A Comparative Study of the Physical Properties of Thermally Treated Poplar and Plane Woods

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Effects of heat treatment on some physical properties of poplar and plane wood specimens were investigated. The main aim was to compare effects of heat on some physical properties of low-density poplar wood and high-density oriental plane wood. Heat treatment was conducted at temperatures of 150 and 200 °C for 3 h in the presence of air at atmospheric pressure. After the heat treatment, the mass loss; oven-dried density; tangential, radial, and volumetric swelling; fiber saturation point; and moisture content were determined. Regression analyses between mass loss and volumetric swelling were performed. The findings were analyzed statistically with ANOVA and the T-test. The results showed that heat treatment at 200 °C influenced the physical properties of both poplar wood and plane tree wood. In addition, the heat treatment had a little greater effect on the swelling and fiber saturation point of poplar wood than it did on the properties of plane wood.

Keywords: Heat treatment; Thermal treatment; Physical properties; Poplar wood; Plane wood

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INTRODUCTION

Wood has some superior advantages compared to other engineering materials. It can be formed easily with simple tools, and it is a renewable, recyclable, biodegradable, and relatively inexpensive material (Risbrudt 2005). However, it also has some disadvantages, such as its lack of biological durability, its hygroscopicity, and its dimensional instability (Simpson and Tenwolde 1999). To overcome these disadvantages, methods for modifying wood have been developed and applied. To increase its biological durability, wood can be treated with chemical substances by different impregnation methods, but such substances can be environmentally hazardous (Kocaefe *et al*. 2008; Gündüz *et al*. 2008; Garcia *et al*. 2012). Heat treatment is also used to modify wood, and several different processes have been developed for this purpose, including the oil heat treatment, Thermowood, Rectification, Huber Holz, Le Bios Perdure, and Plato processes (Esteves and Pereira 2009).

The wood of different types of trees has different physical, chemical, and mechanical properties. The proportions of chemical components, such as cellulose, hemicelluloses, lignin, and extractives, differ from one type of tree to another. As a result of these differences, heat treatment can be expected to have a different effect on the wood from different types of trees. In addition, the different types of woods that exist in the trunk of the same tree have different properties. For example, the physical, mechanical, and chemical properties of juvenile wood, mature wood, heartwood, and sapwood usually are different, even though these different types of wood exist in the same tree. The effects of heat on these different types of wood vary. On this subject, Kortelainen *et al*. (2006) studied the water absorption of heat-treated sapwood and heartwood of Scots pine and Norway spruce, and the results showed that the sapwood and heartwood absorbed different quantities of water. Severo *et al*. (2012) studied the physical and chemical changes in heat-treated juvenile and mature woods of *Pinus elliottii*, and the results demonstrated that heat treatment had less of an effect in juvenile wood than in mature wood. Bal (2013) studied the physical properties of heat-treated *Cedrus libani* heartwood and sapwood and noted that "the differences between the physical properties of heartwood and sapwood were not clear at 140, 160, 180, and 200 °C, but there were clear differences when the samples were treated at 220 °C." Aydemir *et al.* (2011) studied low-density Uludağ fir and high-density hornbeam wood, and they reported that the relative decrease in swelling and water absorption for Uludağ fir wood was higher than for hornbeam wood. In these studies, the authors indicated that density, extractives content, and chemical properties affected the results of the heat treatment. Some researchers who conducted experiments on wood from different types of trees, including beech, pine, spruce, and poplar, reported that heat treatment affected swelling of high-density woods to a greater extent than low-density woods (Giebeler 1983; Tjeerdsma *et al*. 1998). Even so, it remained unclear how heat treatment using hot air would affect low-density and high-density woods. Therefore, in this study, it was investigated how such heat treatment affects the physical properties of low-density poplar wood and high-density plane wood.

