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SOME SURFACE PROPERTIES OF HEAT TREATED AND NATURAL WEATHERED ORIENTAL BEECH

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ABSTRACT

This study was performed to investigate some surface characteristics such as color, surface roughness and glossiness of heat treated Oriental beech (*Fagus orientalis* L.) wood specimens after natural weathering. Heat treatment of Oriental beech wood was carried out by hot air in an oven for 1, 4, and 8 h at 140, 170, and 200°C.

Our results showed that heat treatment caused decrease in surface roughness and glossiness of Oriental beech. The decrease in L^* of heat treated wood indicates that the specimens become darker. Heat treatment resulted in better surface roughness and glossiness compared to non-heated Oriental beech after natural weathering. According to our results, while heat treated Oriental beech wood specimens become lighter after natural weathering, non-heated wood become darken after natural weathering. The negative values of Δa^* and Δb^* indicate a tendency of wood surface to become greenish and bluish after natural weathering. Generally, higher temperature and duration of treatment resulted in better surface characteristics of Oriental beech after natural weathering.

KEYWORDS: Heat treated, Oriental beech, surface roughness, gloss, color, natural weathering.

INTRODUCTION

Wood has been preferred for residential construction since ancient times because of its natural beauty and excellent properties, such as, high specific strength, heat insulation, and ease of handling and processing (Su 1997). But, it has less desirable properties such as poor durability and poor dimensional stability. This problem can be reduced by using chemical treatments. Increased environmental awareness has raised the demand for more environmentally friendly methods. Heat treatment is an alternative method for improving these properties with no use of chemical additives (Johansson 2008). Heat treated wood possesses new physical properties such as reduced hygroscopy, improved dimensional stability, better resistance to degradation by insects and micro-organisms, and most importantly, attractive darker color. These new versatile and attractive properties help heat treated wood to become popular for outdoor applications (Huang et al. 2012). Heat treated wood has a large application for outdoor use in cladding, decks, garden furniture, and window frames as well as indoor use for kitchen furniture, parquet, decorative panels, and mainly for the interior of saunas (Esteves and Pereira 2009). Huang et al. (2012) reported that lignin content of birch wood increases slightly with heat treatment. This increase becomes more important as the treatment temperature increases. They also found that the heat treatment increases the crystallized cellulose content. The increase in lignin and crystallized cellulose contents brought about by heat treatment protects heat treated birch wood against degradation taking place during weathering. Although heat treated wood shows the advantage in terms of aesthetic properties (uniform and effective change in color) and some technical guidelines (much reduced swelling and shrinkage and improved resistance to the fungus), it has some shortcomings when compared to normal wood. The mechanical properties are substantially reduced, so that the material generally used for fully supported the structure (Vukas et al. 2010).

Outdoor conditions can cause degradation of wood surface primarily due to the effects of sunlight (ultraviolet light) and water (Yalinkilic et al. 1999, Turkoglu et al. 2015). Weathering of wood is primarily a surface phenomenon that results in the slow erosion of wood fibers from 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). Many chemical protective systems for wood to prevent photodegradation were investigated: acetylation, the grafting of UV absorbers, treatments with inorganic salts, especially chromium salts etc. More than 95 % of exterior wood coatings are applied as liquid coatings with either organic solvent or water as the carrier for the other coatings ingredients. The use and subsequent emission of volatile organic compounds (VOCs) to the environment has been increasingly considered as a problem during the last 20 years from the both an air-pollution and health and safety point of view (de Meijer 2001). Also, some wood preservatives such as creosote, pentachloro-phenol and chromated copper arsenate contain components that are poisonous for the environment and human health (Kocaefe et al. 2007, Yildiz et al. 2013). The modified chromophoric lignin structure due to heat treatment may interfere with light absorption process, thereby inducing photo-stability (Srinivas and Pandey 2012). Ayadi et al. (2003) investigated color stability of heat treated wood during artificial weathering. They found that heat treatment increased the color stability of wood. The best photostability of retified wood color could be partially explained by the increase of lignin stability by condensation and phenol content during the heat treatment. Yildiz et al. (2011) studied on color stability of heat treated alder wood after natural weathering. They reported that there was a tendency on color changes in heat treated and weathered stakes compared to the weathered control stakes. Deka et al. (2008) found that color changes of heat treated spruce wood were lower than non-heated spruce wood after long term artificial UV-light exposure. The objective of this study was to determine some surface characteristics such as color, gloss, and surface roughness changes of heat treated Oriental beech wood after natural weathering.

