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THE EFFECT OF HEAT TREATMENT ON THE SOME PHYSICAL AND MECHANICAL PROPERTIES OF BEECH (*FAGUS ORIENTALIS* LIPSKY) WOOD

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ABSTRACT

This study describes the effect of heat treatment on the some of the physical and mechanical properties of beech (*Fagus orientalis* Lipsky) wood at different temperatures and times. Samples of beech wood were heat-treated at 150, 175, and 200°C for 1, 3 and 5 h. The mechanical properties of the heat-treated and untreated samples were determined by bending tests, modulus of elasticity in bending, compression strength parallel to grain, and Brinell hardness. Physical properties were determined by weight loss, density, and volumetric swelling tests. The results showed that the heat treatment increased the weight loss, density loss and dimensional stabilization. In addition, an increase was observed for compression strength parallel to grain (except for at 200°C for 5 h), while a small increase was determined in the bending strength, modulus of elasticity in bending, hardness values of heat-treated wood samples at 150°C for 1 and 3 h. However, the heat treatment at higher temperature and duration clearly decreased bending strength, modulus of elasticity in bending,and hardness.

KEYWORDS: Heat treatment, beech, properties of physical, properties of mechanical.

INTRODUCTION

Wood materials have long been used in building because of their many desirable features (such as esthetic appearance, reasonable cost, ease of use, low density, and high mechanical

strength). However, wood also has some undesirable-structural properties. For this reason many studies have been done to improve and compensate for the drawbacks of wood material. For several decades, different thermal treatment methods have significantly improved and enhanced some of the properties of wood without the use of chemical additives. Wood is composed of cellulose, hemicelluloses, lignin and a small amount of extractives. These polymers constitute the cell wall and are responsible for the physical and chemical properties of wood. These chemical components change depending on temperature and duration of heat treatment (Aksoy et al. 2011, Borrega and Karenlampi 2008, Pandey et al. 2009, Wikberg 2004, Yıldız and Gumuskaya 2007; Boonstra 2008; Alen et al. 2002).

Hemicelluloses degrade more easily at lower temperature and duration than the other chemical macromolecular components (Esteves et al. 2008, Esteves and Pereira 2009). Cellulose degradation occurs at a higher temperature than hemicelluloses (Hill 2006). Kim et al. (2001) reported that in one-hour isothermal treatments, cellulose crystallites did not decompose at 300°C, however they completely decomposed at 340°C. Lignin is the most stable polymeric material against thermal degradation, however, some thermal degradation of lignin can start at relatively low temperatures and the changes to the lignin are depend upon the temperature and the duration of treatment (Sudo et al. 1985). Extractives disappear and degrade during the heat treatment, especially with the most volatile materials. Nuopponen et al. (2003) reported that fats and waxes migrate to the surface when pine sapwood is heat treated at 100-160°C. Heat treatment is one of a variety of modification methods that can improve the dimensional stability and bio-durability of wood materials. The temperature and time for heat treatment generally in the 180-280°C range and from 15 min to 24 h depending on the method, wood species, specimen size, moisture content of the wood specimen and the desired mechanical properties, resistance to biological attack and dimensional stability of the final product (Kamden et al. 2002). There are several commercial heat treatment processes. The main differences among the processes are in the process conditions (e.g., process stage, oxygen or nitrogen, water steaming, water spray, use of oils) (Militz 2002).

When wood is heated at a high temperature, it becomes more brittle and its mechanical strength decreases depending on the level and duratrion of the thermal treatment; however, the dimensional stability of heat-treated wood is increased (Bekhta and Niemz 2003, Esteves and Pereira 2009, Korkut 2008, Yıldız 2002, Korkut et al. 2015). Bengtsson et al. (2002) reported that heat-treatment of spruce (*Picea abies*) and pine (*Pinus sylvestris*) beams brought a reduction in bending strength of approximately 50 %, while the modulus of elasticity decreased by 3.5 %. Shi et al. (2007) studied the mechanical behaviour of Québec wood species (spruce, pine, fir, aspen and birch) heat-treated using a ThermoWood process. As a result, the modulus of rupture (MOR) decreased between 0-49 % for heat-treatedspruce, pine, fir, aspen; for birch the MOR increased slightly after the heat treatment at 6 %. Heat-treated spruce's and pine's modulus of elasticity (MOE) decreased between 4-28 %, however, for fir, aspen and birch the MOE increased.

