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SOME PHYSICAL CHARACTERISTICS OF THERMALLY MODIFIED ORIENTAL-BEECH WOOD

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ABSTRACT

Heat treatment of Oriental-beech (*Fagus orientalis*) wood was carried out by hot air in an oven for 2, 4, and 8 h at 140, 170, and 200°C. After heat treatment, some physical characteristics such as surface roughness, color, glossiness, and mass loss of Oriental-beech wood specimens were measured.

Our results showed that heat treatment caused decrease in surface roughness, glossiness, and mass loss values of Oriental-beech (*Fagus orientalis*) wood specimens. The decrease in lightness at all temperatures indicates that the specimens become darker with the treatment time. While, a^* coordinate (red component) decreased as temperature increased, b^* coordinate (yellow component) initially increased at 140°C and then decreased at 170°C and 200°C.

Keywords: Heat treatment, oriental-beech, surface roughness, glossiness, color, mass loss.

INTRODUCTION

Throughout the course of history, wood has remained one of the most important renewable natural resources available to man. It is a natural, cellular, composite material of botanical origin and possesses unique structural and chemical characteristics that render it desirable for a broad variety of end uses. On the other hand, despite its versatility as a constructional material, wood is being superseded in several areas where other expensive materials such as metals, concrete, plastics, ceramics, etc. are emerging as preferred materials for use, even when the initial cost benefit favors the use of wood (Yalinkilic 2000). However, timbers that are not naturally durable are treated with preservatives to prevent decay by wood- boring crustaceans and mollusc, and fungi and insect attack. When timber is used as a construction material, it is generally treated with a chemical preservative to prevent damage by these aggressive biodeteriogens (Craig *et al.* 2001). However, many of the effective poisonous chemicals are also questionable. Increased environmental awareness has raised the demand for more environmentally friendly methods. Heat treatment is an alternative process for improving these properties with no use of chemical additives (Johansson 2008). Wood that has been heat treated in the temperature interval 150-250°C displays notably changed properties and can therefore in some sense be considered a "new" material (Sundqvist 2004). Heat treatment of wood changes its chemical composition by degrading both cell wall compounds and extractives (Esteves *et al.* 2008a). The thermal modification of wood has been known as a process enhancing wood properties by reducing moisture absorption and increasing dimensional stability and biological durability (Akgul and Korkut 2012).

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Heat-treated wood has been suggested as a substitute for some tropical hardwoods Heat treatment of wood gives reddish brown colour that is often appreciated. However, this generated reddish brown colour is not stable when it is exposed to light. The coloured substances in the woods are eventually degraded and washed out if the wood is exposed outdoors, leaving a bleached and greyish appereance (Sundqvist 2004). Color of wood is important from the viewpoint of aesthetic concepts for the consumers. Depending on culture country, and income level, wood products may have higher market volume solely due to their color. Heat treatment provides an inexpensive alternative method to darken wood to imitate more expensive exotic species (Korkut *et al.* 2013). Korkut *et al.* (2013) reported that wood color changed significantly after treatment and treated samples had showed lower redness and lower yellowness. Gunduz and Aydemir (2009) found that the treatment temperature had a much more significant effect on color changes than the duration of the treatment. Akgul and Korkut (2012) reported that darkening as a result of heat treatment was clearly visible and it increased with treatment time and temperature. Gloss is a measurement of the light reflectance of a sample surface (Cakicier *et al.* 2011). Thermal modification of wood causes gloss loss of wood in some extent. Aksoy *et al.* (2011) and Korkut *et al.* (2013) reported that gloss values of heat treated wood decreased with increasing treatment temperature and duration. Surface roughness of solid wood and wood products plays an important role for the finishing process (Korkut *et al.* 2013). However, the roughness of wood is a complex phenomenon. Several factors such as anatomical structure of wood, growing characteristics, machining properties and pre-treatments of wood before machining should be considered for the evaluation of the surface roughness of wood (Aydin and Colakoglu 2003, and 2005, Temiz *et al.* 2005). Korkut and Budakci (2010) investigated the influence of heat treatment on the surface roughness of Rowan (*Sorbus aucuparia*) wood. They found that surface roughness decreased by up to 12.85% in samples heat-treated at 180°C for 10 h when compared with the control samples. This increase in smoothness is very important for many applications of solid wood. In addition, losses occurring in the planing machine are reduced and high quality surfaces are attained. In another study, Karagoz *et al.* (2011) reported that surface roughness decrease with the increasing temperature.

