results shown, range to approximately 50%. In general, the swelling and shrinking reductions in the tangential direction were found to be greater than the reductions in the radial and longitudinal directions. According to Tab. 1, the lowest decrease of swelling and shrinking in the tangential, radial, and cross-sectional directions, as compared to control specimens were obtained from the 2 h treatment time. For this treatment time, the percentages as 18.2%, 28.2%, 54.1% and 17.4%, 19.1%, 49.5%. The highest decrease ratio of the swelling and shrinking in tangential, radial and cross-section was observed in treatment time in 12 h as 29.1%, 36.9%, 76.3% and 31.4%, 30%, and 70.2%.

Heat treatment significantly reduces tangential and radial swelling. The swelling and shrinkage of the wood are very low. Desired changes begin to appear at about 150°C, and the changes continue as the temperature is increased in stages (Jamsa et al., 1999). In another study (Yildiz, 2002), the technique used suggested that increases in temperature and treatment times resulted in changes in dimensional stability from 55% to 90%.

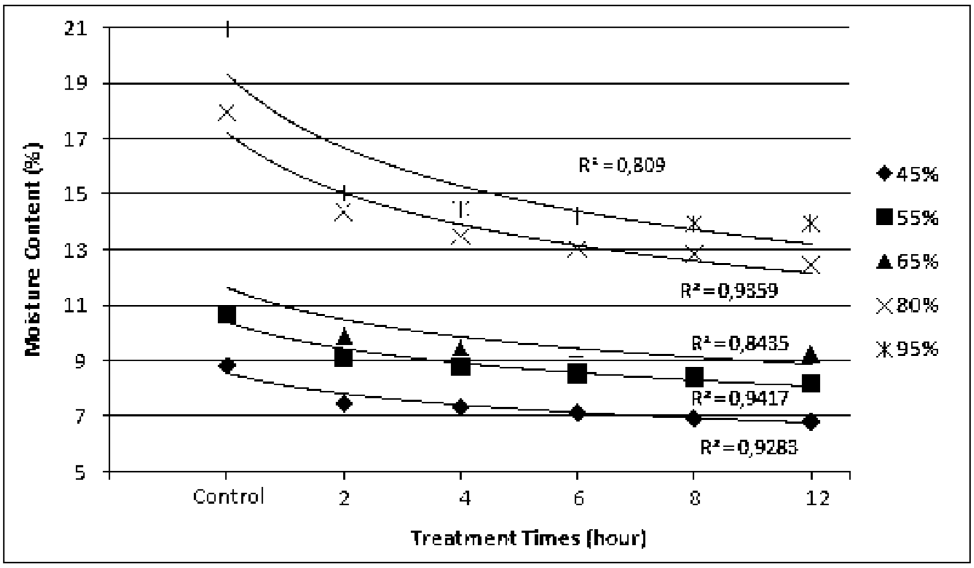

Fig. 1: Shows that increases in treatment time cause improving from the standpoint of the equilibrium moisture content of Castanea wood

Heat-treated wood absorbs less moisture than the control specimens. According to Fig. 1, When wood was treated at 180 °C for 2 hours, the minimum loss in the equilibrium moisture content was lower 15.1% at 35% RH (Relative Humidity); 15% at 55% RH, 19.1% at 65% RH; 19.9% at 80% RH and 28.1% at 95% RH compared to untreated wood, respectively. The low-intensity treated (180°C for 2 and 4 hours) Castanea samples, at a relative humidity of 65%, showed reductions in EMC from 15% to 22.8%, respectively. Medium-intensity heat treatment at 180°C for 6 and 8 hour showed at 65% relative humidity an EMC loss from 23.3% to percent 24.4% in castanea wood, respectively. Strong-intensity treated castanea samples at 180°C for 12 hour exhibited an EMC loss at 24.6% (65% RH).

These results show that after heat treatment of wood, the EMC is decreased as compared to the control specimens. A similar result was reached by Burmester (1975), Giebeler (1983), and Hanger et al. (2002).

The effects of treatment time on mechanical properties of heat-treated Castanea wood: The effects of treatment time on bending strength (BS) and modulus of elasticity in bending (MOE) of Castanea wood treated at a temperature of 180°C and treatment times of 2, 4, 6, 8, and 12 hours were determined (Fig. 2).