Unsal and Ayrılmıs (2005) studied variations in compression strength and surface roughness of heat-treated Turkish river red gum (*Eucalyptus camaldulensis*) wood. Eucalyptus wood was heat treated at temperatures varying from 120-180°C for durations of 2-10 h. The results showed that density and compression strength values decreased with as treatment temperature and durations increased.

Weight loss occurs when wood is heated;the amount of weight loss depends on the process conditions. Weight loss increases with increasing process temperature and duration of the heat treatment (Borrega and Karenlampi 2008, Esteves et al. 2007).

Many studies have also reported, changes in dimensional stability. These studies reported that dimensional stability generally increased with temperature and duration (Bekhta and Niemz 2003, Tjeerdsma et al. 1998, Viitanen et al. 1994).

Gunduz et al. (2009b) investigated heat-treated hornbeam (*Carpinus betulus)* wood samples that were subjected to heat treatment at 170, 190, and 210°C for 4, 8, and 12 hours. After heat treatment, hardness values in tangential, radial, and longitudinal directions approximately decreased by 55, 54, and 38 %, respectively. In another study, Pena et al. (2009) conducted experiments on heat-treated beech (*Fagus sylvatica* L.), Scots pine (*Pinus sylvestris* L.), and Norway spruce (*Picea abies* L.) woods, and they noted relationships between mass loss and chemical composition.

The main purpose of this study was to determine the effect of heat treatment on some physical and mechanical properties of beech (*Fagus orientalis* Lipsky) wood species naturally grown in Turkey.

MATERIAL AND METHODS

Wood material

Air-dried beech (*Fagus orientalis* Lipsky) was wood used in this study. Wood materials were obtained by random selections in the Siteler-Ankara province of Turkey. Beech wood having high usage potential is an important species in lumber industry. The lumber was cut parallel to the grain from the logs in sawmill according to the TS 4176 (1984).

Preparation of physical and mechanical test specimens

Beech lumber was planed and then cut into smaller clear specimens for determination of air-dry density (20x20x30 mm) according to TS2472 (1976), volumetric swelling (20x20x30 mm) according to TS4086 (1983), compression strength parallel to grain (20x20x30 mm) according to TS2595 (1976), bending strength (20x20x360 mm) TS2474 (1976), modulus of elasticity in bending according to TS2478 (1976), and Brinell-hardness (50x50x50 mm) according to TS2479 (1982). For each experiment, 10 samples were prepared.

Heat treatment

Heat treatments were conducted in a temperature-controlled small heating unit. Three different temperatures (150, 175, and 200˚C) and three different durations (1, 3, and 5 h) were applied to specimens under atmospheric pressure. The total heat treatment was performed in three continuous phase for 60 h (Fig. 1). Thesephases are follows.

In the first phase, the kiln temperature was raised from room temperature to 100°C using water vapour and heat for 10 h.The kiln temperature was then steadilyincreased up to 130°C for 15 h. In the second phase, the temperature inside the kiln was increased from 130 to 150, 175 and 200°C for 10 h. Once the target level reached the desired temperature it was kept for 1, 3 and 5 h. In the third phase, the temperature was reduced, and this was continued until the moisture of the wood had reached 4 to 6 % using water vapor.

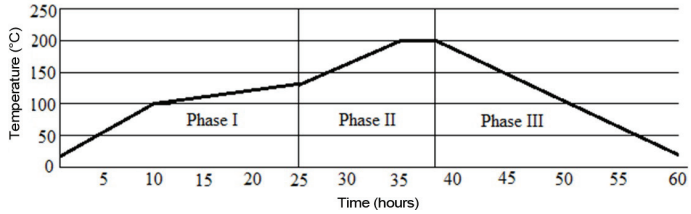

Fig. 1: Process schedule used in the experiment (at 200˚C for 3 hours).

After heat treatment, treated and untreated samples were conditioned at 20 ± 2°C and 65 % (±5) relative humidity (RH) (TS642/ISO554 1997). Prior to the tests, the dimensions were measured by digital caliper (resolution: 0.001 mm) and their weights were recorded by digital weihgt scale (accuracy: 0.001 g).

