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EFFECTS OF HEAT TREATMENT ON TURKISH FIR WOOD PROPERTIES

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ABSTRACT

In this study, Turkish fir wood (*Abies nordmanniana* subsp. *bornmulleriana*) was subjected to two heat treatment process with varying temperatures (150, 180 and 200°C) and durations (2, 4 and 6 h). Some properties of the heat treated Turkish fir wood; mass change, water absorption, volumetric swelling, bending strength, modulus of elasticity (MOE), compression strength parallel to grain, color change and surface roughness have been tested and evaluated by statistical analysis. Consequently, volumetric swelling and water absorption values of the heat treated wood samples reducing. Bending strength, modulus of elasticity and compression strength parallel to grain values were decreased by heat treatment at high temperatures. Additionally, color change and surface roughness values of heat treated wood decreased with weathering compared to those of control samples.

KEYWORDS: Heat treatment, durability, wood strength, weathering.

INTRODUCTION

Wood is used as a nutrient by wood destroying organisms such as fungi, insects and termites. Thus, molecular constituents of wood are broken down by these organisms and assimilated into food cycles. This process can be seen as an advantage for recycling of biomass but, this is not desirable for wood in service situation such as construction components (Hill 2006). Undesirable properties of wood can be improved by the wood preservatives, mainly water and oil based preservatives. Chromated copper arsenate (CCA) was used as a major water-borne wood preservatives for many applications including utility poles, children's playground, residential and commercial applications (Gezer and Cooper 2016, Temiz et al. 2014). Inorganic pentavalent arsenic and hexavalent chromium are classified as hazardous compounds to the environment and human (Gezer and Cooper 2016, Hingston et al. 2001, Temiz et al. 2014, Townsend et al. 2004). Human health and environmental concerns have caused to the restriction of arsenic-containing preservatives in many countries since 2004 (Hingston et al. 2001, Stirling and Temiz 2014, Temiz et al. 2014, Temiz et al. 2013; Townsend et al. 2004). In last two decades, arsenic free wood preservatives including copper and organic co-biocides such as quaternary ammonium compounds, azoles have been introduced into wood protection industry (Gezer and Cooper 2016; Lebow and Tippie 2001, Stirling and Temiz 2014, Temiz et al. 2014). Since copper has high aquatic toxicity, new formulations are under scrutiny. Wood protection industry focused on products and chemicals that has not adverse effect on environment and human health such as thermal modification (Temiz et al. 2013).

Thermal modification is considered as one of the environmentally friendly methods for wood preservation. Heat treatment processes have gained commercial scale industry and known in Europe with different names such as Thermowood in Finland, Platowood in Holland, OHT in Germany and Rectification in France. Thermal modification is based on the heating of wood above the temperature of 200°C without any chemical treatment. In this technology, heating of wood at high temperature causes structural changes in wood i.e. hemicelluloses start to decompose, lignin softens and cellulose modified (Kocaefe et al. 2007). The hemicellulose is the first structural compounds in wood to be thermally affected, even at low temperatures (Esteves and Pereira 2009). The degradation of hemicellulose starts by deacetylation, and the released acetic acid acts as a depolymerization catalyst that further increases polysaccharide decomposition. Acid catalyzed degradation of polymers leads to the formation of formaldehyde, furfural and other aldehyde (Tjeerdsma et al. 1998). Hydroxyl groups of hemicellulose decreased with dehydration reactions (Weiland and Guyonnet 2003). The amount of carbohydrate and its content decreased with increasing treatment factors such as treatment temperature and time. In contrast to hemicellulose, cellulose is lower affected by the heat treatments because of its durable structures (Esteves and Pereira 2009). Additionally, crystallinity of cellulose increases due to degradation on amorphous cellulose resulting in decreased accessibility of hydroxyl groups to water (Boonstra and Tjeerdsma 2006). Guaiacylic and syringyl units of lignin loosed methyl radicals with heat treatment and thus increase of phenolic groups. These chemical reaction lead to higher crosslinking, responsible for the increase of dimensional stability in lignin (Tjeerdsma et al. 1998).

