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Variations in compression strength and surface roughness of heat-treated Turkish river red gum (*Eucalyptus camaldulensis*) wood

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Abstract This article reports the effects of heat treatment on compression strength parallel to the grain, the surface roughness [average roughness (R_a)], and the air-dry density of wood from the river red gum tree (*Eucalyptus camaldulensis* Dehn.) planted in Turkey. Eucalyptus wood was heat-treated at temperatures varying from 120° to 180°C for durations of 2–10h. Samples cut from the heat-treated wood were tested for air-dry density, compression strength parallel to grain, and surface roughness properties. Roughness measurements by the stylus method were made in the direction perpendicular to the fiber. Based on the findings in this study, the results showed that density, compression strength, and surface roughness values decreased with increasing treatment temperature and treatment times. Eucalyptus wood could be utilized by using proper heat treatment techniques without any losses in strength values in areas where working, stability, and surface smoothness, such as in window frames, are important factors.

Key words Eucalyptus wood · River red gum · Heat treatment · Surface roughness · Air-dry density · Compression strength

Introduction

The river red gum (*Eucalyptus camaldulensis* Dehn.) has been grown in Turkey in previous years to dry bogs; however, eucalyptus wood was recently introduced to the wood industry of Turkey. Because eucalyptus is a fast-growing tree species, it may have importance in some usages such as pulp, fiber, and chip industries and packing box production. Recently, planting of eucalyptus has been encouraged by the pulp and paper industry in Turkey. Besides many advantages, eucalyptus wood has certain disadvantages such as high swelling rate, low dimensional stability, and drying problems, which cause some limitations in use.

Yildiz[1] reported that modification of wood by heat treatment is a known method that improves some wood properties such as increasing dimensional stability, biological resistance, permeability, the quality of surface treatments, and decreasing equilibrium moisture content. Also, Stamm and Hansen[2] and Tiemann[3] determined a distinctive decrease in hygroscopicity of wood material by applying heat treatment to dried wood and by drying at high temperature. Weight loss in wood material is another disadvantage of heat treatment, which increases with temperature and time. Unsal et al.[4] evaluated color properties, swelling, and janka hardness of heat-treated Turkish river red gum (*Eucalyptus camaldulensis* Dehn.) wood as a part of this project in the Forestry Faculty of Istanbul University, Turkey. They measured the color changes with an Elrepho 3300 spectrophotometer at 23°C and 50% relative humidity and used D65 illumination, 10° standard observer, and 34-mm aperture. They found a significant lightness drop in the samples during the first 6h and the lightness reached a minimum value (23.21) after 10h of treatment. Moreover, the janka hardness and the swelling of the samples decreased with increasing thermal treatment temperature and duration.[4]

Fengel[5] found that spruce (*Picea abies* L.) wood subjected to heat treatment for 24h incurred weight losses of 0.8% and 15.5% at 120° and 200°C, respectively. On the other hand, the hardness and strength of wood decrease with heating and increase with cooling. Yildiz[1] reported that this effect is usually seen with prolonged heat treatment. MacLean,[6] Millett and Gerhards,[7] and MacLean[8,9] showed that the least-affected mechanical property is the modulus of elasticity (MOE) while the most-affected strengths are impact and static-bending strengths.

To our knowledge, there is no information about the influence of heat treatment on some technological properties, such as density, compression strength, and surface roughness of eucalyptus wood. The objective of this study was to evaluate the effects of heat treatment on these technological properties of eucalyptus wood grown in Turkey.

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Eucalyptus wood was obtained from Tarsus, Turkey, and was subjected to heat treatment at varying temperatures and for different durations. Following heat treatment, air-dry density, compression strength parallel to the grain, and surface roughness of the samples were tested.