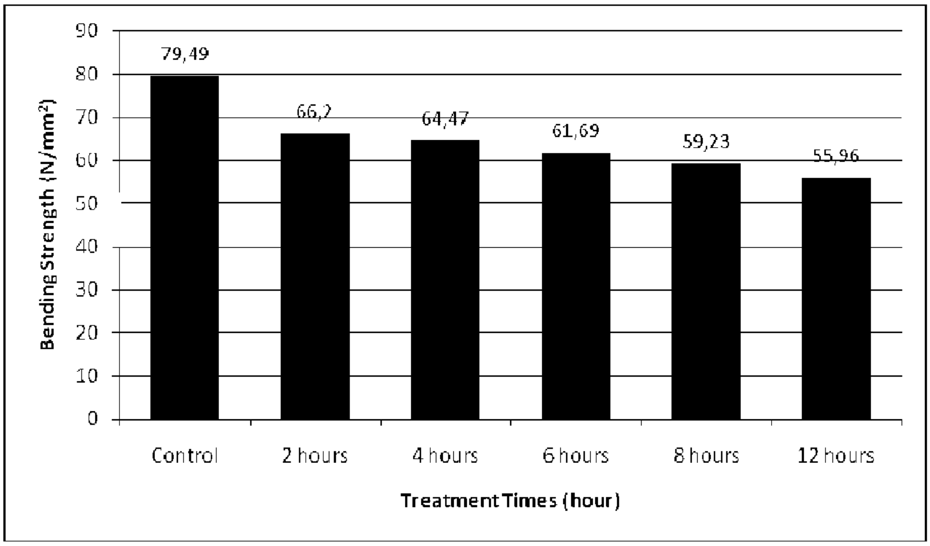

Fig. 2: The effect of treatment times on bending strength (BS)

The lowest decrease in BS as compared to control specimens was determined for the 2 h, 4h, 6h and 8h treatment time to be 16.7%, 18.8%, 22.3% and 25.4%. The highest decrease ratio of BS was observed at a treatment time of 12 hour as 29.6%. Yildiz (2002) observed that the lowest bending strengths for beech and spruce were observed when the wood samples were treated at 200°C for both 6 and 10 hour. The decrease was 63.9% and 63.6% for beech and 63.8% and 72.7% for spruce for 6 and 10 hour treatment times at 200°C. Bekhta and Niemz (2003) found that the bending strength of spruce wood decreased nearly 44–50% as the treatment temperature was raised from 100 to 200°C, whereas temperature had no effect on the modulus of elasticity. The modulus of elasticity was lower for the wood specimens dried at room temperature (20°C) under 95% RH and higher under 35% and 65% RH than for the specimens heated at 100–200°C.

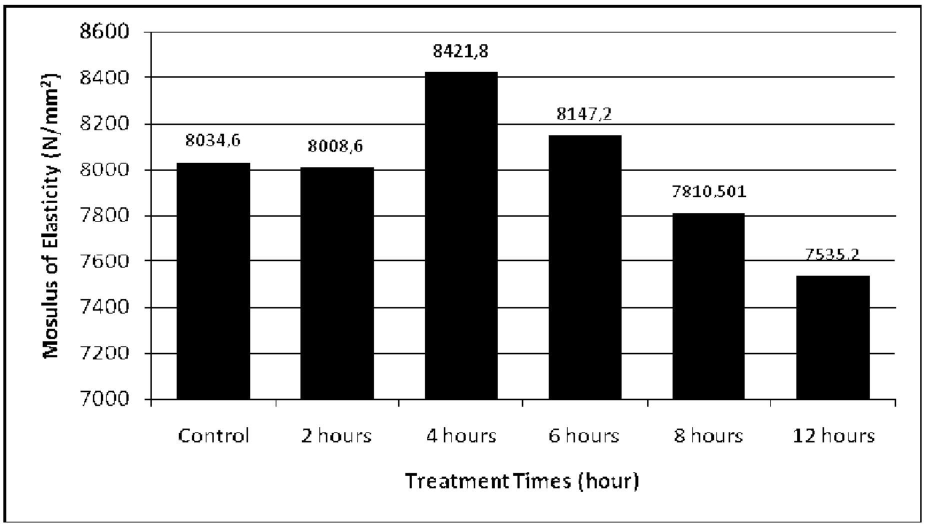

Fig. 3: The effect of treatment times on modulus of elasticity bending

According to Fig. 3, MOE in 2 h treatment time was decreased at 0.3% as compared to control specimens. While the BS had a minimum decrease ratio between 4 and 6 h treatment times, the MOE in these treatment periods was shown to have a maximum increasing ratio. The increasing ratios were 4.8% for 4 hours and 1.4% for 6 h. MOE for 8 and 12 h treatment times was re-decreased in 2.7% and 7.4, respectively. Yildiz (2002) obtained that the highest decrease in modulus of elasticity for spruce was 41,5% at 200°C for 6 h. On the other hand, a slight increase (8,4%) in modulus of elasticity was observed at 130°C for samples treated for 10 h. For beech, heat treatment at 200°C for 10 h resulted in a 39% increase in the modulus of elasticity. In another study, the highest values of the bending strength were reached when the treatment temperature was 100°C. Both bending strength and modulus of elasticity decreased when the treatment temperature rose over 100°C. When the wood was dried at room temperature, the bending strength was 5% lower than in wood specimens heated at 100°C and 150°C, respectively, and about 33% higher than in wood specimens heated at 200°C (Bekhta and Niemz 2003).