Thermal modification is one of the effective methods to improve the wood properties such as dimensional stability and biological resistance (Bazyar 2012) due to modification of hydrophilic groups in wood. However, thermal modification might cause a decrease some of wood mechanical properties such as density, janka-hardness, bending strength, compression strength, tension strength and modules of elasticity (MOE) in bending due to detrimental effect of long chain

molecules (Akyildiz et al. 2009, Korkut 2008, Korkut et al. 2008, Shi et al. 2007, Unsal and Ayrilmis 2005, Unsal et al. 2003). Researchers generally focused on the effects of temperature, time and wood species on physical and mechanical properties of heat treated wood. However, research on the effect of different heat treatment method on the Turkish fir wood properties which is known non-durable and refractory species is limited.

The purpose of this paper is to compare the effects of two different heat treatment processes on the water adsorption, volumetric swelling, bending strength, MOE, compression strength, color change and surface roughness of heat treated Turkish fir.

MATERIALS AND METHODS

Materials

Turkish fir (*Abies nordmanniana*) sapwood samples were obtained from Kastamonu, province of Turkey. Wood samples were kept at 20 ± 2°C and 65±5 % relative humidity conditions till to constant weight before testing. Before the treatments, wood samples were cut into dimensions of the test samples to determine some physical and mechanical properties according to related standards. Boiled linseed oil was purchased from Yeni Turan™ Ankara, Turkey.

Methods

Heat treatment process

Heat treatment of wood was applied with two different processes. First process was based on oil heat treatment (OHT). In this method, conditioned wood samples were immersed in a preheated linseed oil bath at experiment temperatures (150, 180, and 200 °C) for 2, 4, and 6 h. The end of the treatment, wood samples was removed in oil bath, cleaned and oven dried at 103±2°C for 48 h; cooling with a silica gel in desiccator and weighting (Dubey et al. 2012). Second process was performed in an oven at different temperatures (150, 180, and 200°C) for three different treatment durations (2, 4, and 6 h) under nitrogen atmosphere (N_2).

Water absorption (WA) and volumetric swelling (VS) tests)

Weight percentage change (WPC) of the heat treated wood samples was calculated according to Eq. 1.

$$WPC = 100\times(W_2-W_1)/W_1 , \quad (\%) \tag{1}$$

where: W_2 - the oven dry weight after treatment (g),
W_1 - the oven dry weight before treatment (g) (Dubey et al. 2012).

Water absorption and volumetric swelling test samples were prepared from Turkish fir sapwood according to the (ISO 4859,1982) standard. The test samples (20x20x30 mm) were submerged during 40 minutes in deionized water. W_A and VS values were calculated according to Eq. 2 and 3.

$$W_A = 100\times(Wa-Wb)/Wb, \tag{2}$$

$$V_S = 100\times(Da-Db)/Db, \tag{3}$$

where: Wa - weight at 12% moisture,
Wb - wet weight after water soaking,
Da - wet dimensions after water soaking, D_b= dimensions at 12% moisture (mm).

Mechanical tests

Static bending strength, modulus of elasticity in bending and compression strength parallel to grain tests were performed in accordance with (ISO 3133, 1975; ISO 3349, 1975) and (ISO 3787, 1976), respectively.

Above ground test

Above ground experiment was carried out in Kastamonu, Turkey during 6 months from June to November, 2013. Weathering samples was prepared in 1 x 7.5 x 20 cm (radial x tangential x longiditonal). In addition, color and surface roughness measurements were performed before and after the weathering test.

Color measurement

Konica® Minolta spectrophotometer model CM2500d was used for color evaluation. The L*a*b color space was used for color test, in which L* represents the lightness in the range from black (0) to white (100), and a* and b* are the chromaticity coordinates; +a* for red (+60), -a* for green (-60), +b* for yellow (+60), and -b* (-60) for blue (Temiz et al. 2006). For each test samples, six measurement points were marked before ageing. Color coordinates L*, a*, and b* values were determined both before and after natural weathering test. These values were used to calculate the color change ΔE^* as a function of the total UV irradiation value according to the standard (ISO 7724-2, 1984).