Materials and methods

Materials

Eucalyptus cameldulensis logs (minimum diameter 30 cm) were obtained from Tarsus, Turkey. Lumber from the logs was prepared in the sawmill of the Forestry Faculty of Istanbul University, Turkey. Eucalyptus lumber was finished by a fixed-knife planer with a feed speed of 1 m/s. The bias angle of the knife was 45° for the lumber. Sampling methods and general requirements for the physical and mechanical tests were carried out based on ISO 3129.[10] Small clear samples were obtained for density (20 × 20 × 30 mm), compression strength (40 × 40 × 60 mm), and surface roughness measurements (40 × 40 × 60 mm). The average annual ring width and air-dry density were 5.00 mm and 0.704 g/cm^3, respectively, for samples of eucalyptus wood. The fiber direction was parallel to the long side of the specimens.

Methods

The samples were subjected to heat treatment at 120°, 150°, or 180°C for 2, 6, or 10 h in a small heating unit controlled to within ±1°C under atmospheric pressure. After heat treatment, treated and untreated samples were conditioned at 20° ± 2°C and 65% (±5%) relative humidity (RH) in a conditioning room to reach an equilibrium moisture content (EMC) of 12%. Tests for density (40 samples) and compression strength (20 samples) were carried out based on ISO 3131[11] and TS 2595,[12] respectively. After mechanical strength tests, the moisture content of the samples was measured according to ISO 3130[13] and strength values were corrected based on 12% EMC.

Surface roughness of the samples was measured by using a profilometer (Mitutoyo Surftest SJ-301). The surface roughness of the samples was measured with the profile method using a stylus device standard. The measuring speed, pin diameter, and pin top angle of the tool were 10 mm/min, 4 μm, and 90°, respectively. The points of roughness measurement were randomly marked on the surface of the samples. Measurements were made in the direction perpendicular to the fiber of the samples. Average roughness (R_a) which is the parameter characterized by ISO 4287[14] was recorded. The R_a is by far the most commonly used parameter in surface finish measurement and was expressed as the arithmetic mean of the absolute values of the profile deviations from the mean line. Specification of this parameter is described by Hiziroglu[15] and Hiziroglu and Graham.[16] Roughness values were measured with a sensitivity of 0.5 μm. The length of scanning line (L_t) was 15 mm and

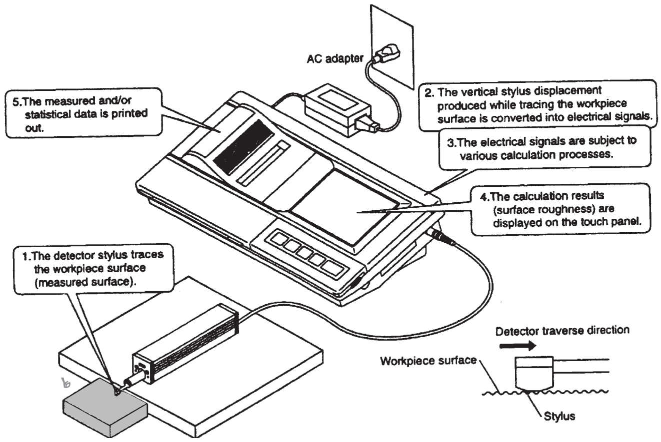

Fig. 1. Mitutoyo Surftest SJ-301

the cutoff was $\lambda = 2.5$ mm. The measuring force of the scanning arm on the samples was 4 mN (0.4 gf). Measurements were performed at room temperature and the pin was calibrated before the tests. Figure 1 shows the Mitutoyo Surftest SJ-301.

For the average roughness, 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

Table 1 displays the changes in air-dry density, compression strength parallel to grain (CS), and surface roughness R_a at varying treatment temperatures and durations. It is evident from Table 1 that the density, CS, and R_a values obtained decrease with increasing temperature and heat-treatment time under the conditions used. Heat-treated wood samples at a temperature of 180°C for 10 h gave the lowest air-dry density, CS, and R_a values when compared with other conditions studied.

