Effect of Heat Treatment on Surface Characteristics of Wild Cherry Wood

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Heat treatment effects on surface properties of wild cherry (*Prunus avium*) including surface roughness, glossiness, and color stability were evaluated. Samples were exposed to a temperature of 212 °C for 1.5 and 2.5 h. A stylus type profilometer, glossmeter, and spectrophotometer were employed to determine surface characteristics of heat-treated specimens. Glossiness and surface roughness values of the samples decreased with heat treatment compared to those of control specimens. The glossiness and values of surface roughness decreased for the samples with all treatment combinations. The samples had significant discoloration as a result of heat exposure. Color difference of the specimens increased as a result of all treatment schedules.

Keywords: Heat treatment; Wild cherry; Surface roughness; Glossiness; Color stability

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INTRODUCTION

Heat treatment of wood has been developed in Europe within the last 20 years. The main objective of heat treatment is to improve the physical and mechanical properties of wood and wood products so that they can be used more effectively during their service life (Kasemseri *et al.* 2012; Bakar *et al*. 2013; Dilik and Hiziroglu 2012). Typical heat exposure of wood takes place at temperatures of 120 °C to 280 °C and exposure times ranging from 24 h to 15 min, respectively depending on the process (Kasemseri *et al*. 2012; Bakar *et al*. 2013).

In previous studies, properties of heat-treated Eastern red cedar samples were investigated (Dilik and Hiziroglu 2012), and spruce, beech, and hazelnut wood were exposed to heat treatment using temperature levels of 120 °C and 200 °C for 24 h (Yildiz 2002; Yildiz *et al*. 2006; Korkut and Hiziroglu 2009). It was concluded that overall strength properties of such species decreased due to heat treatment, increasing temperature, and exposure time (Kasemsiri *et al*. 2012; Bakar *et al*. 2013; Yildiz 2002).

Surface roughness of solid wood and wood products plays an important role for the finishing process. Overall quality of the sanding and the quantity of the finishing that will be used for an accepted finishing process are two main issues closely related to the surface of the wood material. Currently there is no accepted quantitative method used to evaluate surface roughness of solid wood. The stylus method has been successfully used for various experimental studies (Hiziroglu 1996; Hiziroglu and Graham 1998). A study on the surface roughness of heat-treated Eastern red cedar found that surface quality of the samples exposed to higher temperature was enhanced as a result of possible changes of bio-chemical constituents in the cell wall (Bakar *et al*. 2013). In the same study oak specimens had the highest surface roughness values among the others even though longer exposure time was used.

Color of wood is also important from the viewpoint of aesthetic and hedonic concepts for the consumers. Depending on culture, country, and income level, wood products may have higher market volume solely due to its color. Heat treatment would also provide an inexpensive alternative method to darken wood to imitate more expensive exotic species.

It is known that wood changes its color as a result of complex chemical degradation of lignin and extractives during heat exposure. Hemicelluloses are the most sensitive components of wood for thermal treatment. While lignin and extractives may be better known for their contributions to color change, hemicelluloses also can contribute (Sandoval-Torres *et al*. 2012). Surface discoloration of wood has been studied in several previous investigations (Yildiz *et al*. 2011; Chen *et al*. 2012). In one of these studies the CIE $L^*a^*b^*$ system was employed successfully to evaluate color changes of heat-treated specimens (Akgül and Korkut 2012).

Wild cherry (*Prunus avium*) is a deciduous tree that grows to a height of 15 to 30 m, with a trunk diameter up to 1.5 m. *P. avium* is native to Europe, western Turkey, and northwestern Africa. Its wood is hard, reddish brown, and widely used for wood turning, manufacturing cabinet, veneer, and musical instruments (Eşen *et al*. 2005). Recently the use of wild cherry wood has grown in popularity in Turkey and surrounding countries due to its high demand. Both mechanical and physical characteristics of this species have been investigated, but there is limited or no information on how heat treatment would effect its surface quality and color changes. Therefore, the main objective of this work was to obtain initial data on surface roughness, discoloration, and glossiness of heat-treated wild cherry wood so that such species can be used more effectively and efficiently to produce value-added products.