Surface roughness

The Mitutoyo® SJ-201 instrument was used for surface roughness measurements. The mean roughness parameter (Ra) of wood samples was measured according to (DIN 4768, 1990). The length of scanning line was 5 mm and the cut off was 2.5 mm. The measurements were made vertical to the fibers at three different points on each sample. Fifteen replicates were used for each group to evaluate surface roughness.

Statistical evaluation

Test results were evaluated with analysis of variance (ANOVA) by IBM® SPSS program for determining heat treatment factors effects on the experiment. When statistically significant differences were detected, duncan test was used to evaluate realtionship between heat treatment factors at 95% confidence level.

RESULTS AND DISCUSSION

Effect of temperature and time on mass change (MC)

The mass change values difference between OHT and N_2 samples was statistically found to be significant ($P<0.05$, Tab. 1).

Tab. 1: ANOVA results of heat treatment factors effects on the experiment

Experiment	Heat treatment Type (A)	Temperature (B)		Treatment time (C)		(B) x (C)	
		N_2	OHT	N_2	OHT	N_2	OHT
Mass change	*	ns	*	ns	*	ns	*
Water absorption	*	*	ns	ns	ns	ns	ns
Volumetric swelling	*	*	ns	ns	*	ns	ns
Bending strength	*	*	*	ns	ns	ns	ns
MOE	ns	ns	*	ns	ns	ns	ns
Compression strength	*	ns	*	ns	*	ns	ns
Total color change	*	*	*	ns	*	ns	*
Surface roughness	*	*	*	ns	*	ns	*

*: significant at $P<0.05$, ns: not significant

Mass change results are presented in Tab. 2 with water absorption and volumetric swelling. In general, the OHT test samples gained a significant amount of weight due to the oil uptake during to oil-heat treatment process. In fact, OHT treated samples at 150°C for 2 h gained approximately 40% extra mass (Tab. 2). In addition, temperature and time difference of OHT for the MC samples was found to be significant ($P<0.05$, Tab. 1). However, no significant differences for treatment temperature and time were statistically determined between N_2 samples (Tab. 1). N_2 test samples lost a little amount of mass due to the degradation of wood components during heat treatment. The mass change value of N_2 samples were positive at 150°C for 2, 4 and 6 h but, these value were negative at 200°C for 6 h with 5.66% mass loss. The amount of carbohydrate and the wood components decreased with increasing treatment factors such as treatment temperature and time. In contrast to hemicellulose, cellulose is lower affected by the heat treatments because of its durable structures (Esteves and Pereira 2009).

Tab. 2: Effect of heat treatment type, temperature and time on mass change, water absorption and volumetric swelling (%).

Heat treatment	Temp (°C)	Time (h)	Mass change		Water absorption		Volumetric swelling	
Control	-	-	-	-	54.6^{C}	(18.2)	8.71^{A*}	(1.62)**
N_2	150	2	-0.22 ^{D}	(0.28)	36.3^{B}	(5.53)	9.22 ^{A}	(1.00)
		4	-0.19 ^{D}	(0.12)	36.07^{B}	(15.7)	7.83 ^{D}	(0.62)
		6	-2.0 ^{D}	(0.10)	35.97^{B}	(6.75)	7.83 ^{D}	(0.60)
	180	2	-0.59 ^{D}	(0.40)	21.70^{A}	(4.94)	5.44 ^{ABC}	(1.44)
		4	-1.02 ^{CD}	(0.88)	25.10^{AB}	(8.58)	5.91 ^{BC}	(0.63)
		6	-1.94 ^{C}	(0.46)	25.73^{AB}	(9.66)	5.59 ^{BC}	(1.17)
	200	2	-1.85 ^{C}	(0.37)	28.85^{AB}	(11.9)	5.95 ^{CD}	(2.04)
		4	-3.54 ^{B}	(0.28)	18.65^{A}	(6.56)	4.78 ^{AB}	(0.53)
		6	-5.66 ^{A}	(2.42)	18.05^{A}	(7.83)	4.14 ^{A}	(0.85)
Control	-	-	-	-	31.08 ^{E}	(1.99)	9.24 ^{E}	(0.53)