EXPERIMENTAL

Materials

Poplar (*Populus x euramericana* I-214) lumber and oriental plane lumber (*Platanus orientalis* L.) were obtained from a lumberyard in Kahramanmaraş, Turkey. The lumber was cut into sticks with dimensions of 30 x 30 x 1000 mm (width x height x length), and the test specimens were prepared from these sticks. The dimensions of the test specimens were 30 x 30 x 15 mm (width x height x length). Figure 1 shows the specimen preparation plan. As samples were cut from the sticks, they were assigned to different test groups as a means of reducing the heterogeneity of the wood. Twenty-five specimens were prepared for each test group.

Methods

Samples were dried in an electrical oven at 103±3 °C until their moisture content was 0%. Then, they were weighed. Heat treatment was performed at temperatures of 150 and 200 °C for 3 h in air and at atmospheric pressure. Heating time of the samples at 150 °C and 200 °C were approximately 45 and 75 min, respectively. After heat treatment, the oven was switched off, and the samples were cooled in the same oven. The samples were not humidified before, during, or after heat treatment. After heat treatment, the weights and dimensions (width x height x length) of the test samples were measured again to obtain their oven-dried densities. The samples were stored in a room at ambient conditions for five days, after which the samples were immersed in water for two weeks. The samples were removed from the water, and the dimensions and weights of the samples were measured to calculate moisture content, fiber saturation point, and swelling percentage. The density values, linear swelling (tangential and radial), and volumetric swelling were determined according to Turkish standards TS 2471, TS 2472, TS 4084, and TS 4086, respectively. Mass loss (*ML*) and fiber saturation point (*FSP*) were calculated using equations (1) and (2), respectively,

$$ML\ (\%) = ((M_1 - M_2) / M_1) \times 100 \quad (1)$$

where *ML* is the mass loss, M_1 is the mass of the sample after being dried in an oven at 103 °C before heat treatment, and M_2 is the mass of the sample after heat treatment.

$$FSP\ (\%) = (V_s / D_o) \times 100 \quad (2)$$

In Eq. 2, *FSP* is the fiber saturation point, V_S is volumetric swelling, and D_o is oven-dried density.

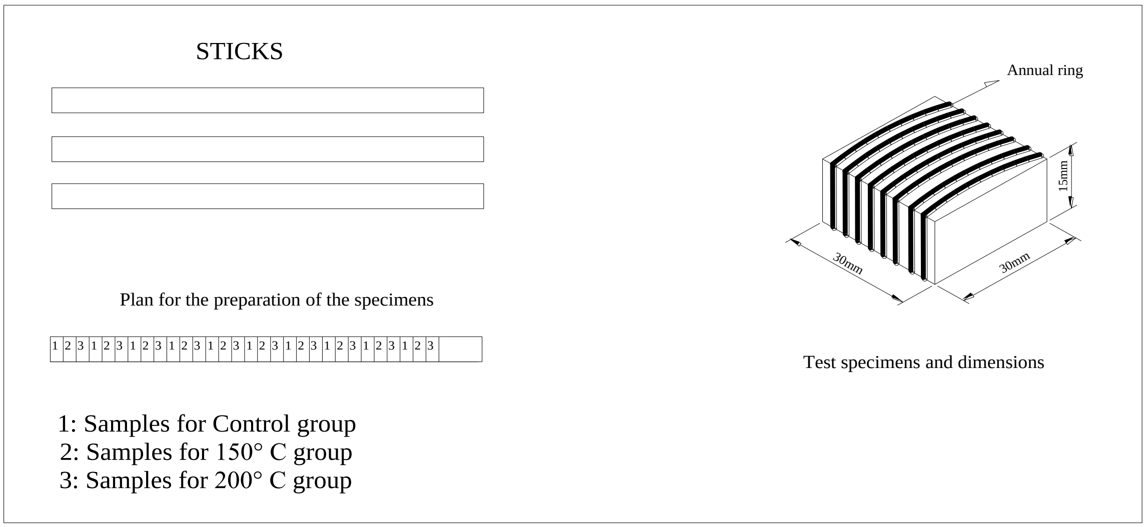

Fig. 1. Preparation of test specimens from sticks and the dimensions of the specimens