EXPERIMENTAL

Materials and Methods

Three trees with a diameter at breast height of 45 cm were harvested from mixed stands in Duzce, Turkey. Defect-free small clear samples were cut from the lumber with 150 mm thickness. Wild cherry lumber was finished with a fixed-knife planer at a feed speed of 1 m/s. The bias angle of the knife was 45^o for the lumber. If the wood pieces are sawn so that the annual rings are at least at a 45^o angle to the surface, the deformations will be smaller, the hardness of the surface will be stronger, and the ‘‘general looks’’ after heat treatment is better. A total of 40 specimens were prepared for measurements of surface properties. Specimens measuring 100 mm by 100 mm by 10 mm were used for roughness and glossiness measurements, and samples measuring 50 mm by 50 mm by 10 mm were used for color measurement tests.

After all samples were conditioned in a climate chamber at 20^oC and relative humidity of 65%, they were heat treated (ISO 554 1976). A commercial heat treatment process described in the Finnish TermoWood Handbook was followed for heat treatment of the specimens (Anonymous 2003). The facility of a local company, Nova ThermoWood, Gerede was employed for the treatment.

Samples were exposed to an initial temperature of 100^oC in a pilot type commercial oven until they reached the temperature (130^oC) of the oven before they were kept at a target temperature of 212°C for 1.5 and 2.5 h. In the final stage of treatment schedule, temperature of the oven was reduced to 80°C using a water spray system, resulting in an average moisture content of 6% of the samples. Following heat treatment the specimens were conditioned in a climate chamber at 20°C and relative humidity of 65% to a target equilibrium moisture content of 12%. Control samples were also conditioned in these conditions.

Surface roughness values for the control and heat-treated samples were determined using a stylus type equipment, Mitutoya Surftest SJ-301. Six measurements were randomly taken from both surfaces of each sample using above profilometer across the grain orientation and a 15 mm tracing length. The tracing speed, stylus tip diameter, and tip angle were 10 mm/min, 4 µm, and 90°, respectively. Three accepted roughness parameters – average roughness (R_a), mean peak-to-valley height (R_z), and maximum roughness (R_y) – were used to evaluate the effect of heat treatment on roughness of the specimens. Roughness values were measured with an accuracy of 0.01 µm, and the force on the surface of the samples from the stylus tip was only 0.4 g, which did not apply any significant pressure or any damage on the samples (ISO 4287 1997).

After the treatment applications using light reflections, sample glossiness was measured with the aid of a Picogloss 562 MC glossmeter according to TS 4318 EN ISO 2813 (2002) standards, as illustrated in Fig. 1. Forty samples for each test type were used in the experiments. Two measurements were taken from the surface of each sample, one parallel to and one across the grain orientation.

Gloss is a measurement of the light reflectance of a sample surface. In gloss measurement tests, a beam of light is directed toward the test surface of the specimens at a certain angle from the perpendicular. The percentage of the beam that is reflected at the same angle is measured by a photocell. Two standard angles are used for the measurement, namely 60° for general gloss readings and 85° for sheen readings. Complete specular light reflection, which is perfect gloss, would be 100%, and complete diffuse light reflection mat would be 0% (Çakıcıer *et al.* 2011a).

Fig. 1. Glossmeter

Fig. 2. Elrepho Spectrophotometer

Discoloration of the samples before and after heat treatment was measured employing an Elrepho Spectrophotometer according to ASTM D2244-07e1 (2007) as shown in Fig. 2. Forty samples for each test type were used in the experiments. The Elrepho measures the color as three coordinates in three-dimensional color space as illustrated in Fig. 3. This system is called CIE $L^*a^*b^*$ and works according to the CIE Standard. The part of the coordinate system that is of interest in this work is the first quadrant; *i.e.*, positive values of a^* and b^* (Hunt 1995).