However, when excluding surface roughness, samples heat-treated at all temperature levels (120°–180°C) for 2 h showed better performance for density and CS than the other treated samples. It was determined that changes in the values of density, CS, and R_a are significant due to heat treatment on the basis of Duncan's multiple range test (Table 1). Surface roughness decreased by up to 27.9% in the sample heat-treated at 180°C for 10 h when compared with the control samples. This increase in smoothness is very important for many usage areas of solid wood. In addition, losses occurring in the planing machine are reduced and high quality surfaces are attained.

The results in Table 2 demonstrate that the decreases in all properties tested are the highest when the wood samples are subjected to heat treatment at 180°C for 10 h. Additionally, the air-dry density, CS, and R_a decrease with increasing treatment temperature and time (Table 2). The smallest

Table 1. Statistical values and results of compression strength (cs), surface roughness (R_a), and air-dry density of river red gum wood subjected to heat treatments at varying temperatures and times

Time (h)	Temperature (°C)	Statistical values	Air-dry density (g/cm^3)	CS // (N/mm^2)	R_a (μm)
Control		Avg	0.704	46.33	10
		s	0.08	5.89	0.54
		s^2	0.006	34.69	0.29
		V	11.38	12.71	5.40
		n	40	20	20
2	120	Avg	0.693	45.51	9.27**
		s	0.051	6.146	0.44
		s^2	0.002	37.77	0.19
		V	7.47	13.50	4.76
		n	40	20	20
	150	Avg	0.688	44.34	9.16**
		s	0.069	9.014	0.83
		s^2	0.005	81.26	0.7
		V	10.05	20.32	9.14
		n	40	20	20
	180	Avg	0.656*	43.60	8.90**
		s	0.06	7.411	0.54
		s^2	0.004	54.92	0.29
		V	9.26	16.99	6.14
		n	40	20	20
6	120	Avg	0.676	43.25	8.39**
		s	0.07	6.421	0.71
		s^2	0.004	41.23	0.51
		V	9.80	14.84	8.57
		n	40	20	20
	150	Avg	0.670	42.44*	8.13**
		s	0.05	6.472	1.07
		s^2	0.003	41.88	1.15
		V	8.29	15.24	13.19
		n	40	20	20
	180	Avg	0.648*	41.94*	7.98**
		s	0.07	5.622	0.45
		s^2	0.005	31.61	0.20
		V	11.14	13.40	5.63
		n	40	20	20
10	120	Avg	0.672	41.83**	7.46**
		s	0.05	7.835	0.72
		s^2	0.002	61.39	0.52
		V	7.69	18.72	9.73
		n	40	20	20
	150	Avg	0.654**	38.67**	7.39**
		s	0.05	6.649	0.8
		s^2	0.002	44.21	0.64
		V	8.28	17.19	10.84
		n	40	20	20
	180	Avg	0.633**	37.50**	7.21**
		s	0.06	6.447	0.73
		s^2	0.004	41.56	0.54
		V	10.21	17.19	10.25
		n	40	20	20

Avg, average; *s*, standard deviation; s^2, variance; *V*, coefficient of variation; *n*, number of samples used in each test
* $P < 0.05$
** $P < 0.01$

Table 2. Decreases in some properties of river red gum wood as a function of temperature and time of heat treatment

Time-temperature (h) (°C)	Percentage decrease (%)		
	Air-dry density (g/cm^3)	CS // (N/mm^2)	R_a (μm)
2–120	1.5	1.7	7.3
10–150 (A)	7.1	16.5	26.1
10–180 (B)	10.0	19.0	27.9

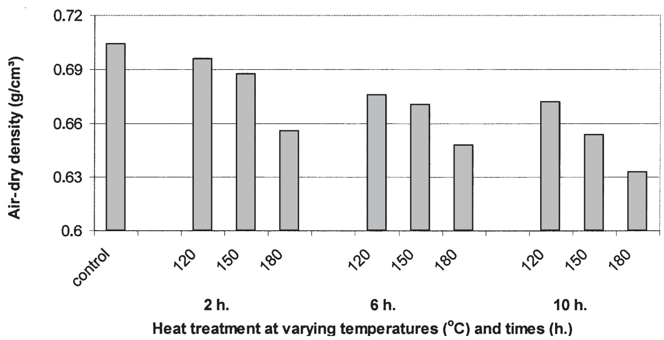

Fig. 2. Variation in air-dry density of heat-treated samples at varying temperatures and times