The weight loss (WL), air-dried density (D), compression strengthparallel to grain (CS), bending strength (MOR), modulus of elasticity in bending (MOE), and Brinell hardness (HB) (radial-R, tangential-T, longitudinal-L)were calculated following formulas 1, 2, 3, 4, 5, and 6, respectively. For the volumetric swelling (VS), the test samples were dried in an oven at 103±2°C until their weights were stable. The dimensions and weights of the test samples were measured to calculate volumetric swelling. To calculate volumetric swelling, the test samples were immersed in distilled water until their dimensions were stable. At the end of the immersion period, the dimensions and weights of the test samples were measured again.

$$WL = (M_{BH} - M_{AH}) / M_{BH} \times 100 \quad (\%) \tag{1}$$

where: M_{BH} - kiln-dried weight of samples before heat treatment (g),
M_{AH} - kiln-dry weight of samples after heat treatment (g).

$$D_{12} = M_{12}/V_{12} \quad (g.cm^{-3}) \tag{2}$$

where: M - the weight of the sample (g),
V - the volume of the samples (cm^3).

$$CS = F_{max}/a.b \quad (N.mm^{-2}) \tag{3}$$

where: F_{max} - maximum load (N),
a - the samples width (mm),
b - the sample thickness (mm).

$$MOR = 3.F_{max}.L/2.b.h^2 \quad (N.mm^{-2}) \tag{4}$$

where: F_{max} - maximum load (N),
L - the distance between two supports (mm),
b - the sample width (mm),
h - the sample thickness (mm).

$$MOE = \Delta F.L^3/4.b.h^3.\Delta f \quad (N.mm^{-2}) \tag{5}$$

where: ΔF - the the load increment (N),
L - the distance between two supports (mm),
Δf - is the deflection increment,
b is the sample width (mm),
h is the sample thickness (mm).

$$HB = 2 \times F/ \pi \times D \left(D-\sqrt{D^2 - b^2}\right) \tag{6}$$

where: F - the load applied (N),

d - the diameter of the indentation made by the steel ball on the surface of the test specimens (mm),
D - the diameter of the steel ball (mm).

For all parameters, all multiple comparisons were first subjected to analysis of variance (ANOVA) and significant differences between mean values of control and treated samples were determined using Duncan's Multiple Range Test. P-values of ≤ 0.05 were considered significant.

RESULTS AND DISCUSSION

Results of variance analyses are given in Tab. 1.

Tab. 1: Results of variance analyses.

	Factor	Degrees of freedom	Sum of squares	Mean square	F Value	P ≤ 0.05
WL	Factor A	2	506.481	253.240	2995.28020	0.0000
	Factor B	3	656.108	218.703	1635.4656	0.0000
	A*B	6	105.812	17.635	131.8778	0.0000
	Error	108	10.832	0.134	-	-
	Total	119	1279.233	-	-	-
CS	Factor A	2	565.888	282.944	13.121	0.0001
	Factor B	3	1374.266	458.089	38.8591	0.0000
	A*B	6	1359.117	226.529	19.2162	0.0000
	Error	108	954.866	11.788	-	-
	Total	119	4254.137	-	-	-
MOR	Factor A	2	3036.960	1518.48	27.3815	0.0000
	Factor B	3	2639.914	879.991	24.2292	0.0000
	A*B	6	1017.077	169.513	4.6674	0.0004
	Error	108	2941.804	36.319	-	-
	Total	119	9635.755	-	-	-
MOE	Factor A	2	23607957.050	11803979.53	33.7306	0.0000
	Factor B	3	16960934.492	5653644.897	12.2058	0.0000
	A*B	6	9903151.683	1650525.281	3.5634	0.0035
	Error	108	37518512.375	463191.511	-	-
	Total	119	87990555.600	-	-	-
VS	Factor A	2	202.564	101.282	85.1589	0.0000
	Factor B	3	345.683	115.228	195.0655	0.0000
	A*B	6	82.159	13.693	23.1806	0.0000
	Error	108	47.848	0.591	-	-
	Total	119	678.254	-	-	-