MATERIAL AND METHODS

Preparation of test specimens

Specimens 10 x 100 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 (140, 170, and 200°C) and three treatment durations (1, 4, and 8 h) were applied to wood specimens under atmospheric pressure and in the presence of air.

Natural weathering test

Each groups consisted of 10 individual wood specimens. In total, 10 groups of wood specimens for each species were exposed to weathering conditions during winter (from December 2013 to February 2014) in 2013-2014.

Wood panels were prepared for weathering exposure according to ASTM D 358–55 (1970). A test site was established close to the Regional Meteorological Observation Station of Mugla, which is in Southern Aegean Region, to enable practical assessments. The details of the climate condition of Mugla city in this period are given in Tab. 1 (Turkish State Meteorological Service Database, 2014).

Tab. 1: Details of the climate condition of Mugla city during winter in 2013-2014.

Years	2013	2014	
Months	**December**	**January**	**February**
Average temperature (°C)	4.9	6.9	7.2
The highest temperature (°C)	18.2	15.6	20
The lowest temperature (°C)	-5.3	-2.3	-2.2
Sunbathing time per month (hour)	58.1	63.7	112.6
The number of the rainy days	10	13	5
Total rainfall per month ($kg.m^{-2}$)	41.2	230	28.6
Humidity (%)	72.7	87.2	79.2

Color measurement

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 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 total color difference, (ΔE^*) was determined for each treatment group as follows (ASTM D 1536–58, 1964):

$\Delta a^*= af^* - ai^*$
$\Delta b^* = bf^* - bi^*$
$\Delta L^*= Lf^*- Li^*$
$(\Delta E^*) = [(\Delta a^*)2 + (\Delta b^*)2 + (\Delta L^*) 2]$ ½

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

Glossiness test

The gloss of wood specimens was determined using a glossmeter (BYK Gardner, MicroTRI-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.

Surface roughness test

Surface roughness of specimens was measured by the Mitutoyo Surftest SJ-301 according to DIN 4768 (1990). The surface roughness measurement instrument consists of a main unit and a pick-up unit, which has a skid-type diamond stylus with 5 μm tip radius and 90º tip detector conical taper angle. The stylus scans the surface at a constant speed of 0.5 $mm.s^{-1}$ over a sampling length of 8 mm (Zhong et al. 2013). Three roughness parameters were measured: mean arithmetic deviation of profile (Ra), mean peak-to-valley height (Rz), and root mean square (Rq) and these parameters were widely employed in former studies to evaluate surface characteristics of wood and wood based materials (Hiziroglu 1996, Hiziroglu and Graham 1998).

Evaluations of test results

The results of color, glossiness and surface roughness tests were evaluated by a computerized statistical program composed of analysis of variance followed by Duncan tests at the 95 % confidence level. Statistical evaluations were made on homogeneity groups of which different letters reflected statistical significance.

RESULTS AND DISCUSSION

Color changes

L^*, a^*, b^* values of non-heated and heat treated Oriental beech before natural weathering and the changes of ΔL^*, Δa^*, Δb^*, and ΔE of non-heated and heat treated Oriental beech after natural weathering are given in Tab. 2. L^* of non-heated wood was higher than heat treated wood before natural weathering.

Tab. 2: The color changes of heated Oriental beech before and after natural weathering.