RESULTS AND DISCUSSION

Table 1 shows the density, mass loss, swelling percentage, anisotropic factor (S_T/S_R), fiber saturation point, and moisture content of both poplar and plane wood. In addition, the significance levels of one-way ANOVA and T-test (for *ML*) are given below the properties. When the data in Table 1 were analyzed, it could be seen that the physical properties of poplar wood treated at 150 °C were not statistically different from those of the control group. However, when the poplar wood was treated at 200 °C, all of its properties except density and moisture content were significantly different from those of the control group. The physical properties of plane wood treated at 150 °C were not significantly different from those of the control group. However, the physical properties of plane wood that was heat-treated at 200 °C were significantly different from those of the control group. Thus, it can be stated that a heat-treatment temperature of 150 °C did not affect the physical properties of either poplar or plane wood, but, when both types of wood were heat treated at 200 °C, their properties were changed significantly. Actually the wood treated at 150 °C does not belong to the category of thermally treated wood. Rather, it can be regarded as high temperature dried wood. Ibach (2010) and Cademartori *et al*. (2013) stated that many of the commercial heat treating processes take place in the absence of air at temperatures ranging from 180 to 260 ^oC. As mentioned above, Table 1 showed that the properties of wood treated at 150 ^oC were not statistically different from those of the control group. In previous studies, the influence of heat treatment on the chemical composition of treated wood was investigated. Brito *et al*. (2008) reported that hemicelluloses of thermally treated wood decreased, and lignin content increased significantly when compared to the original wood from both *Pinus* and *Eucalyptus*. But glucose content did not alter to a significant extent. Similar results about decrease of holocellulose and increase of lignin were reported by Cademartori *et al*. (2013) and Pena *et al*. (2009). According to Ibach (2010), improved dimensional stability is thought to be due to loss hydroscopic hemicelluloses sugars and their conversion to less hydroscopic furan-based polymers. In addition, Kocaefe *et al*. (2008) noted that "hydroxyl groups in hemicelluloses are much more accessible to water than those of cellulose because of the amorphous structure. Removal of hemicelluloses decreases hygroscopicity. It also increases the crystalline part in wood material due to relative increase of cellulose component."

Mass loss is an indicator value of heat treatment, and, at severe conditions, it can be very high. In addition, the mass loss of some conifer trees during heat treatment may be very high because these trees contain greater amounts of extractive components. In this study, the mass loss of the plane wood was a little greater than that of the poplar wood. According to Ibach (2010), in general, mass loss occurs to a greater extent in hardwoods than in softwoods. With this in mind, one would think that the percentage decrease in the swelling properties of the poplar wood would be less than that of plane wood, but the opposite results were observed. Thus, other factors, such as density, the properties of the fibers, the amount of rays, and different chemical properties, may have contributed to this discrepancy. Concerning this issue, Garcia *et al*. (2012) reported that the results of heat treatment were influenced by the species of wood, the chemical and anatomical characteristics of the wood, the initial moisture content of the wood, and various process parameters, such as the treatment media, the processing temperature, and the processing time. As shown in Table 1, all swelling percentages of plane wood were determined to be greater than those of poplar wood. In general, as the density of wood increases, the swelling percentages also increase. Some researchers have indicated that there is a strong relationship between density and volumetric swelling (Simpson and Tenwolde 1999; Bal and Bektaş 2012a).

Fiber saturation point percentages of both poplar and plane wood were influenced significantly by heat treatment at 200 °C (Table 1). Similar results were obtained for heat treated wood in previous studies. Almeida *et al.* (2009) studied wood-water relationships of heat treated three *Eucalyptus* species, results showed that fiber saturation point values decreased with an increase of treatment temperature for three species, especially at temperature higher than 220 °C. Bal and Bektaş (2012b) studied that the effects of heat treatment on the physical properties of juvenile wood and mature wood of *E. grandis,* and they noted that fiber saturation point values were different only for the groups of samples that were treated at 180 °C. In another study, Bal (2013) studied that effects of heat treatment on the physical properties of heartwood and sapwood of *Cedrus libani*, and it was reported that the percentage decreases of fiber saturation point were greater for sapwood than for heartwood.