The aim of this study was to investigate some physical characteristics such as, surface roughness, color, glossiness, and mass loss of thermally modified Oriental-beech (*Fagus orientalis*) wood specimens.

MATERIAL AND METHODS

Preparation of test specimens

Specimens measuring 6 x 75 x 150 mm (radial by tangential by longitudinal) were machined from the air-dried sapwood of Oriental-beech (*Fagus orientalis L.*) lumber. All specimens were conditioned at 20ºC and 65% relative humidity for two weeks before tests.

Heat modification

Heat treatment was performed using a temperature-controlled laboratory oven. Three different temperatures (140°C, 170°C, and 200°C) and three treatment durations (2, 4, and 8 h) were applied to wood specimens under atmospheric pressure and in the presence of air.

Surface roughness

The Mitutoyo Surftest SJ-301 instrument was employed for surface roughness measurements according to DIN 4768 (1990). Three roughness parameters which are mean arithmetic deviation of profile (*Ra*), mean peak-to-valley height (*Rz*), and and root mean square (*Rq*). *Ra* is the average distance from the profile to the mean line over the length of assessment. *Rz* can be calculated from the peak-to-valley values of five equal lengths within the profile *Rq* is the square root of the arithmetic mean of the squares of profile deviations from the mean line (Mummery 1993). Surface roughness measurements were made in the direction parallel to the fiber.

Color test

The color parameters a^*, b^*, and L^* were determined by the CIELAB method. 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 colors of the specimens were measured by a colorimeter (X-Rite SP Series Spectrophotometer) before and after the heat treatments. The measuring spot was adjusted to be equal or not more than one-third of the distance from the center of this area to the receptor field stops. The color difference, (ΔE^*) was determined for each wood as follows (ASTM D 1536–58/ 1964):

$$\Delta a^* = a^*f - a^*i$$
$$\Delta b^* = b^*f - b^*i$$
$$\Delta L^* = Lf^* - L^*i$$
$$(\Delta E^*) = [(\Delta a)2 + (\Delta b^*)2 + (\Delta L^*)\ 2]\ 1/2$$

where: Δa^*, Δb^*, and ΔL^* are the changes between the initial and final interval values. Color measurements were made in the direction parallel to the fiber.

Glossiness test

The glossiness of wood specimens was determined using a gloss meter (BYK Gardner, Micro-TRI-Gloss) according to ASTM D523-08 (2008). The chosen geometry was an incidence angle of 60º. Results were based on a specular gloss value of 100, which relates to the perfect condition under identical illuminating and viewing conditions of a highly polished, plane, black glass surface. Glossiness measurements were made in the direction parallel to the fiber.

RESULTS AND DISCUSSION

Surface roughness

Surface roughness parameters such as *Ra, Rz,* and *Rq* values of heat treated Oriental-beech wood are given in table 1. Untreated control specimens had average *Ra, Rz,* and *Rq* values 2,06- 13,57- and 2,71 respectively. Our results showed that heat treatments decreased surface roughness of Oriental- beech. The decrease of *Ra* was 1,73 to 35,52 *Rz* was 0,45 to 42,01 and *Rq* was 0,80 to 37,40 respectively. This increase in smoothness is very important for many applications of solid wood. In addition, losses occurring in the planing machine are reduced and high quality surfaces are attained. (Korkut *et al.* 2009). Also, the wooden materials with rough surface require much more sanding process compared to one with smooth surface, which leads to decrease in thickness of material and, therefore, increases the losses due to the sanding process (Dundar *et al.* 2008). However, wood is a heterogeneous, anisotropic and brittle material. The surface roughness of wood products depends on many factors such as wood anatomical features (vessels, cell lumen, annual ring width, hardness etc.), machine conditions (feed rate, spindle speed etc.) and cutting properties (Karagoz *et al.* 2011). Bakar *et al.* (2013) investigated the surface roughness of heat treated Rubber wood, Red oak and Eastern red cedar. They found that *Rz* values of heat treated Rubber wood, Red oak, and Eastern red cedar exposed to a temperature of 190°C for 2 h had corresponding values of 23,09%, 34%, 19%, and 33,87% reduction in *Ra*, respectively. Korkut *et al.* (2013) investigated the surface roughness of heat treated of wild Cherry wood. They found that *Rz* values of heat treated wild cherry wood was reduced by 12% to 22% at 212 °C for 1,5 h and 2 h, respectively. Our results are in good agreement with those findings. According to our results, higher temperature and duration resulted in lower surface roughness of Oriental-beech wood. When the studies in the literature are examined, it can be stated that the values of surface roughness decreased with increasing treatment temperature and durations (Korkut *et al.* 2013, Gunduz *et al.* 2008, Korkut and Guller 2008, Moura and Brito 2008).