Heat treatment (°C)	Time (hour)	Before natural weathering			After natural weathering			After natural weathering			
		L_i^*	a_i^*	b_i^*	L_f^*	a_f^*	b_f^*	ΔL^*	Δa^*	Δb^*	ΔE^*
Control	-	69.46(11.81)	10.77(1.72)	19.33(2.20)	52.03(7.66)	3.16(0.55)	11.34(1.53)	-17.43	-7.59	-7.99	20.62^{a}
140	1	54.21(8.26)	10.70(1.37)	19.58(2.96)	70.43(9.94)	3.11(0.38)	11.81(1.86)	16.22	-7.53	-7.77	19.50^{a}
	4	53.47(8.68)	10.30(1.50)	18.60(2.15)	69.64(8.37)	3.18(0.59)	12.07(1.68)	16.17	-7.38	-6.53	18.94^{ab}
	8	57.58(7.95)	9.77(1.62)	18.96(2.61)	72.46(9.38)	3.56(0.61)	14.31(2.07)	14.88	-6.21	-4.65	16.78^{bc}
170	1	55.73(8.13)	7.25(0.97)	12.49(1.58)	68.21(8.27)	3.20(0.47)	7.61(1.22)	12.48	-6.84	-4.88	15.04^{c}
	4	57.64(7.60)	10.58(1.09)	18.25(3.16)	71.67(9.89)	3.04(0.38)	13.88(1.95)	14.03	-5.91	-4.37	15.84^{c}
	8	52.29(9.08)	8.89(1.18)	15.03(1.53)	65.49(7.74)	4.24(0.70)	12.67(1.75)	13.20	-4.64	-2.36	14.19^{c}

200	1	61.51(9.91)	10.41(1.64)	17.58(2.55)	74.18(8.81)	3.13(0.33)	13.38(2.57)	12.67	-5.59	-4.20	14.47^{c}
	4	57.03(7.68)	10.36(1.25)	16.98(2.84)	66.67(9.18)	4.77(0.59)	15.47(1.49)	9.64	-4.05	-1.51	10.56^{d}
	8	52.62(8.65)	13.86(1.75)	17.97(2.37)	61.67(8.04)	10.55(1.65)	16.96(1.78)	9.05	-3.31	-1.01	9.69^{d}

Note: Small letters ($^{a-d}$) given as superscript over ΔE^* values represent significant difference by Duncan's homogeneity groups (P<0.05). Values in parenthesis are standard deviations. Ten replicates were made for each treatment group.

The decrease in L^* of heat treated wood indicates that the specimens become darker. Generally, our results showed that heat treatment caused a decrease a^* and b^* values of Oriental beech wood in some extent before natural weathering. Natural weathering darkened and changed the color of non-heated and heat treated Oriental beech wood specimens. L^* was the most sensitive parameter for wood surface color after natural weathering. While positive ΔL^* indicates that heat treated Oriental beech wood specimens become lighter after natural weathering, negative ΔL^* of non-heated Oriental beech wood specimens become darker after natural weathering. While ΔL^* of non-heated Oriental beech was -17.43, it changed from 9.05 to 16.22 for heat treated Oriental beech after natural weathering. The color of both non-heated and heat treated Oriental beech wood became greenish and bluish after natural weathering. The negative values of Δa^* and Δb^* indicate a tendency of wood surface to become greenish and bluish after natural weathering. Our results showed that the Δa^* and Δb^* of natural weathered Oriental beech decreased with increasing treatment temperature and duration of treatment. Olărescu et al. (2014) investigated ΔL^* of heat treated wood panels after three months of natural weathering. They found that the heat treated panels display the tendency of getting lighter (positive values of ΔL^*), while the untreated ones get darker (negative values of ΔL^*). Yildiz et al. (2011) investigated Δa^* and Δb^* of heat treated wood specimens after natural weathering. They found that Δa^* and Δb^* of heat treated wood specimens showed a tendency of greenish and bluish after natural weathering. Our results are in good agreement with these researchers findings. Total color changes (ΔE^*) at the end of the natural weathering were higher for the non-treated wood than the heat treated wood. The total color changes ΔE^* of non-heated Oriental beech wood was 20.62, it was changed from 9.69 to 19.50 heat treated Oriental beech. ΔE^* of Oriental beech wood decreased with increasing temperature and duration of treatment. There was statistically significant in ΔE^* values between non-heated and heat treated Oriental beech after natural weathering. Our results showed that heat treated Oriental beech wood showed better color stability compared to non-heated Oriental beech. Ayadi et al. (2003) reported that the color difference of heat treated heartwood for ash, beech, maritime pine and poplar was lower than non-heated wood during the 835 h of UV light exposure Ahajji et al. (2009) reported that lignin can affect color performance of heat treated wood. This is because lignin molecules are partially modified during the heat treatment and then low molecular weight products occur, which cause color change (Ahajji et al. 2009, Garcia et al. 2014).