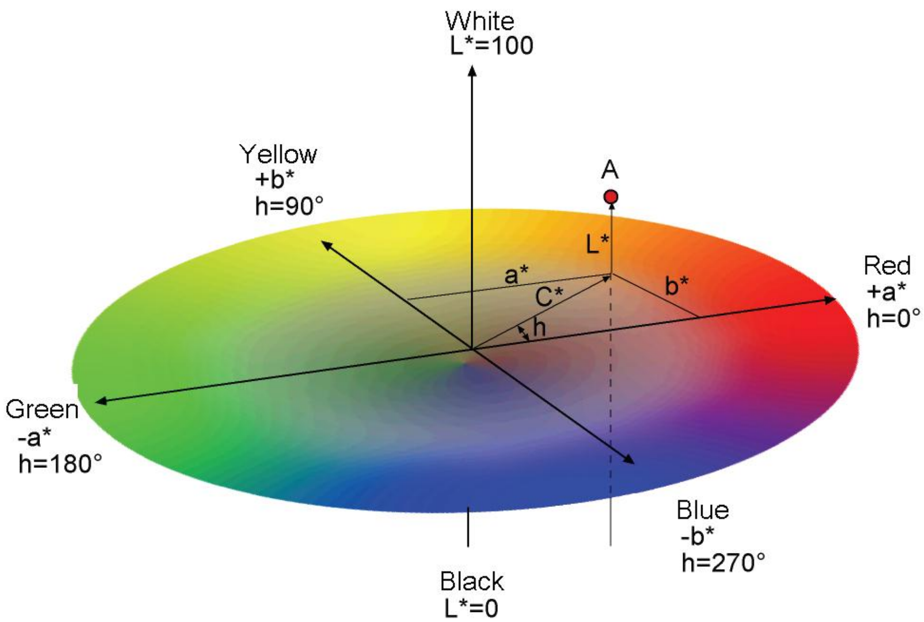

Fig. 3. The three-dimensional CIEL*a*b* color space (Johansson 2005).

The L^* axis represents the lightness, whereas a^* and b^* are the chromaticity coordinates. The + a^* and -a^* parameters represent red and green, respectively. The +b^* parameter represents yellow, whereas -b^* represents blue. L^* can vary from 100 (white) to zero (black) (Zhang 2003).

The three measured coordinates, L^*, a^*, and b^*, were transformed to ΔE values, according to Eq. 1 (Sundqvist 2002; Temiz *et al*. 2005).

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \tag{1}$$

The CIE $L^*a^*b^*$ system was chosen since only one color variable is needed to denote hue, *i.e*. red, green, blue, or yellow, and furthermore, this system is easy to refer to our experience of color characteristics such as lightness. Each color parameter, L^*, a*, b*, and ΔE^* was measured for each material, time, and temperature. The average color values, standard deviations, and 95% confidence intervals (5% significance level), based on t-distribution, were calculated assuming a normal distribution. The lower value of ΔE^* indicates that the color either is unchanged or the change is negligible (Temiz *et al*. 2005; Sundqvist 2002).

For all parameters, multiple comparisons were first subjected to an analysis of variance (ANOVA) and significant differences between average values of control and treated samples were determined using Duncan's multiple range test at a P-value of 0.05 (Kalipsiz 1994).

RESULTS AND DISCUSSION

Table 1 displays test results for the specimens. Control samples had an average R_a value of 8.48 µm. This value was reduced by 25.58 % when the samples were exposed to a temperature of 212 ^{o}C for 2.5 h. In a previous study, samples of rubberwood, red oak, and eastern red cedar exposed to a temperature of 190 ^{o}C for 2 h had corresponding values of 23.09%, 34.19%, and 33.87% reduction in roughness, respectively (Bakar *et al*. 2013). Based on statistical analysis, a significant difference was found between the surface roughness of the control samples and those exposed to heat treatment for 1.5 h. Also, treatment times of 1.5 and 2.5 h showed a significant difference. The decrease of Rz was 12% and 22% and Ry was 6% and 22% for samples treated at 1.5 h and 2.5 h, respectively. These findings agreed with those determined in past studies (Kasemseri *et al*. 2012; Bakar *et al*. 2013; Dilik and Hiziroglu 2012).

The surface roughness of machined parts is a significant design specification that is known to have considerable influence on properties such as wear resistance and fatigue strength. Surface roughness in turning has been found to be influenced in varying amounts by a number of factors such as cutting parameters, cutting fluid, and workpiece hardness. Important properties such as working with hand tools, sanding, drilling, trimming, workpiece hardness, strength, and toughness are greatly influenced by heat treatment processes (Kopac and Bahor 1999; Korkut and Kocaefe 2009).

Gloss changes are the most pronounced at the end of the exposure, and initially they are very small compared to the beginning for wood species. The lowest glossiness values (parallel and perpendicular to grain) were 2.443 and 1.725, respectively, for wild cherry wood obtained after heat treatment at 212 ^{o}C for 2.5 h. These results are in accordance with the findings of some of the earliest experiments conducted (Çakıcıer *et al*. 2011b). In a previous work the gloss values of Scots pine (*Pinus sylvestris* L.) decreased 5.5 to 36.6 % after heat treatments. In general, gloss values of heat-treated Scots pine specimens decreased with increasing treatment duration and temperature (Aksoy *et al*. 2011).