Table 1. Physical Properties of Poplar Wood and Plane Wood

		D	ML	S_T	S_R	S_T/S_R	S_V	FSP	MC
		kg/m³	%	%	%	-	%	%	%
Poplar wood	Control	377	-	9.0a[1]	3.4a	2.7a	12.4a	32.9a	184
		(30)	-	(0.5)[2]	(0.3)	(0.3)	(0.7)	(1.8)	(15)
	150 °C	376	0.56a	8.7a	3.4a	2.6ab	12.1a	32.0a	182
		(27)	(0.12)	(0.4)	(0.3)	(0.2)	(0.6)	(1.4)	(17)
	200 °C	367	2,35b	6.2b	2.6b	2.4b	8.8b	24.1b	174
		(28)	(0.45)	(0.7)	(0.3)	(0.4)	(0.9)	(2.4)	(14)
	Significance level	NS	***	***	***	**	***	***	NS
		D	ML	S_T	S_R	S_T/S_R	S_V	FSP	MC
		kg/m³	%	%	%	-	%	%	%
Plane wood	Control	683a	-	12.6a	3.9a	3.3a	16.5a	24.1a	97a
		(10)	-	(0.8)	(0.6)	(0.6)	(0.92)	(1.3)	(2)
	150 °C	680a	0.61a	12.5a	3.8a	3.3a	16.3a	24.0a	95a
		(11)	(0.12)	(0.8)	(0.6)	(0.6)	(1.0)	(1.5)	(2)
	200 °C	660b	3.20b	8.9b	3.1b	2.9b	12.0b	18.2b	89b
		(12)	(0.74)	(0.8)	(0.6)	(0.5)	(1.2)	(1.6)	(3)
	Significance level	***	***	***	***	*	***	***	**

[1]Means followed by the same letter are not significantly different.
[2]Standard deviations are shown in parentheses.
D: Oven dried density, ML: Mass loss, S_T: Tangential swelling, S_R: Radial swelling, S_T/S_R: anisotropic factor, S_V: Volumetric swelling, FSP: Fiber saturation point, MC: Moisture Content, NS: nonsignificant

Table 2 shows the percentage decrease of the physical properties of poplar and plane wood after heat treatment. The physical properties of low-density poplar wood were affected to a little greater extent by heat treatment than that of high-density plane wood, with the exceptions of the anisotropic factor and moisture content. Thermal treatment makes the anisotropic of wood's swelling smaller, which can be considered as another advantage. Bal and Bektaş (2012b) studied low-density juvenile wood and high-density mature wood of *E. grandis,* and Aydemir *et al.* (2011) studied low-density Uludağ fir and high-density hornbeam wood, and they reported similar results

In addition, the difference in the anisotropic factor may originate from the amount of rays; plane wood has more rays than poplar wood. Many researchers have noted that heat treatment results in a greater reduction of S_T than of S_R (Gündüz *et al*. 2008; Korkut and Guller 2008; Almeida *et al.* 2009; Calonego *et al*. 2012; Bal 2013). In addition to the other positive results of heat treatment, this reduction in the anisotropic factor results in less tension in the wood when it is exposed to changes in climatic conditions (Militz 2002; Almeida *et al*. 2009).

Another factor that influenced the results was the density of the wood. The density of the wood is a key factor because it has a significant effect on the physical and mechanical properties of the wood. As the density of wood increases, its mechanical properties, swelling, and shrinkage percentage also increase (Simpson and Tenwolde

1999). Additionally, it has been reported that the extractive content of wood influences the relationship between density and swelling percentage (Bal 2013).