Surface roughness

Surface roughness parameters such as Ra, Rz, and Rq values of non-heated and heat treated Oriental beech before and after natural weathering are given in Tab. 3.

Non-heated control specimen had average *Ra, Rz*, and *Rq* values 2.53, 16.60 and 3.13, respectively before natural weathering. According to the studies in the literature, the values of surface roughness decreased with increasing treatment temperature and duration of treatment (Baysal et al. 2014, Korkut et al. 2009, Sevim Korkut et al. 2008). Our result showed that surface roughness of non-heated Oriental beech wood was higher than heat treated Oriental beech wood after natural weathering. Natural weathering increased surface roughness of both non-heated and heat treated Oriental beech. While the increase of *Ra, Rz*, and *Rq* were by 204.7, 139.3

Tab. 3: The surface roughness of heated Oriental beech before and after natural weathering.

Heat treatment (°C)	Time (hour)	Before natural weathering			After natural weathering			Change (%)			Difference		
		Ra	***Rz***	***Rq***	***Ra***	***Rz***	***Rq***	***Ra***	***Rz***	***Rq***	***Ra***	***Rz***	***Rq***
Control	-	2.53(0.43)	16.60(2.40)	3.13(0.52)	7.71(0.79)	39.72(5.68)	7.24(0.65)	204.7	139.3	131.3	5.18^{a}	23.12^{a}	4.31^{a}
140	1	2.42(0.31)	20.67(3.17)	3.70(0.45)	5.89(0.85)	37.89(5.04)	7.84(0.90)	143.4	83.3	111.9	3.47^{b}	17.22^{b}	4.14^{a}
	4	2.26(0.36)	14.89(1.82)	2.63(0.38)	4.58(0.53)	28.75(3.93)	5.39(0.54)	102.7	93.1	104.9	2.32^{bc}	13.86^{b}	2.76^{bc}
	8	4.54(0.81)	18.15(2.67)	6.09(1.12)	7.80(0.94)	32.97(7.13)	9.41(1.79)	71.8	81.7	54.5	3.26^{b}	14.82^{b}	3.32^{b}
170	1	2.60(0.28)	17.82(2.88)	4.27(0.60)	5.21(0.58)	32.44(5.91)	7.55(1.12)	100.4	82.0	76.8	2.61^{bc}	14.62^{b}	3.28^{b}
	4	2.42(0.36)	15.60(2.59)	3.28(0.49)	4.54(0.50)	29.30(6.57)	5.64(0.61)	87.6	87.8	72.0	2.12^{bc}	13.70^{b}	2.36^{c}
	8	3.30(0.64)	14.33(1.55)	4.11(0.66)	5.60(0.87)	28.69(4.18)	7.02(1.58)	69.7	100.2	70.8	2.30^{bc}	14.36^{b}	2.91^{bc}
200	1	2.03(0.22)	13.91(1.32)	6.32(0.97)	4.05(0.59)	27.15(5.20)	8.63(1.84)	108.9	95.2	36.6	2.02^{bc}	13.24^{b}	2.31^{c}
	4	3.56(0.72)	18.82(2.82)	5.04(0.74)	5.75(0.96)	33.16(6.66)	7.50(1.55)	61.5	76.2	48.8	2.19^{bc}	14.34^{b}	2.46^{c}
	8	4.63(0.66)	17.93(2.54)	5.07(0.81)	5.62(0.84)	30.06(5.75)	6.29(0.88)	21.4	67.7	24.1	0.99^{c}	12.13^{b}	1.22^{d}

Note: Small letters ($^{a-d}$) given as superscript over Ra, Rz, and Rq values indicate significant difference by Duncan's homogeneity groups ($P<0.05$). Values in parenthesis are standard deviations. Ten replicates were made for each treatment group.

and 131.3 % respectively, for non-heated Oriental beech, the increase range of *Ra* was from 21.4 to 143.4 %, *Rz* was from 67.7 to 100.2 %, and *Rq* was from 24.1 to 111.9 %, for heat treated Oriental beech except for *Rq* values of Oriental beech heat treated at 140°C for 1 h, there was statistically significant difference in *Ra, Rz*, and *Rq* values between non-heated and heat treated Oriental beech after natural weathering. Yildiz et al. (2013) reported that heat treatment seemed to protect wood surface from becoming rougher after weathering for softwood. Baysal et al. (2014) reported surface roughness of non-heated Scots pine wood was higher than heat treated Scots pine wood after artificial weathering. Our results are in good agreement with these researchers' findings.