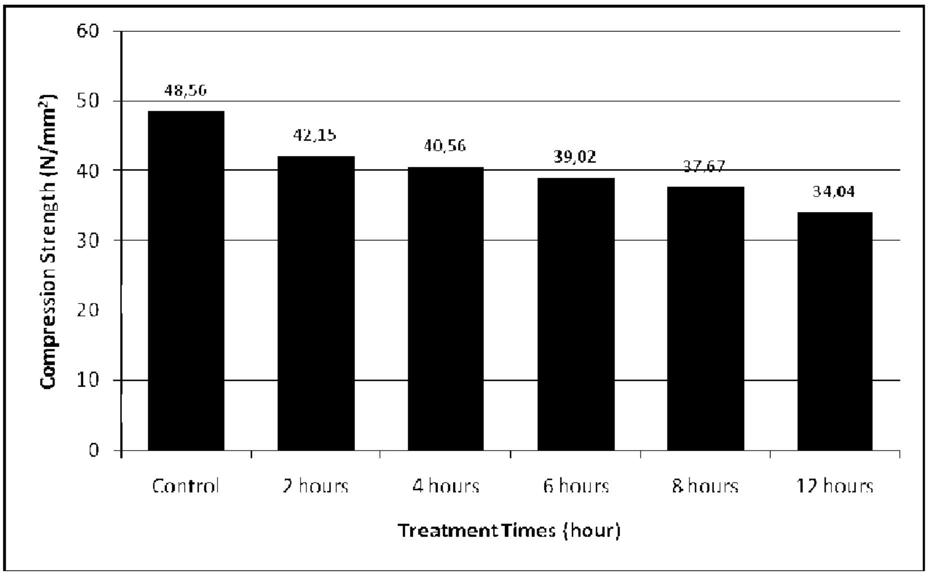

Fig. 4: The effect of treatment times on compression strength

The effect of treatment time on compression strength (CS) of heat-treated Castanea wood is shown in Fig. 4. According to Fig. 4, as treatment time increases from 2 hour to 12 hour, it was determined that CS decreased. After heat treatment, the CS decreased in the rates at 13.2% in 2 hours and 16.4% in 4 hour of treatment time as compared to the control specimens. The rates of CS losses for 6, 8, and 12 h were found as 19.6%, 24.4% and 29.8%, respectively. While the rates of CS losses at treatment times of 2, 4, and 6 h were similar to each other, the rates of CS losses occurred higher decrease in 8 and 12 h. According to Korkut's study (2007) related to heat-treatment of Scots pine (*Pinus sylvestris* L.) at 120, 150 and 180°C for 2, 6, and 10 hours, the maximum rate of CS losses was observed at 180°C and 10 hours of treatment as 25.4%. In a study on the effect of heat treatment with pine sapwood heated at 110, 130, 150 and 180°C, it was found that compression strength decreased by 5% (Schneider 1973). Unsal and Ayrilmis (2005) also found that the maximum compression strength parallel to grain decrease in Turkish river red gum (*E. camaldulensis* Dehn.) wood samples was 19.0% at 180°C and 10 h. Compression strength of wood decreases when the wood is heated and increases when the wood is cooled. This is exactly the effect achieved with the treatment when applied for a long time (Yildiz 2002). Yildiz (2002) obtained similar compression strength results for beech wood at the same treatment times and temperatures. In this case, it can be said that temperature might have greater influence on strength properties than time.

According to the results obtained in this study of the heat treatment of Castanea wood at 180°C for various treatment times affected mechanical properties in the range of 0.3 to 29.8% and affected moisture content in the range of 15.1 to 33.7%. Dimensional stability of the wood was also affected. In this study, the minimum rate of loss of mechanical properties and improvement in moisture content and dimensional stability occurred for treatment times of 6 h and 8 h.

CONCLUSION

If proper heat-treatment techniques are used, Castanea wood can be utilized without any losses in strength values in areas where woodworking and stability are important. Due to improving moisture content and swelling and shrinkage (dimensional stability), heat-treated Castanea wood is suited for outdoor applications such as external cladding, window frames, and garden furniture. As a result of its dimensional stability, the heat-treated wood has better durability for coating. When wood has been treated at high temperatures and for long durations, we recommend that such wood not be used structurally for load-bearing purposes. Based on the findings of this study, it is concluded that the physical properties of the observed wood decreased as treatment temperatures and times increased.

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