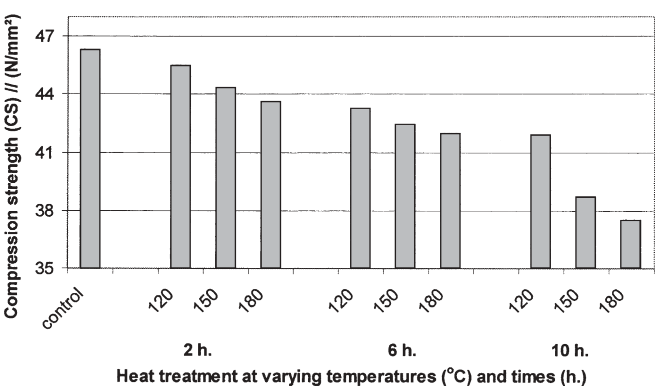

Fig. 3. Variation in compression strength of heat-treated samples at varying temperatures and times

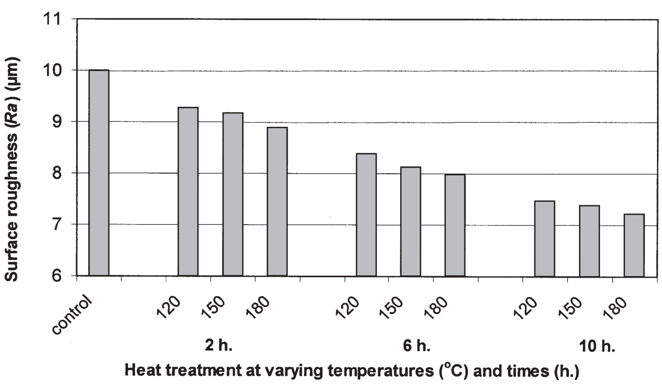

Fig. 4. Variation in surface roughness of heat-treated samples at varying temperatures and times

decreases were found at the treatment temperature of 120°C for 2h (Figs. 2, 3, and 4). The largest decrease was found for R_a, followed by CS and the air-dry density. As shown in Table 1, no obvious difference in R_a values was found between the heat treatment type A (150°C and 10h) and type B (180°C and 10h).

Yildiz[1] reported that the density and CS of beech wood heated at 200°C for 10h decreased by about 18.4% and 35%, respectively. However, the CS increased slightly after treatment at 130°C for 6h. Moreover, Schneider[17] found that CS values of pine sapwood heated at 110°, 130°, 150°, and 180°C decreased by about 5%. Feist and Sell[18] and Rusche[19] reported that these changes resulting from heat treatment could be explained by losses in the cell wall and hemicellulose degradation due to the high temperature applied.

Although there has not been any study on the effect of heat treatment upon roughness in solid wood, there are a few studies on wood veneers. Hecker[20] found no influence of cooking and peeling temperature on surface roughness in peeled veneer from Douglas fir. However, Kantay et al.[21] found that surface roughness of peeled veneer from beech wood steamed at 60°C for 40h increased with increased peeling temperature from 20° to 50°C.

Conclusion

In conclusion, it was found that the density, surface roughness, and compression strength of the river red gum decreased for all treatment conditions (temperatures and times). The smallest decrease was determined at the heat treatment of 120°C for 2h. The largest decrease found was for R_a, followed by CS and the air-dry density, when treated with heat under the conditions studied here. This wood species can be utilized by applying adequate heat-treatment techniques that result in negligible losses in strength values in areas where working, stability, and surface smoothness are important factors.

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