HB	R	Factor A	2	219.415	109.707	18.9836	0.0000
		Factor B	3	49.212	16.404	6.1832	0.0008
		A*B	6	75.139	12.523	4.7204	0.0004
		Error	108	214.894	2.653	-	-
		Total	119	558.660	-	-	-
	T	Factor A	2	272.480	136.24	23.4358	0.0000
		Factor B	3	111.657	37.219	14.1113	0.0000
		A*B	6	93.302	15.55	5.8958	0.0000
		Error	108	213.640	2.638	-	-
		Total	119	691.079	-	-	-
	L	Factor A	2	501.005	250.503	45.2699	0.0000
		Factor B	3	257.307	85.769	20.2185	0.0000
		A*B	6	209.593	34932	8.2346	0.0000
		Error	108	343.610	4.242	-	-
		Total	119	1311.515	-	-	-

Factor A=Treatment temperature, Factor B=Treatment duration, A*B= Interaction of Factor A and Factor B.

According to variance analysis (Tab. 1), the impact of heat treatment temperature and heat treatment duration on WL, CS, MOR, MOE, VS, andHB (radial-R, tangential-T, longitudinal-L) was found statistically meaningful ($P<0.05$).

Tab. 2 displays results of tests for the control and heat-treated samples for three combinations of exposure and time. Based on the findings in this study, all of the mechanical properties tested, with the exception of CS decreased with increasing temperature and time, except for CS. Although, WL also increased, depending on heat treatment temperature and time, VS decreased.

Tab. 2: Duncan test results of beech wood ($P\leq0.05$)

Heat treatment (°C)	**Hour**	**Statistical values**	**WL (%)**	**D ($g.cm^{-3}$)**	**CS ($N.mm^{-2}$)**	**MOR ($N.mm^{-2}$)**	**MOE ($N.mm^{-2}$)**	**VS (%)**	**HB ($N.mm^{-2}$)**		
									R	**T**	**L**
Untreated (Control)		Mean	-	0.7346	73.33	124.42	12721	17.12	34.90	36.31	66.71
				A	DE	AB	AB	A	CD	BC	B
		s		0.045	3.254	5.893	906.448	0.678	2.389	2.555	1.584
150°C	1	Mean	1.060	0.7248	75.52	127.40	12843	16.02	36.60	38.20	69.47
			H	AB	D	A	A	B	A	A	A
		s	0.059	0.052	4.024	5.297	313.362	1.381	1.938	1.754	2.330
	3	Mean	2.241	0.7050	78.65	125.05	12824	15.37	36.07	37.16	68.41
			G	ABC	C	AB	A	BC	AB	AB	AB
		s	0.179	0.049	4.749	4.633	291.479	1.600	2.393	1.211	2.921
	5	Mean	3.779	0.6945	79.43	120.41	12541	14.80	34.88	36.14	66.67
			F	BCD	C	BC	AB	C	BC	BC	B
		s	0.112	0.038	5.011	6.184	442.688	0.937	1.721	1.301	2.052

175°C	1	Mean	4.829	0.6727	82.50	118.39	12347	14.72	33.71	34.90	67.36
			E	CDE	B	C	ABC	CD	CDE	CD	B
		s	0.402	0.049	4.681	6.286	246.656	0.576	1.638	1.118	1.918
	3	Mean	5.902	0.6647	84.52	115.40	12151 BC	14.10	33.19	34.10	63.11
			D	DE	AB	CD		D	DEF	DE	C
		s	0.530	0.053	3.799	6.402	368.231	0.540	1.613	1.201	2.294
	5	Mean	7.506	0.6550	87.49	110.40	11843	13.30	32.74	33.20	62.30
			C	DEF	A	DE	CD	E	EFG	EF	CD
		s	0.532	0.033	3.256	9.236	521.365	1.022	0.872	1.609	2.777
200°C	1	Mean	7.444	0.6486	86.57	111.60	11838	12.90	32.20	32.90	62.50
			C	EF	A	DE	CD	E	FGH	EF	C
		s	0.389	0.031	2.832	7.260	534.249	0.412	1.919	1.844	1.771
	3	Mean	8.937	0.6341	81.58	108.80	11372	11.31	31.41	32.21	61.70
			B	EF	BC	EF	D	F	GH	F	CD
		s	0.478	0.029	3.173	7.687	1006.773	0.436	0.803	1.743	1.731
	5	Mean	9.602	0.6241	72.48	103.50	10671	9.50 G	30.81	31.80	60.49
			A	F	E	F	E		H	F	D
		s	0.543	0.028	3.176	4.854	776.604	0.355	1.087	1.900	2.507
LSD			0.3242	0.0396	3.040	5.337	602.7	0.6808	1.442	1.438	1.824