OHT	150	2	39.86 ^{D}	(.20)	7.87 ^{A}	(0.33)	5.44 ^{D}	(0.28)
		4	23.89 ^{BC}	(5.08)	6.98 ^{A}	(0.41)	3.77 ^{AB}	(0.61)
		6	27.56 ^{C}	(4.86)	9.22 ^{B}	(0.91)	4.54 ^{BC}	(0.67)
	180	2	36.76 ^{D}	(4.60)	9.02 ^{B}	(0.84)	4.52 ^{BC}	(0.76)
		4	22.5 ^{B}	(4.88)	11.12 ^{D}	(0.69)	4.70 ^{CD}	(0.71)
		6	15.36 ^{A}	(5.60)	10.04 ^{BCD}	(0.16)	3.95 ^{ABC}	(0.34)
	200	2	13.90 ^{A}	(2.27)	10.46 ^{CD}	(0.46)	4.52 ^{BC}	(0.57)
		4	16.74 ^{A}	(3.82)	9.88 ^{BC}	(0.44)	4.44 ^{BC}	(0.79)
		6	15.03 ^{A}	(3.30)	7.22 ^{A}	(1.12)	3.54 ^{A}	(0.45)

* Similar letter shows no statistical significance

** Numbers of parenthesis are standard deviation

Effects of temperature and time on water adsorption and volumetric swelling

Test results of W_A showed that heat treatment samples had lower water absorption values than the control samples. W_A values difference between OHT and N_2 samples was statistically found to be significant ($P<0.05$, Tab. 1). Additionally, W_A values of samples decreased with increasing treatment temperatures from 150 to 200°C (Tab. 2). The lowest W_A values of N_2 treatment samples were found in at 200°C for 6 h (18%) for OHT samples at 180°C for 6 h (7%) (Tab. 2). OHT samples gained extra hydrophobic characteristics due to oil uptake during heat treatment. Thus, OHT samples showed low water absorption values than N_2 treatment. OHT was more effective treatment for stabilization of wood against water. Additionally, no significant difference was observed between W_A values in OHT samples for treatment temperature and time (Tab. 1).

Tab. 2 presents the effect of heat treatment temperature and time on volumetric swelling (VS) of the fir wood. The VS values of the heat treated fir wood decreased compared to the control samples. In addition, VS values of OHT and N_2 samples decreased with increase in treatment temperature. Regarding to VS values; heat treatment type difference, temperature difference in N_2 and treatment time difference in OHT was statistically found to be significant. Wood becomes more stable against water after heat treatments at high temperatures (Dubey et al. 2012). Additionally, VS values of OHT samples were lower than N_2 treated samples. This situation can be explained by extra hydrophobic characteristics of OHT samples. The lowest VS values were found in OHT (3.38%) and N_2 (4.14%) samples treated at 200°C for 6 h (Tab. 2).

Effect of temperature and time on mechanical properties

Tab. 3 shows the changes in bending strength (BS) values caused by the heat treatment. Heat treatment type for the BS test was statistically found to be significant ($P<0.05$, Tab. 1). The BS values were increased range from 3.75 to 12.98% with OHT. However, BS values of N_2 samples showed a decrease with increasing treatment temperature. It is reported that heat treatment reduces some mechanical properties (Akyildiz et al. 2009, Korkut 2008, Korkut et al. 2008, Shi et al. 2007, Unsal and Ayrilmis 2005, Unsal et al. 2003). Heat treatment method in oil might be used to reduce detrimental effect of heat process on bending strength due to oil uptake during to oil heat treatment process. Maximum decreasing ratios of bending strength were 8.25% for N_2 treated samples at 200 °C for 6 h. Heat treatment temperature for all test samples was statistically found to be significant ($P<0.05$, Tabs. 1,3). Heat treatment in the air medium lead to higher loss in mechanical properties than heat treatment carried out in an inert gas atmosphere such as N_2 and OHT. Heating wood in the presence of water or steam causes the formation of organic acids, which catalyzes the hydrolysis of the hemicelluloses to soluble sugars, thus accelerating the degradation level (Mitchell 1988).