Table 2. Percentage Decreases in the Physical Properties of Poplar and Plane Wood

	S_T	S_R	S_T/S_R	S_V	FSP	MC
Poplar wood						
Control	0.00	0.00	0.00	0.00	0.00	0.00
150 °C	2.82	0.53	2.65	2.19	2.70	1.36
200 °C	30.63	22.91	9.36	28.52	26.66	5.70
Plane wood						
Control	0.00	0.00	0.00	0.00	0.00	0.00
150 °C	0.75	1.44	-0.02	0.91	0.41	1.67
200 °C	29.31	19.08	12.30	26.90	24.37	7.77

The relationship between mass loss and volumetric swelling of poplar wood and plane wood was negative, as indicated in Fig. 2-A and 2-B, respectively. The coefficients of determination (R^2) for poplar wood and plane wood were determined to be 0.53 and 0.79, respectively. Both relationships were linear and negative, *i.e.*, volumetric swelling decreased as mass loss increased. Mass loss occurs in the wood components during heat treatment, especially at higher temperatures. Hemicelluloses are degraded, the degree of cellulose crystallinity increases, and a crosslinking occurs between lignin and other wood polymers. As a result of these changes, wood becomes less hygroscopic (Kocaefe *et al*. 2008; Calonego *et al*. 2012).

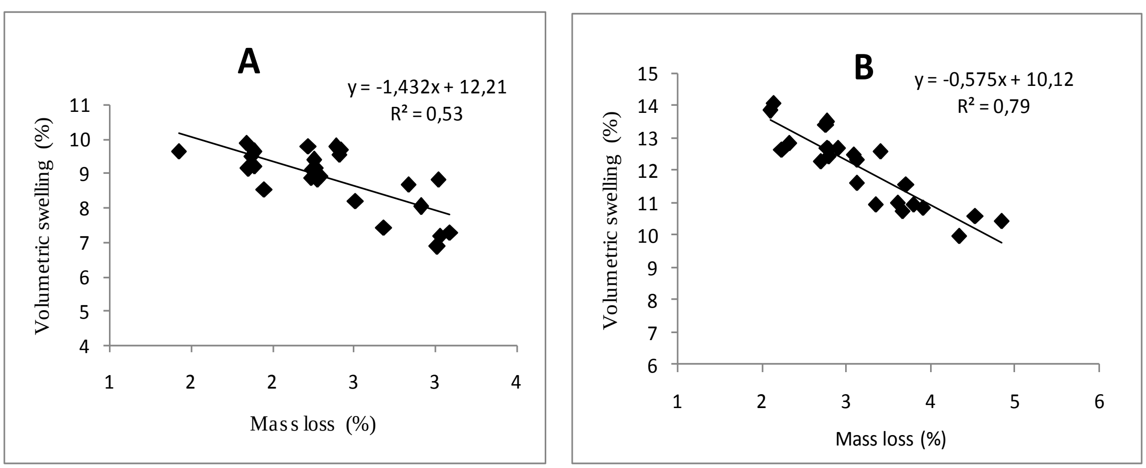

Fig. 2. Relationships between *ML* and *VS* for the 200 °C group (A: poplar wood, B: plane wood)

CONCLUSIONS

1. Changes in the physical properties of both poplar wood and plane wood treated at 150 °C were insignificant compared to the control group. However, when the treatment temperature was 200 °C, statistically significant changes were observed in

the properties of both types of wood, with the exception of the density and moisture content of poplar wood.

2. The relationships between mass loss and volumetric swelling were strong, and both relationships were negative. The coefficient of determination of plane wood was greater than that of poplar wood.
3. Percentage swelling decreases and the fiber saturation point of plane wood were lower than those of poplar wood, *i.e.*, the increased heat-treatment temperature had a little greater impact on poplar wood.
4. As expected, tangential swelling decreased to a greater extent than did radial swelling. The anisotropic factor decreased in both poplar and plane wood when the heat-treatment temperature was 200 °C.

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