Mean= average value; s = Standard deviation; A: Homogeneity groups(according to the Duncan's multiply range test at $P < 0.05$).

As can be seen, a lesser effect of heat treatment was observed when the samples were treated at a lower temperature. In addition there was a slight increase in mechanical strength at low temperature (150°C) and then reduced strength due to an increase in temperature and time.

Tab. 3 shows the percentage decrease and increase of values in relation to the control for each treatment and each measured parameter. The highest weight loss was obtained in heat-treated samples at 200°C for 5 h (9.602 %) and the lowest in heat-treated samples at 150°C for 1 h (1.06 %). Weight loss increased with treatment time and temperature. Weight loss of wood is one of the most important characteristics of heat treatment and is commonly referred to as an indication of quality (Esteves and Pereira 2009). The weight loss of the heat-treated wood specimens is due to the degradation of wood polymers (hemicelluloses, cellulose, and lignin), mainly the hemicelluloses in this range of temperature, which are the most thermally sensitive wood components (Poncsak et al. 2006; Yildiz et al. 2006). Zaman et al. (2000) treated Scots pine and silver birch at temperatures between 200 and 230°C for 4-8 h and determined that the mass losses for Scots pine varied from 5.7 % (4 h) to 7.0 (8) at 205°C, and from 11.1 (4) and 15.2 % (8 h) at 230°C and for silver birch 6.4 (4) and 10.2 (8) at 200 and 13.5 (4) and 15.2 % (8 h) at 220°C.

The highest density was obtained in control samples (0.7346 $g.cm^{-3}$) and the lowest in heat-treated samples at 200°C for 5 h (0.6241 $g.cm^{-3}$) (Tab. 2). The density of the treated wood samples decreased significantly compared to the control samples. The results connected with density decrease ratio are shown in Tab. 3. The highest losses in density (15.04 %) were realized at 200°C. Degradation of hemicellulose into volatile substances and evaporation of extractives are considered the main parameters responsible for the density reduction of wood exposed to heat (Esteves and Pereira 2009). Korkut and Guler (2008) conducted research on heat-treated red-bud maple (*Acer trautvetteri* M.) and confirmed the density decrease. In addition, Boonstra et al. (2007) reported a 10 and 8.5 % decrease on density for heat-treated Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* Karst.), respectively.

Tab. 3: Percentage decrease and increase of technological properties in Beech (Fagus orientalis Lipsky) wood following heat treatment for different durations.

Heat treatment	Times (h)	WL (%)	D (%)	CS (%)	MOR (%)	MOE (%)	VS (%)	HB (%)		
								R	T	L
150°C	1	1.06	-1.33	2.98	2.4	0.95	-6.43	4.87	5.2	4.13
	3	2.241	-4.19	7.25	0.49	0.8	-10.22	3.35	2.34	2.54
	5	3.779	-5.45	8.3	-3.22	-1.41	-13.55	-0.05	-0.46	-0.05
175°C	1	4.829	-8.42	12.49	-4.84	-2.94	-14.02	-3.40	-3.88	-0.97
	3	5.902	-10.51	15.25	-7.25	-4.48	-17.64	-4.89	-6.08	-5.39
	5	7.506	-10.83	19.30	-11.27	-6.90	-22.31	-6.18	-8.56	-6.61
200°C	1	7.444	-11.7	18.04	-10.3	-6.94	-24.65	-7.73	-9.39	-6.31
	3	8.937	-13.68	11.24	-12.55	-10.6	-33.94	-10.01	-11.29	-7.51
	5	9.602	-15.04	-1.16	-16.82	-16.11	-44.51	-11.71	-12.42	-9.32

-:decrease (%).

