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SURFACE CHARACTERISTICS OF HEATED AND VARNISHED ORIENTAL BEECH AFTER ACCELERATED WEATHERING

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ABSTRACT

This study was performed to investigate some surface characteristics such as surface hardness, surface roughness, and color changes of heated and varnished Oriental beech

(*Fagus orientalis* Lipsky) after accelerated weathering. Heat treatment of Oriental beech wood was carried out by hot air in an oven for 0.5, 1, and 1.5 h at 210, 220, and 230°C. After heat treatment, Oriental beech wood specimens were varnished using a polyurethane varnish.

The results showed that accelerated weathering generally caused increase of surface hardness of Oriental beech. Surface roughness and total color changes of heated and varnished Oriental beech were lower than only varnished (control) Oriental beech after accelerated weathering. Heated and varnished Oriental beech wood gave better surface characteristics than only varnished oriental beech after accelerated weathering.

KEYWORDS: Oriental beech, heat treatment, varnish, surface properties, accelerated weathering.

INTRODUCTION

The most important external elements that affect the wood appearance are weathering process. Weathering,as the term is used to descript the degradation of materials exposed to the weather (Williams 2005). The weathering process mostly ends up with discoloration, a physical deterioration of the wood surface primarily due to the effects of sunlight (ultraviolet light) and water (Yalinkilic et al. 1999, Miklečić and Irouš-Rajković 2011, Turkoglu et al. 2015a). It causes change in the chemical, physical, and mechanical properties of the wood (Pandey 2005, Rasouli et al. 2016). Some studies revealed that natural or accelerated weathering leads to destruction of the lignocellulosic network and reduces the wood components. The depolymerization of cellulose and lignin also lead to reduction in some physical, chemical, and biological properties of wood (Temiz et al. 2005). Weathering of wood is mainly a surface event that results in the gradual erosion of wood fibers on the surface (Williams et al. 2001). The weathering initially causes the discoloration and gloss loss, followed by the occurrence of surface checking and increased roughness of the wood (Denes and Young 1999, Ozgenc et al. 2012). Wood has been protected from damage caused by various weather factors using some modification methods (thermal, chemical, and impregnation) and finishes. Environmental concerns associated with the use of conventional wood preservatives, however, have increased interest in thermal modification approaches (Hill 2006). Thermally modified wood, also called heat-treated wood has a variety of uses for outdoor application such as cladding, decks, garden furniture, and window frames (Esteves and Pereira 2009, Turkoglu et al. 2015b). Heat treated wood gets out of new physical properties such as reduced hygroscopy and improved dimensional stability (Huang et al. 2012). It is known that various paints, varnishes, and other coatings are also available to enhance or maintain against to weathering (Chang and Chou 2000, Kielmann et al. 2016 a,b). Against these damages wood may be effectively protected with combination of heat treatment and surface protection. Gupta et al.(2016) explained that wood finishes improve aesthetics and provide a cleanable and protected surface to weathering agents such as moisture, light, temperature, wind, and abrasion. Among of the wood coatings, polyurethane (PU) is hard, abrasion-resistant and durable, and is known to act as a good moisture barrier for wood products (Poaty et al. 2013). Turkoglu et al. (2015c) also reported that polyurethane varnish (PV) coated Scots pine wood has a better performance during exposure to weathering than uncoated and synthetic varnish coated pine. Cakicier et al. (2011) carried out about the effects of heat treatment and varnish application combinations on some surface properties of wood materials sampled from limba, iroko, ash, and Anatolian chestnut. They found that the glossiness of the varnished samples after heat treatment was observed to be higher than that of varnished untreated samples. Turkoglu et al. (2015b) revealed that heat treatment resulted in better surface roughness and glossiness compared to unheated Oriental beech after natural weathering. The combined treatment both heat treatment and PV varnish application can be expected to improve the performance of wood surface properties to prevent photo-degradation effect. Therefore, the objective of this work was the influence of accelerated weathering on some surface characteristics such as surface hardness, surface roughness,and color changes of heated and varnished Oriental beech wood.