Table 1 shows discoloration values of the samples. The total color difference (ΔE) of the heat-treated sample for 2.5 h was determined as 36.25. The corresponding value for those exposed to heat for 1.5 h was 29.021. On the other hand, the Δb value related to yellowness of discoloration also increased with increasing exposure time, as can be observed from Table 1. Wood is a composite of mainly cellulose, hemicellulose, and lignin and is capable of absorbing heat, resulting in discoloration (Chen *et al*. 2012). Average lightness difference (ΔL) of the specimens treated for 2.5 h was 35.02, while 28.49 was determined for those treated for 1.5 h. The green-red (Δa) and yellow-blue (Δb) color coordinates also significantly changed by exposure time.

Wood color changed significantly after thermal treatment, and treated samples had lower redness (lower a^* value) and higher yellowness (higher b^* value). This was consistent with the findings in previous studies (Şahin *et al*. 2010; Akgül and Korkut 2012). The change in wood color during heat treatment may be due to a combination of the following factors (Dubey *et al*. 2011):

- Formation of oxidative products such as quinonnes and other colored products from degradation of hemicelluloses and lignin, which migrate towards the surface during the heat treatment;
- Removal or migration of extractives and nutritive compounds such as low molecular sugars and amino acids towards the surface.

Table 1. Test Results of Heat-Treated Specimens

Sample Type		Roughness Parameters (µm)			Discoloration				Glossiness	
		Ra	***Rz***	***Ry***	**∆*E****	**∆*L****	**∆*a****	**∆*b****	***//***	⊥
Control		8.484 A (2.071)* *24.410* *40*	56.507 A (10.798)* *19.109* *40*	75.322 A (25.076)* *33.292* *40*	-	-	-	-	3.855 A (0.467)* *12.11* *40*	3.505 A (0.318)* *9.067* *40*
Temperature 212 °C	**1.5 h**	6.557 B (1.581)* *24.11* *40*	49.642BC (10.126)* *20.397* *40*	70.538BC (21.206)* *30.063* *40*	29.021 (1.393)* *4.798* *40*	28.49 (1.341)* *4.708* *40*	-3.508 (0.9403)* *-26.81* *40*	3.988 (1.373)* *34.42* *40*	2.828BC (0.337)* *11.93* *40*	2.238BC (0.228)* *10.21* *40*
	2.5 h	6.312 C (1.669)* *26.44* *40*	43.95 C (9.065)* *20.62* *40*	58.677 C (16.643)* *28.364* *40*	36.259 (1.831)* *5.050* *40*	35.015 (1.854)* *5.296* *40*	-1.34 (0.45)* *-33.6* *40*	9.189 (1.177)* *12.81* *40*	2.443 C (0.416)* *17.02* *40*	1.725 C (0.226)* *13.11* *40*

*Values in parentheses are standard deviation. Italic values are coefficient of variation and number of samples used in each test.
Groups with the same letters in each column indicate that there is no statistical difference ($p < 0.05$) between the samples according to the Duncan's multiple range test.

CONCLUSIONS

This study investigated the effect of heat treatment on surface roughness, glossiness, and color stability of wild cherry (*Prunus avium*) samples. Heat treatment showed an interesting potential to increase the wood quality in regards to color and its value for solid timber products from wild cherry. Increasing the severity of thermal treatment resulted in smoother surfaces. In other words, surface quality of the samples was enhanced noticeably as a result of heat treatment. It appears that data from this research can be successfully used by the wood products industry, especially in the furniture manufacturing. Using the thermal modification technique, wild cherry wood could be obtained which have more attractive characteristics for outdoor application. In further studies, it would be desirable to determine physical and mechanical properties such as oven-dry density, weight loss, swelling, anti-swelling efficiency (ASE), compression strength parallel to grain, bending strength, modulus of elasticity in bending, janka-hardness (cross-section, radial, tangential), impact bending strength, and tension strength perpendicular to grain of wild cherry as a function of temperature and exposure time to have a better understanding of heat treatment on properties of such species.

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