The highest compression strength was obtained in heat-treated samples at 175ºC for 5 h (87.49 N.mm^{-2}) and the lowest in heat-treated samples at 200ºC for 5 h (72.48 N.mm^{-2}) (Tab. 2). According to Tab. 3, after all heat treatments, compression strength values showed an increase (between 2.98 and 19.3 %), however, after heat treatment at 200ºC for 5 h, compression strength values showed a small decrease (1.16 %). Korkut et al. (2008) reported a decrease in compression strength by 2.026-32.297 % for red-bud maple (*Acer trautvetteri* Medw.). According to Vital et al. (1983) compression parallel to grain in *Eucalyptus saligna* wood samples heated to 100-155°C for 10-160 hours, generally deteriorated with increase in temperature or exposure time. Yildiz et al. (2006) also suggested that the decrease in compression strength properties can be reduced by using a closed system with an inert gas like nitrogen or water vapor as the shielding gas instead of air. On the one hand, a study of bothspruce (*Picea orientalis* L.) and beech (*Fagus orientalis* L.) heat-treated at 200°C for 6 h resulted in a 36 % decrease in compression strength. On the other hand, a slight increase in compression strength was observed at 130°C for 6 h (Yildiz 2002). Similar results have been reported by Kol (2010), where compression strength values increased by 4.2 % for pine and 17 % for fir with heat treatment.

Tab. 2 shows the changes in MOR and MOE caused by the heat treatment. The MOR and MOE increased in the initial stage of the heat treatment and then decreased. According to Tab. 3, MOR value showed a slight increase (2.4-0.49 %) after heat treatment at 150°C for 1-3 h. Similarly MOE had a small increase (0.95-0.80 %) after heat treatment at 150°C for 1-3 h. In the present study, the lowest MOR and MOE values were obtained for samples heat-treated at 200°C for 5 h (103.50 and 11838 N.mm^{-2}) (Tab. 2). The highest decrease in MOR and MOE were 16.82 and 16.11 %, respectively (Tab. 3). Esteves and Pereira (2009) reported that the modulus of elaticity seems to increase for moderate heat treatments and to decrease for more severe heat treatments.The decreases in the mechanical properties can be explained by the rate of thermal degradation and losses in or changes of substance after heat treatments. The decrease in mechanical strength is mainly because of the depolymerization reactions of wood polymers (Esteves et al. 2008; Kotilainen et al. 2000). The primary reason for the mechanical strength loss is the degradation of hemicelluloses, which are less resistant to heat than cellulose and lignin. Losses of hemiselluloses play key roles in the mechanical strength properties of wood heated at high temperatures (Hillis, 1984; Gunduz et al. 2009a). In the literature, Kol (2010) studied the characteristics of heat-treated Turkish pine (*Pinus nigra* Arnold.) and fir (*Abies bornmülleriana*

Mattf.) wood after ThermoWood processing. Pine and fir samples were thermally modified for 2 h at 212 and 190˚C, respectively. The MOE was reduced by 13.1 for pine and by 9.5 % for fir with the heat treatment. In addition, heat treatment caused a decrease in MOR by 59.5 and 10.5 % for pine and fir, respectively. Korkut (2008) reported a decrease in MOE of 35 and in MOR of 16 % at 180˚C over 2 h for fir heat-treated in an oven. Tiryaki (2015), reported MOR and MOE values of heat treated beech (*Fagus orientalis* Lipsky) and spruce (*Picea orientalis* (L.) Link.) woods were decreased.

In the present study, the highest volumetric swelling was obtained in control samples (17.12 %) and the lowest in heat-treated samples at 200˚C for 5 h (9.50 %) (Tab. 2). Volumetric swelling decreased depending on heat treatment temperatures and durations. The decrease of swelling with heat treatment was statistically significant compared to the untreated control samples (Tab. 2). Volumetric swelling of a heat-treated sample at 200 ºC for 5 h was decreased by 44.51 % with theheat treatment (Tab. 3). The decrease in the equilibrium moisture of wood due to heat treatments leads to an improvement of wood's dimensional stability(Esteves and Pereira 2009). Heat-treated wood largely increases in dimensional stability and loses hygroscopicity because of the degradation of hemicelluloses, polymer reticulation and breaking of hydroxyl groups from the amorphous zone of cellulose (Weiland and Guyonnet 2003). Previous studieshave reportedincreases in wood dimensional stability due to a large reduction in the hemicellulose content, and thus, improves the dimensional stability of the wood (Bekhta and Niemz 2003, Esteves and Pereira 2009). Korkut and Guller (2008) reported decreases in swelling to radial, tangential and longitudinal directions of red-bud maple wood were found to be 23.43, 34.64, and 20.04 % respectively, when treated at 180˚C for 10 h.