MATERIALS AND METHODS

Preparation of test specimens

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

Heat treatment

Heat treatment was performed using a temperature-controlled laboratory oven. Three different temperatures (210, 220, and 230°C) and three treatment durations (0.5, 1.0, and 1.5 h) were applied to wood specimens under atmospheric pressure and in the presence of air.

Varnish application

A polyurethane varnish (PV) of a two component type consisting of an aliphatic isocyanate-terminated component and an active hydrogen-bearing monomer, which when blended cures at room temperature with 4–5 h pot life of the blend was used. Polyurethane varnish was applied over heat treated Oriental beech wood. To avoid potential interference in the surface characteristics of wood, filler was not used. Instead, varnish was applied as a primer coating for filling the voids and as a topcoat. Sufficient time for coat setting was allowed between successive applications. Specimens were left at ambient conditions for 24 h before the top coating according to the instructions given by the varnish manufacturer. Surfaces were gently sanded with abrasive paper to obtain a smooth surface prior to applying the topcoat.

Accelerated weathering

Accelerated weathering experiment was performed in a QUV weathering device (Q - Lab, USA) equipped with eight UVA 340 lamps according to principles of ASTM G154 (2006) standard. Specimens were exposed to cycles of 8 h UV-light irradiation followed by condensation for 4 h in QUV device for a total of 500 h. The average irradiance was 0.89 $W \cdot m^{-2}$ at the maximum intensity of 340 nm wavelengths (λmax = 340 nm). The temperature at the light irradiation period and at the condensation period was 60°C and 50°C, respectively. Since the moisture content is an important parameter affecting the properties of wood, specimens were conditioned at 20°C and 65% relative humidity until constant weight was achieved before and after accelerated weathering experiment.

Surface hardness test

The surface hardness of wood specimens was measured as the Konig hardness according to ASTM D 4366–14 (2013). Wood specimens were placed on a panel table, and a pendulum was placed on the panel surface. Then, the pendulum was deflected through 6° and released, at the same time, a stopwatch was started. The time for the amplitude to decrease from 6° to 3° was measured as Konig hardness.

Surface roughness test

The Mitutoyo Surftest SJ-301 instrument was employed for surface roughness measurements according to DIN 4768 (1990). Surface roughness parameter such as *Rz* can be calculated from the peak-to valley values of five equal lengths within the profile (Mummery 1993).

Color test

The color parameters L^*, a^* and b^* were determined by the CIEL*a*b* 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 accelerated weathering. 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 D1536–58 T (1964):

$$\Delta a^* = af^* - ai^*$$
$$\Delta b^* = bf^* - bi^*$$
$$\Delta L^* = Lf^* - Li^* (\Delta E^*) = [(\Delta a^*)^2 + (\Delta b^*)^2 + (\Delta L^*)^2]^{1/2}$$

where: Δa^*, Δb^*, and ΔL^* the changes between the initial and final interval values.

RESULTS AND DISCUSSION

Changes in surface hardness

Surface hardness values of the heated and varnished Oriental beech before and after accelerated weathering are given in Tab. 1 and Fig. 1. It is known that wood type and density primarily affect hardness (Gašparík et al. 2016).

Tab. 1: Surface hardness values of heated and varnished Oriental beech wood specimens before and after accelerated weathering.

Heat treatment (°C)	Hours	Before accelerated weathering		After 500 h accelerated weathering		
		Mean	SD	Mean	SD	Changey (%)
Control (only varnished)		41.4	1.82	39.4	1.34	-4.83
210°C	0.5	41.0	3.39	40.2	1.79	-1.95
	1	43.6	3.21	45.4	3.36	4.13
	1.5	39.0	4.42	41.6	4.62	6.67
220°C	0.5	40.8	5.17	38.8	4.55	-4.90
	1	40.2	1.79	42.8	1.30	6.47
	1.5	38.4	2.07	42.6	1.95	10.94
230°C	0.5	37.8	3.70	34.4	4.04	-8.99
	1	38.0	4.53	41.4	5.03	8.95
	1.5	38.6	1.14	44.8	3.63	16.06

Note: Five replicates were made for each group. SD: Standard deviations.