Tab. 3 indicated the changes in MOE values caused by the heat treatment. OHT temperature difference for the MOE test was statistically found to be significant (P<0.05, Tab. 1). MOE values of test samples increased a little amount with heat treatment. Maximum increasing ratios of MOE samples were 9.1 % for N_2 treatment at 150°C for 4h. According to (Mitchell 1988), heat treatment in nitrogen atmosphere there was no decrease of MOE values of wood samples, while with air decrease was observed. In addition, some researchers reported that a slight increase of MOE showed after the heat treatment (Esteves et al. 2007, Santos 2000). Tab. 3 shows the changes in the compression strength parallel to grain at different treatment temperature and time. Statistical tests show that effect of heat treatment type were significant at compression strength parallel to grain test (P<0.05, Tab. 1). Moreover, effect of different OHT temperature and time significant for this test (P<0.05, Tabs. 1, 3).

Tab. 3: Effect of heat treatment type, temperature and time on bending strength, MOE and compression strength ($N.mm^{-2}$).

Heat treatment	Temp (°C)	Time (h)	Bending strength		MOE		Compression strength	
Control	-	-	60.14 ^{AB}	(4.36)	7381.67 ^{A}	(682.75)	39.10 ^{A*}	(3.77)**
N_2	150	2	62.19 ^{AB}	(3.00)	773870 ^{AC}	(683.87)	40.45 ^{AC}	(1.61)
		4	65.25 B	(2.47)	8383.35 ^{C}	(353.319	39.41 ^{AB}	(1.57)
		6	63.22 ^{AB}	(4.40)	7924.40 ^{AC}	(441.96)	41.00 ^{AC}	(2.43)
	180	2	61.54 ^{AB}	(2.97)	7546.43 ^{AB}	(530.01)	41.14 ^{AC}	(1.80)
		4	61.93 ^{AB}	(4.31)	8039.55 ^{AC}	(296.14)	41.89 ^{AC}	(1.97)
		6	59.27 ^{AB}	(2.07)	7386.19 A	(445.46)	44.42 ^{C}	(1.19)
	200	2	62.65 ^{AB}	(5.76)	8215.55 ^{BC}	(326.72)	41.83 ^{AC}	(1.79)
		4	58.22 ^{A}	(5.61)	7633.93 ^{AC}	(762.58)	42.07 ^{BC}	(1.10)
		6	57.69 ^{A}	(4.03)	7860.18 ^{AC}	(633.10)	42.82 ^{C}	(1.42)
Control	-	-	62.89 ^{AB}	(2.95)	7681.64 ^{AB}	(376.53)	33.90 ^{A}	(0.85)
OHT	150	2	67.12 ^{BC}	(2.02)	7782.71 ^{AB}	(512.87)	33.23 ^{A}	(1.27)
		4	59.95 A	(6.69)	7643.18 ^{AB}	(595.18)	39.58 ^{C}	(1.01)
		6	65.25 ^{AC}	(4.26)	746.41 ^{A}	(562.58)	39.03 ^{BC}	(1.34)
	180	2	68.68 ^{BC}	(4.86)	8138.24 ^{AB}	(470.69)	33.39 ^{A}	(1.68)
		4	70.11 ^{BC}	(6.58)	7943.57 ^{AB}	(609.53)	40.49 ^{C}	(2.33)
		6	71.05 ^{C}	(2.81)	8175.92 ^{AB}	(676.76)	40.47 ^{C}	(2.32)
	200	2	69.73 ^{BC}	(6.79)	8049.88 ^{AB}	(704.48)	37.02 ^{B}	(1.48)
		4	69.54 ^{BC}	(3.28)	8357.26 B	(335.81)	41.35 ^{C}	(2.01)
		6	67,28 ^{BC}	(6.27)	8042.84 ^{AB}	(664.77)	41.32 ^{C}	(2.72)

* Similar letter shows no statistical significance

** Numbers of parenthesis are standard deviation

Effect of temperature and time on above ground

Tab. 4 shows the changes in the total color change at different treatment temperature and time. Total color change of N_2 treated samples increased with increase in treatment temperature and time. Similar results were reported by other researchers. In their studies, they reported that color change of wood material increased with the treatment temperature (Kačíková et al. 2013, Barcík et al. 2015). The total color change ΔE^* of the N_2 samples range from 4.78 to 29.64 at 150°C for 2h and 200°C for 6h. However, the total color change values of the OHT samples at

same condition were 40.33 and 58. In addition, total color change of OHT samples was higher than N_2 samples. Fig. 1 shows total color change of OHT wood samples after weathering. The highest ΔE* values was seen on the untreated control samples during the weathering. However, heat treatment provided color stability of wood. A low total color change ΔE* refer a stable color (Yildiz et al. 2011). Moreover, OHT samples have more color stability than N_2 samples. Heat treatment was improving color stability of wood against weathering (Temiz et al. 2006).