Table 1. Surface roughness of Oriental- beech (*Fagus orientalis*) wood before and after thermal modification [a].

Temp.	Duration	Thermal modification						Differences (%)		
		Before			After					
		Ra	*Rz*	*Rq*	*Ra*	*Rz*	*Rq*	*Ra*	*Rz*	*Rq*
Control		2,06(0,82)[b]	13,57(5,14)	2,71(1,08)	-	-	-	-		
140	2	2,89(0,63)	17,55(4,18)	3,75(0,86)	2,84(0,59)	17,47(3,20)	3,72(0,67)	-1,73	-0,45	-0,80
	4	2,80(0,66)	14,90(6,54)	3,56(0,83)	2,72(0,59)	14,65 (6,60)	3,56(0,85)	-2,85	-1,67	-1,38
	8	2,46(0,88)	18,36(4,26)	3,16(1,23)	2,37(1,12)	17,81(2,76)	3,08(1,51)	-3,65	-2,99	-2,53
170	2	2,13 (0,76)	13,71(4,65)	4,55(1,13)	2,05(0,62)	13,41(4,53)	2,87(0,56)	-3,75	-2,18	-9,74
	4	2,45(0,98)	14,97(5,67)	3,18(1,10)	2,15(0,45)	14,54(2,43)	3,79(1,67)	-12,24	-2,87	-16,70
	8	3,59(0,77)	20,60(6,50)	2,71(0,96)	2,93(1,31)	17,63(6,63)	2,17(0,83)	-18,38	-14,41	-19,92
200	2	2,38(0,90)	14,94(5,06)	3,06(1,15)	2,08(0,46)	13,70(3,72)	2,75(0,67)	-12,60	-8,29	-10,13
	4	2,05(0,26)	12,94(2,30)	2,61(0,35)	1,69(0,33)	10,72(2,42)	2,17(0,45)	-17,56	-17,15	-16,85
	8	2,28(0,47)	14,97(2,33)	2,99(0,60)	1,47(0,42)	8,68(1,73)	1,87(0,53)	-35,52	-42,01	-37,40

[a] Ten replicates were made for each treatment group.
[b] Values in parntheses are standard deviations.

Color changes

The changes of *L*, a*, b**, and *ΔE** are given in table 2. The decrease in *L** indicates that the specimens become darker. Darkening with heat treatment increased with treatment temperature and duration and this is consistent with earlier findings (Mitsui *et al.* 2003, Militz 2002, Esteves *et al.* 2008b, Akgul and Korkut 2012). For instance, *L** of Oriental-beech, decreased by 2,28%, 5,52%, and 15,23%, within 2 h of treatment at 140°C, 170°C, and 200°C, respectively. Esteves *et al.* (2008b) reported a 52,9% decrease in lightness of pine wood for a treatment at 200°C for 12 h. Gunduz and Aydemir (2009) reported a 64,23% decrease in lightness of Hornbeam wood for a treatment at 200 °C for12 h. In our study, the maximum lightness reduction was approximately 57,63% at 200°C after 8 h of treatment. The darkening of heat- treated Oriental-beech might be due the to degradation of lignin and other non-cellulosic polysaccharides (Hon and Chang 1985, Grelier *et al.* 2000, Petric *et al.* 2004). As wood is heated, acetic acid is formed from acetylated hemicelluloses by hydrolysis (Forsman 2008). The released acid serves as a catalyst in the hydrolysis of hemicelluloses to the soluble sugars (Finnish Thermowood Association 2003). The heat caramelizes the sugar to a brown color which affects the color of wood. As the degradation of hemicelluloses accelerates with temperature, the color will become darker with increased treatment temperature (Forsman 2008). The positive values of *a** indicate a tendency of wood surface to become reddish. The *a** of heat-treated Oriental-beech decreased with treatment temperature and duration. For heat- treated Oriental-beech, *a** decreased by 0,78% to 42,97% Positive values of *b** indicate a tendency of wood surface to yellowing. The increase may be explained by the modification of some chromophoric groups of lignin (Grelier *et al.* 2000). Our results showed that *b** of Oriental-beech wood initially increased at 140°C and then decreased at 170°C and 200°C. Akgul and Korkut (2012) investigated the effects of heat treatment on color changes of Uludag fir. They found that heat-treated wood specimens, with increasing yellowness initially and decreased yellowness later for more severe treatments. Gunduz and Aydemir (2009) reported that the *b** value of Hornbeam wood increased slightly due to low-intensity thermal treatment. However, even when high temperatures were applied, the *b** value decreased. The results of this study are consistent with these findings. The total color changes *ΔE** of Oriental-beech wood were changed from 1,14 to 42,61. *ΔE** of Oriental-beech wood specimens were drastically increased after the heat treatment at 200°C. Moreover, *ΔE** of Oriental-beech wood increased with temperature and duration.