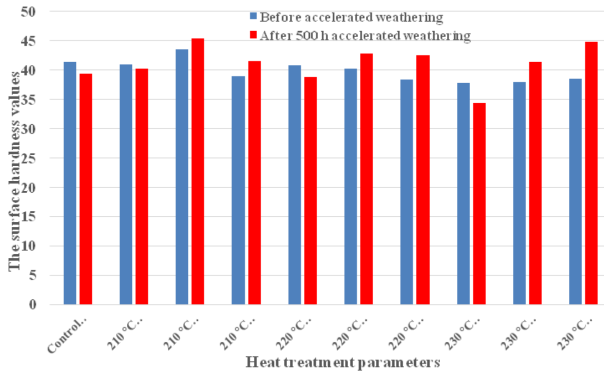

Fig 1: Surface hardness values of heated and varnished Oriental beech wood specimens before and after accelerated weathering.

The surface hardness value of only varnished (control) Oriental beech wood was 41.4 before accelerated weathering, whereas surface hardness values of heated and varnished Oriental beech wood were differed from 37.8 to 43.6. The results of the study showed that except for heat treatments at 210°C for 1 h, surface hardness of heated and varnished Oriental beech was lower than only varnished Oriental beech wood. Cakicier et al. (2011) found that the surface hardness of varnished wood samples measured after heat treatment was to be lower than that of only varnished (un-heated) wood samples. Our results are in similar direction with results of Cakicier et al. (2011). Generally, Oriental beech wood surfaces toughened after accelerated weathering. However, accelerated weathering was only effective on varnished Oriental beech and heated and varnished for 0.5 h Oriental beech wood. The combination of UV light humidity, and temperature can extinguish the structure of wood. For this reason, the deterioration products become water-soluble and become stained, causing the wood surface to undergo erosion (De Meijer 2001). However, increment of surface hardness were listed for other all heated and varnished Oriental beech wood surfaces after accelerated weathering. The maximal surface hardness increases was measured for the Oriental beech wood after accelerated weathering with 16.06% for the wood specimens heated at 230°C for 1.5 h. Except for 0.5 h treatment, heat treatments made contributive effect on the hardness of the wood after accelerated weathering, since heat treatment increased the surface hardness of wood 4.13 to 16.06% after accelerated weathering. According to the hardness test results showed that except for 0.5 h treatments at 220°C and 230°C,, higher temperature and durations resulted in higher surface hardness increases after accelerated weathering.

Changes in surface roughness

Surface roughness parameter like *Rz* values of heated and varnished Oriental beech before and after accelerated weathering is presented in Tab. 2 and Fig. 2.

Tab. 2: Surface roughness values of heated and varnished Oriental beech wood specimens before and after accelerated weathering.

Heat treatment (°C)	Hours	Before accelerated weathering		After 500 h accelerated weathering		
		Rz (Mean)	SD	Rz (Mean)	SD	Change (%)
Control (only varnished)		0.59	0.16	1.74	1.04	194.92
210°C	0.5	0.46	0.20	1.17	0.72	154.35
	1	0.54	0.34	1.29	0.44	138.89
	1.5	0.76	0.48	1.32	0.63	73.68
220°C	0.5	0.44	0.13	1.06	0.35	140.91
	1	0.74	0.43	1.28	0.52	72.97
	1.5	0.53	0.31	0.87	0.34	64.15
230°C	0.5	0.75	0.19	1.32	0.48	76.00
	1	0.48	0.20	0.74	0.30	54.17
	1.5	0.93	0.30	1.29	0.62	38.71

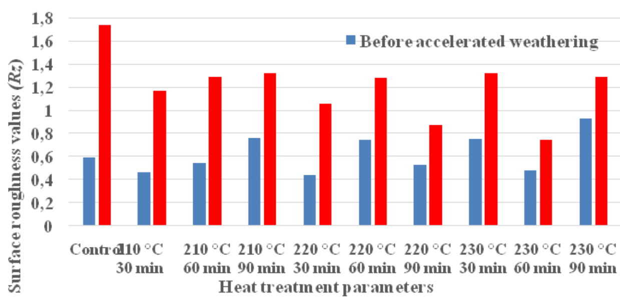

Fig 2: Surface roughness (Rz) values of heated and varnished Oriental beech wood specimens before and after accelerated weathering.