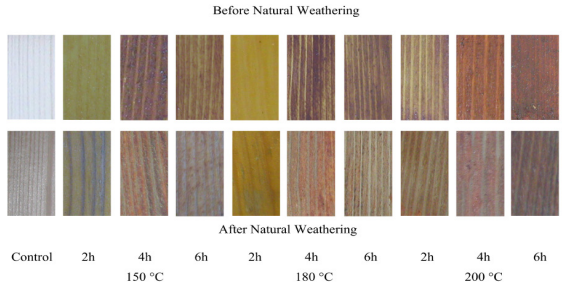

Fig. 1: Color change of OHT wood samples.

Tab. 4: Effect of heat treatment type, temperature and time on color change.

Before weathering				After weathering				
	Temp (°C)	Time (h)	Color Change	1. months	3. months	4. months	6. months	Total
N_2	Control		-	13.8 (3.51)	6.84 (2.50)	6.68 (2.34)	4.91 (2.46)**	323 ^{D*}
	150	2	4.8 ^{A} (1.9)	9.23 (2.79)	6.62 (2.58)	6.72 (2.26)	5.31 (3.14)	27.,9 ^{C}
		4	6.5 ^{A} (2.0)	9.52 (2.79)	6.73 (1.67)	7.01 (2.47)	3.99 (2.79)	27.2 ^{C}
		6	13.8 ^{B} (3.9)	6.94 (2.87)	6.58 (1.80)	6.98 (2.22)	4.51 (3.02)	25.0 ^{BC}
	180	2	15.2 ^{B} (3.2)	6.00 (3.17)	7.15 (3.02)	6.96 (1.45)	3.42 (1.45)	23.5 ^{AB}
		4	20.8 ^{C} (2.5)	7.12 (3.32)	6.54 (2.27)	7.19 (2.36)	4.70 (1.50)	25.5 ^{BC}
		6	23.2 ^{D} (2.6)	4.86 (3.00)	5.17 (2.03)	7.09 (2.44)	4.24 (2.06)	21.3 ^{A}
	200	2	24.0 ^{D} (5.1)	8.99 (5.35)	6.70 (3.58)	7.99 (2.55)	3.87 (1.30)	27.5 ^{C}
		4	28.8 ^{E} (2.6)	9.98 (4.22)	5.06 (1.84)	7.14 (2.76)	4.36 (2.04)	26.4 ^{BC}
		6	29.6 ^{E} (3.7)	0.4 (4.36)	5.53 (3.48)	7.04 (2.76)	4.45 (2.20)	27.4 ^{C}

OHT	Control		-	20.2 (2.5)	7.97 (1.93)	7.54 (2.17)	3.08 (1.35)	38.8 F
	150	2	40.3 B (3.7)	12.8 (2.4)	6.27 (2.46)	3.26 (1.52)	2.96 (1.95)	25.1 E
		4	45.1 C (1.8)	3.4 (1.6)	4.87 (2.0)	2.86 (1.77)	3.10 (2.40)	14.2 AB
		6	52.6 F (2.4)	5.6 (2.2)	7.31 (3.09)	2.79 (2.05)	2.69 (1.32)	18.4 C
	180	2	33.2 A (2.9)	10.8 (1.5)	7.39 (4.30)	3.05 (1.84)	2.64 (1.45)	23.8 DE
		4	49.0 DE (3.6)	5.2 (2.5)	7.92 (4.06)	3.01 (2.03)	3.07 (2.04)	19.1 C
		6	48.5 D (2.7)	4.3 (15)	6.14 (3.31)	2.70 (1.41)	2.67 (2.09)	15.9 B
	200	2	50.9 E (4.1)	7.7 (3.3)	7.43 (4.19)	4.40 (2.96)	3.07 (1.68)	22.6 D
		4	52.8 F (3.3)	4.1 (1.3)	5.30 (2.50)	2.71 (1.19)	1.78 (1.00)	13.9 AB
		6	58.0 G (3.0)	3.2 (1.8)	4.57 (2.60)	2.83 (2.11)	1.97 (1.07)	12.6 A

* Similar letter shows no statistical significance

** Numbers of parenthesis are standard deviation

Effect of temperature and time on surface roughness

The average surface roughness values (Ra) of unweathered (control) and weathered samples are listed in Tab. 5.