Table 2. Color changes of Oriental- beech (*Fagus orientalis*) wood before and after thermal modification [a].

Temp.	Duration	Thermal modification										Differences (%)		
		Before			After									
		L_i^*	a_i^*	b_i^*	L_f^*	a_f^*	b_f^*	ΔL	Δa	Δb	ΔE	L^*	a^*	b^*
Control		2,06(0,82) [b]	13,57(5,14)	2,71(1,08)	-	-	-	-	-	-		-	-	-
140	2	68,62(0,65)	10,41(0,59)	21,51(1,02)	67,05(0,94)	10,27(0,55)	22,09 (0,86)	-0,97	-0,14	+ 0,58	1,14	-2,28	-1,34	-2,62
	4	69,87(1,01)	10,19(0,64)	19,39(1,51)	65,58(1,26)	9,91(2,43)	21,29(1,06)	-4,29	-0,28	+1,90	4,70	-6,13	-2,74	-8,92
	8	69,33(1,34)	10,42(0,70)	19,92(0,59)	63,84(2,21)	10,07(0,80)	21,91(0,69)	-5,49	-0,35	+1,99	5,84	-8,70	-3,35	-9,08
170	2	70,06(0,91)	10,21(0,59)	21,25(1,04)	66,20(1,41)	10,13(0,30)	19,80(0,45)	-3,86	-0,08	-1,45	4,12	-5,52	-0,78	-6,82
	4	69,54(1,32)	10,10(0,55)	21,26(1,10)	59,16(3,21)	9,63(0,39)	19,73(1,12)	-10,38	-0,47	-1,53	10,50	-14,92	-4,65	-7,19
	8	70,01(1,39)	10,47(0,61)	21,70(0,91)	54,24(1,65)	9,74(0,27)	18,61(1,05)	-15,77	-0,73	-3,09	16,08	-22,52	-6,97	-14,23
200	2	69,13(1,08)	10,33(0,41)	21,73(0,91)	58,60(2,76)	9,81(0,41)	18,67(1,04)	-10,53	-0,52	-3,06	10,97	-15,23	-5,03	-14,08
	4	69,38(0,38)	10,43(0,38)	21,50(1,01)	43,52(2,60)	9,03(0,77)	16,84(0,93)	-25,86	-1,40	-4,66	26,31	-37,27	-13,42	-21,67
	8	69,75(0,55)	9,68(0,31)	21,35(0,82)	29,55(1,25)	5,52(1,13)	7,31(1,92)	-40,02	-4,16	-14,04	42,61	-57,63	-42,97	-65,75

[a] Ten replicates were made for each treatment group.
[b] Values in parentheses are standard deviations.

Glossiness

Gloss values of Oriental-beech wood before and after treatments are given in table 3. The lowest glossiness value was 1,58 for Oriental beech wood specimens recorded after heat treatment at 200°C for 8 h. The gloss values of the Oriental-beech wood decreased by 0,63% to 39,69% after heat treatments. Our results showed that gloss values of Oriental-beech wood specimens decreased with increasing treatment temperature and duration. Korkut *et al.* (2013) reported that gloss values of wild chery wood decreased by 36,6 % after heat treatment at 212°C for 2,5 h. In another study, Aksoy *et al.* (2011) obtained similar gloss loss values for Scots pine wood at 200°C for 8 h. The results of this study are consistent with these findings.