Importance of surface roughness as asignificant parameter for determination of the surface quality of wood products are well recognized, and the surface quality of wood is affected by many factors (Yildiz et al. 2013). Gaff et al. (2015) studied surface waviness in plane milling of thermally modified birch wood. They found that the thermal modification of wood did not significantly influence the arithmetic mean deviation of the waviness profile.In similar study, Kvietková et al. (2015) investigated surface quality of both thermally treated and untreated beech wood after the plane milling process. They noted that thermal treatment of wood has no statically significant on roughness In our study, we have observed that only varnished (control) samples are measured to have average *Rz* value of 0.59 before application of accelerated weathering. We disclose that surface roughness of only varnished (control) Oriental beech wood was higher than heat treated and varnished Oriental beech wood after application of accelerated weathering. While the increase of surface roughness for only varnished Oriental beech is found to be increased 194.92%, the range of increment of *Rz* for varnished and heat treated Oriental beech after accelerated weathering was between 38.71 to 154.35 %, for varnished and heat treated Oriental beech wood after accelerated weathering. This afore mentioned increment in slickness is very significant for myriad of solid wood applications. Besides, losses caused by planning machine are reduced and high quality surfaces are obtained (Korkut et al. 2009). Further, rough surfaced wood materials with require much more sandpapering with respect to sleek surfaces, which in turn causes the decrease of thickness of the wood material, therefore, increases the losses caused by application of sandpapering (Dundar et al. 2008). Yet, wood is a fragile, heterogeneous and anisotropic. Anatomical properties of wood (vessels, cell lumen, annual ring width, stiffness etc.), machine conditions (feed rate, spindle speed etc.) and cutting properties and many similar factors effects the wood's surface roughness (Karagoz et al.2011). Baysal et al. (2014a) disclosed that surface roughness of non-heat treated Scots pine wood was higher than heat treated Scots pine wood after application of artificial weathering. Yildiz et al. (2013) observed that surface roughness values of heat treated softwoods were lower than that of un-treated softwoods after weathering. Our findings are in compliance with these aforementioned researchers' findings. We have observed that longer application of heat treatments and utilization of higher temperatures causes decreased surface roughness in Oriental beech wood after application of accelerated weathering. Similar result are also disclosed by Turkoglu et al. 2015b, Baysal et al. 2014b, Gunduz et al. 2008, Korkut and Guller 2008 who investigated the effects of heat treatment on different wood typesin which in these studies it is observed that surface roughness values of wood samples decreased with increments in temperature and duration of heat treatment.

Changes in color

*L**, *a**, *b**values of heated and varnished Oriental beech before accelerated weathering and the changes of *ΔL**, *Δa**, *Δb**, and *ΔE** of heated and varnished Oriental beech after accelerated weathering are demonstrated in Tab. 3 and Fig. 3.

Tab. 3: Color changes ofheated and varnished Oriental beech wood specimens before and after accelerated weathering.

Heat treatment (°C)	Hours	Before accelerated weathering			After 500 h accelerated weathering			Color changes			
		Li*	ai*	bi*	Lf*	af*	bf*	ΔL*	Δa*	Δb*	ΔE*
Control (only varnished)		59.93	11.69	29.29	54.69	15.29	49.89	-5.24	3.60	20.60	21.56
210°C	0.5	25.10	12.31	17.64	29.92	14.45	30.87	4.82	2.14	13.23	14.24
	1	23.09	11.02	14.25	26.67	12.75	26.49	3.58	1.73	12.24	12.87
	1.5	25.32	11.12	16.54	31.16	12.68	26.23	5.84	1.56	9.69	11.42
220°C	0.5	20.33	9.34	10.69	23.65	11.36	22.89	3.32	2.02	12.20	12.81
	1	15.42	5.13	4.68	16.61	5.97	12.63	1.19	0.84	7.95	8.09
	1.5	18.13	8.90	10.14	21.95	9.2	16.79	3.82	0.30	6.65	7.67
230°C	0.5	15.99	7.46	7.43	19.17	8.67	16.22	3.18	1.21	8.79	9.43
	1	8.18	3.42	1.82	14.23	2.59	4.73	6.05	-0.83	2.91	6.77
	1.5	11.07	2.53	1.38	14.95	2.47	6.02	3.88	-0.06	4.64	6.05

Note: Five replicates were made for each group.