Tab. 5: Effect of temperature and time on surface roughness.

Heat treatment	Temp (°C)	Time (h)	Unweathered		4. months		6. months	
N_2	Control		4.97	(1.62)	11.10	(3.95)	11.22AB*	(3.36)**
	150	2	3.93	(1.01)	10.55	(2.70)	13.28 B	(2.97)
		4	3.32	(0.84)	9.09	(3.09)	8.26 A	(2.43)
		6	4.28	(1.42)	9.20	(2.77)	10.75AB	(3.78)
	180	2	6.32	(0.97)	1.36	(4.05)	12.48 B	(3.55)
		4	4.70	(0.89)	12.93	(4.98)	13.44 B	(4.73)
		6	5.46	(1.74)	10.61	(2.78)	11.09AB	(2.79)
	200	2	4.10	(0.73)	9.81	(2.01)	10.13AB	(1.79)
		4	4.09	(1.06)	9.62	(1.38)	10.27AB	(2.04)
		6	5.03	(2.17)	9.28	(3.44)	11.03AB	(4.80)

OHT	Control		6.29	(2.35)	9.93	(3.15)	11.31^{D}	(4.54)
	150	2	5.43	(2.18)	3.24	(1.21)	3.9^{A}	(1.07)
		4	5.59	(2.21)	4.78	(2.82)	4.96^{ABC}	(2.14)
		6	6.95	(2.26)	5.34	(1.89)	5.08^{ABC}	(1.54)
	180	2	8.06	(1.67)	5.67	(2.74)	8.80^{CD}	(1.50)
		4	5.59	(3.70)	3.96	(1.50)	4.45^{AB}	(2.28)
		6	6.29	(1.44)	7.11	(2.50)	8.35^{BCD}	(2.74)
	200	2	8.12	(3.07)	6.47	(2.68)	9.07^{CD}	(3.91)
		4	8.37	(2.28)	9.50	(4.50)	1.34^{D}	(4.09)
		6	6.83	(2.31)	8.54	(2.17)	8.37^{BCD}	(2.21)

* Similar letter shows no statistical significance

** Numbers of parenthesis are standard deviation

Generally, the surface roughness values of untreated wood higher than heat treated wood. The findings indicate that weathering factors was caused by an increase in checks, splits and cracks on wood surfaces. However, surface roughness of some OHT wood samples decreased with weathering. In the literature, using artificial weathering test helps in removing and washing solubilized degradation products from the wood surface. Also, water causes removing loosening fibers and particles produced during the artificial irradiation (Kamdem and Stephane 2002; Temiz et al. 2005). As seen in the Tab. 5. surface roughness value (Ra) of untreated samples of Turkish fir wood increased with weathering time but surface roughness of OHT samples decreased because water helps washing solubilized degradation products from the wood surface (Temiz et al. 2005).

CONCLUSIONS

Turkish fir wood was heat treated with two methods at 3 different temperatures and times. Heat treatments decreased water absorption. The decreasing of water absorption was found to from 54.66 % to 18.05 %, in N_2 samples and from 31.08 % to 7.22 % in OHT samples at 200°C for 6 h. While, the control sample of VS was found 9.24%, treated wood samples was found from 9.22 % to 3.38 %, depending on treatment factors. Generally, mechanical strengths of OHT wood are a little increase due to the oil uptake but some decreases were observed in N_2 wood samples at high temperatures. Total color change of heat treated wood samples was decreased with heat treatment during the weathering. Thus, it can be concluded that heat treatment improve the color stability of wood against weathering. Additionally, surface roughness values of treated samples were found to be positive.

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