Table 3. Glossiness of Oriental- beech (*Fagus orientalis*) wood before and after thermal modification [a].

Temperature	Duration	Thermal modification		Differences (%)
		Before glossiness	After glossiness	
Control		2,84(0,28) [b]	-	-
140	2	3,16(0,33)	3,14(0,28)	-0,63
	4	2,56(0,18)	2,50(0,18)	-2,34
	8	3,00(0,41)	2,74(0,37)	-8,66
170	2	3,02(0,31)	2,86(0,30)	-5,29
	4	3,24(0,19)	2,86(0,28)	-11,72
	8	3,06(0,15)	2,52(0,19)	-17,64
200	2	2,84(0,20)	2,64(0,26)	-14,08
	4	2,90(0,30)	1,92(0,30)	-33,79
	8	2,62(0,13)	1,58(0,26)	-39,69

[a] Ten replicates were made for each treatment group.
[b] Values in parentheses are standard deviations.

Mass loss

Mass losses of heat treated Oriental-beech wood specimens are given in table 4. Mass loss of wood is one of the most important characteristics in heat treatment and is commonly referred to as an indication of quality (Esteves and Pereira 2009). Mass of Oriental beech wood decreased by 4,80% to 14,80% after heat treatment. Our results showed that mass loss of Oriental-beech wood increased with temperature and time of treatment which is in agreement with earlier data for Maritime pine (Esteves *et al.* 2008b), Scots pine (Zaman *et al.* 2000), and spruce (Alén *et al.* 2002). According to our results, the rate of mass loss was higher in the beginning of the treatment and slightly decreased for longer treatments. The higher initial rate of mass loss was due to the thermal degradation of more susceptible compounds mainly hemicelluloses (Esteves *et al.* 2008b). Zaman *et al.* (2000) treated *Pinus sylvestris* wood at temperature 200°C during 4-8 h and determined that the mass loss for pine varied between 5,7% (4h) to 7,0% (8h). Our results showed that treated Oriental-beech wood at temperature 200 °C 4-8 h and determined that the mass loss for Oriental-beech varied between 9,67% (4h) up to 14,80% (8h). These mass losses are higher than those obtained by Zaman *et al.* (2000). Higher degradation of Oriental-beech wood can be explained by the difference in chemical composition, namely in relation to the hemicelluloses which is less resistant to thermal degradation. Additional differences relate to the composition of hemicelluloses, since hardwood xylans have a higher susceptibility to thermal degradation than sapwood mannans (Alén *et al.* 1995).

Table 4. Mass loss of Oriental- beech (*Fagus orientalis*) wood before and after thermal modification [a].

Temperature.	Duration	Thermal modification		Differences (%)
		Before Mass loss	After Mass loss	
Control		39,40(4,98) [b]	-	-
140	2	38,07(0,96)	36,24(0,93)	-4,80
	4	40,35(7,37)	38,02(6,44)	-5,77
	8	43,31(8,63)	40,46(8,02)	-6,58
170	2	45,69(9,03)	43,47(8,45)	-4,85
	4	45,70(7,04)	42,52(6,51)	-6,95
	8	43,19(8,75)	39,90(8,05)	-7,61
200	2	41,07(7,11)	38,17(6,60)	-7,06
	4	41,87(6,90)	37,82(6,08)	-9,67
	8	39,38(3,80)	33,55(2,89)	-14,80

[a] Ten replicates were made for each treatment group.
[b] Values in parentheses are standard deviations.

CONCLUSIONS

Thermal treatment caused a strong darkening of wood surface. While $a*$ parameter decreased with the increase in temperature and duration, the $b*$ increased initially and then decreased at temperatures used that is, 170°C and 200°C. The results showed that mass loss, glossiness, and surface roughness of Oriental beech wood decreased after heat treatments. Higher temperature and duration resulted in lower mass loss, glossiness, and surface roughness of Oriental-beech wood.

In conclusion, because of its high dimensional stability and decay resistance, thermally treated wood may be an alternative structural material for exterior conditions. Moreover, it has a darkened color which is highly preferred in furniture industry. However, thermally treated wood has low mechanical properties. So, thermal treated wood for applications where strength is an important factor is not recommended.

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