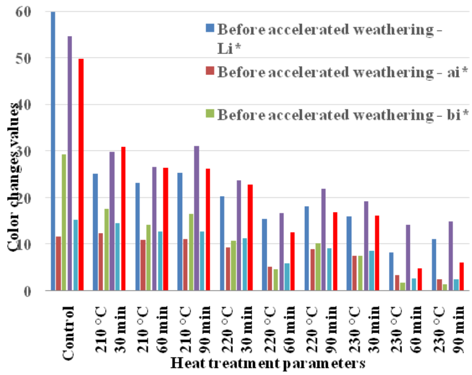

Fig. 3: Color changes of heated and varnished Oriental beech wood specimens before and after accelerated weathering.

*L** value of only varnished (control) wood was much higher than heated and varnished Oriental beech wood before exposed to accelerated weathering. The decrement in *L** value specifies that the samples become darker after application of heat treatment. The darkening of heat-treated Oriental-beech may be caused by degradation of lignin and other noncellulosic polysaccharides (Hon and Chang 1985, Grelier et al. 2000, Petric et al. 2004). During heat treatment of wood, acetic acid is formed from acetylated hemicelluloses via hydrolysis (Forsman 2008). The resultant acid acts as a catalyst in hydrolysis of hemicelluloses to the soluble sugars (Finnish Thermowood Association 2003). Heat causes the caramelization of sugar and this process influences the color of wood sample. Temperature increase also expediate the degradation of hemicelluloses and with increasing heat treatment temperature the color of the wood become darker (Forsman 2008). *L** value was the most sensitive parameter for wood surface color after accelerated weathering. While positive *ΔL** indicates that heated and varnished Oriental beech wood specimens become lighter after accelerated weathering, negative *ΔL** of varnished Oriental beech wood specimens become darker after accelerated weathering. Olărescu et al. (2014) found that the heat treated panels have the dispositionto have a lighter color (positive *ΔL** values), on the other hand the untreated samples have the disposition to have darker (negative values of *ΔL**). In another study, Baysal et al. (2014b) disclosed that heat treated Oriental beech wood samples become lighter after exposure to natural weathering and on the other hand non-heat treated Oriental beech wood samples become darker after exposure to natural weathering. Our results are in compliance with afore mentioned researches. While *ΔL** of only varnished Oriental beech was -5.24, *ΔL** value is changed from 1.19 to 6.05 for heat treated and varnished Oriental beech wood after exposure to accelerated weathering. The results we have obtained suggested that in general application of heat treatment decreases a* and b*values in Oriental beech wood before exposure to accelerated weathering.Accelerated weathering caused an increase of *Δa** and *Δb** of Oriental beech wood. Apart from heat treatments at 230°C for 1 and 1.5 h, , the positive *Δa** and *Δb** values indicate a disposition of wood surface to become reddish and yellowish after exposure to accelerated weathering. We have found that the *Δa** and *Δb** values of Oriental beech wood which is exposed to accelerated weathering decreased with increasing duration and temperature of heat treatment. Total color changes (*ΔE**) at the end of the accelerated weathering were higher for the only varnished wood than heated and varnished wood. The total color changes of only varnished Oriental beech wood was 21.56, this value was between 6.05 and 14.24 for heat treated and varnished Oriental beech. ΔE^* value of Oriental beech wood decreased with increasing duration and temperature of the treatment.

CONCLUSIONS

This study presented that effects of accelerated weathering on some surface characteristics such as surface hardness, surface roughness,and color changes of heated and varnished Oriental beech wood.In general, surface hardness values of heated and varnished Oriental beech increased after accelerated weathering. Heat treatments cause a strong darkening of wood surface. While the decrease in ΔL^* indicates that the specimens become darker, positive values of Δa^* and Δb^* indicate a tendency of wood surface to become reddish and yellowish after accelerated weathering. Surface roughness values of only varnished (control) Oriental beech wood were higher than heated and varnished Oriental beech after accelerated weathering. Higher duration and temperature resulted in lower surface roughness and color changes of heated and varnished Oriental beech after accelerated weathering.

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