The highest hardness (radial, tangential and longitudinal) was obtained in heat-treated samples at 150˚C for 1 h (36.60, 38.20 and 69.47 $N.mm^{-2}$, respectively) and the lowest in heat-treated samples at 200˚C for 5 h (30.81, 31. and 60.49 $N.mm^{-2}$, respectively). The results connected with the hardness decrease ratio are shown in Tab. 3. Maximum hardness loss was obtained for samples heat-treated at 200˚C for 5 h; radial 11.71, tangential 12.42, and longitudinal 9.32 %. The hardness values increased in the initial stage of the heat treatment and decreased thereafter. According to the Tab. 3, the results hardness for radial, tangential and longitudinal hardness values showed an increase of 4.87, 5.20 and 4.13 %, respectively, after heat treatment at 150ºC for 1 h. Similarly, there were small increases of 3.35, 2.34 and 2.54 %, after heat treatment at 150ºC for 3 h, respectively. Yildiz (2002) determined that the greatest decreases in hardness values were observed when beech and spruce samples were treated at 180ºC for 10 h. For beech samples, hardness decreases of 25.9, 45.1, and 41.8 % were observed for longitudinal, radial, and tangential directions, respectively. For spruce, hardness decreases of 19.7, 43.0, and 42.5 % were observed in the longitudinal, radial, and tangential directions, respectively. Unsal and Ayrilmis (2005) reported that in Turkish river red gum (*Eucalyptus camaldulensis*) wood samples the maximum hardness loss was at 180ºC for 10 h treatment. The loss was 23.91 cross-sectionally, 44.22 radially, and 33.57 % tangentially. Several studies showed different effects on the hardness of wood, a decrease but also an increase has been noticed (depending on the wood species and heat treatment method). Brinell hardness parallel to the grain is clearly increased (48), whereas hardness perpendicular to the grain is slightly increased (5 %) after heat treatment (Boonstra et al. 2007). Sundqvist et al. (2006) reported that treatments for birch at 180˚C for 1 to 2.5 h reduced strength and hardness significantly. Korkut et al. (2007) founded highest hardness loss was obtained for samples scots pine (*Pinus sylvestris* L.) treated at 180ºC for 10 h, i.e., 40.99 in the longitudinal direction, 27.41 in the radial direction, and 38.96 % in the tangential direction.

CONCLUSIONS

According to the experimental results, weight loss, air-dry density, volumetric swelling values decreased with increasing heat treatment temperature and time of treatment. Similarly, bending strength, modulus of elasticity in bending, and hardness (longitudinal, radial, and tangential direction) increased in the initial stage of the heat treatment (150°C for 1 and 3 h) and decreased in the later stages. However, compression strength values parallel to the grain showed an increase with the exception of after heat treatment at 200°C for 5 h.While the maximum weight and density loss observed was 9.602 and 15.04 % at 210°C for 5 h, at these heat-treatment conditions, the bending strength and modulus of elasticity in bending approximately decreased 16.82 and 16.11 %, respectively. In addition, hardness values in radial, tangential, and longitudinal directions decreased by approximately 11.17, 12.42, and 9.32 %, respectively. Heat-treated wood has a growing market in outdoor applications such as exterior cladding, windows and door joinery, garden furniture, and decking. There are also many indoor applications for heat-treated wood such as flooring, paneling, and kitchen furnishings and interiors of bathrooms and saunas. Thermal treatment of wood improves its dimensional stability by reducing hygroscopicity. However, because it loses mechanical strength, heat-treated wood is not recommended for head-bearing constructions.

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