Gloss

Gloss values of non-heated and heat treated Oriental beech wood before and after natural weathering are given in Tab. 4.

Tab. 4: The gloss changes of heated Oriental beech before and after natural weathering.

Heat treatment (°C)	Time (hour)	Before natural weathering	After natural weathering	Change (%)	Difference
Control	-	4.07 (0.84)	1.32(0.27)	-67.6	-2.75^{a}
140	1	3.58(0.47)	1.19(0.22)	-66.8	-2.38^{a}
	4	3.65(0.55)	1.59(0.48)	-56.4	-2.06^{ab}
	8	3.61(0.63)	1.61(0.33)	-55.4	-2.00^{ab}
170	1	3.46(0.40)	1.39(0.27)	-59.8	-1.94^{ab}
	4	3.20(0.66)	1.47(0.21)	-54.1	-1.73^{b}
	8	2.89(0.39)	1.83(0.43)	-26.3	-1.06^{c}
200	1	2.54(0.31)	1.57(0.38)	-38.2	-0.97^{c}
	4	2.37(0.44)	1.70(0.40)	-28.3	-0.67^{cd}
	8	2.02(0.35)	1.50(0.37)	-25.7	-0.52^{d}

Note: Small letters ($^{a-d}$) given as superscript over values in the difference column indicate significant difference by Duncan's homogeneity groups ($P<0.05$). Values in parenthesis are standard deviations. Ten replicates were made for each treatment group.

Glossiness, a property of reflecting light in a mirror-like fashion, is very important for aesthetic and decorative appearance of coated wood surface (Cakicier et al. 2011). While the highest gloss value was 3.65 for wood specimens observed after heat treatment at 140°C for 4 h before natural weathering, the lowest gloss value was 2.02 for Oriental beech wood specimens measured after heat treatment at 200°C for 8 h before natural weathering. Natural weathering decreased gloss of heat treated Oriental beech. The decrease of gloss ranged from 25.7 to 66.8 % for heat treated Oriental beech. Our results showed that gloss loss values of Oriental beech wood specimens decreased with increasing treatment temperature and duration of treatment. Sevim Korkut et al. (2013) found that gloss loss of wild cherry wood was 36.6 % after heat treatment at 212°C for 2.5 h. Aksoy et al. (2011) reported 5.5 to 36.6 % gloss loss values for Scots pine wood after heat treatments. Baysal et al. (2014) found 0.63 to 39.69 % gloss loss of heat treated Oriental beech wood. They also reported that gloss values of Oriental beech wood specimens decreased with increasing treatment temperature and duration of treatment. Abrasion on the wood surfaces, along with erosion, causes gloss degradation (Yalinkilic et al. 1999). There was a statistical significant in gloss values between heat treated Oriental beech wood at 140°C and heat treated Oriental beech wood at 200°C. Our results showed that gloss values of Oriental beech enhanced with increasing treatment temperature and duration of treatment after natural weathering.

CONCLUSIONS

Heat treatment caused darkening of wood surface. Heat treated Oriental beech showed better gloss and surface roughness compared to non-heated Oriental beech after natural weathering. While heat treated Oriental beech showed lightener, non-heated Oriental beech showed darkener after natural weathering. Negative values of Δa^* and Δb^* indicate a tendency of wood surface to become bluish and greenish, respectively after natural weathering. In general, higher temperature and duration of treatment improved surface characteristics of Oriental beech wood specimens after natural weathering.

In conclusion, after heat treatment, the wood acquires a darker color. This color change is often seen as a positive effect, especially in hardwoods. The color change creates a potential for wood to reach new markets where more exclusive hardwoods are normally used (Johansson 2008). Natural weathering affected heat treated Oriental beech wood less than non-heated wood in terms of gloss loss and surface roughness. Also, higher temperature and duration of treatment resulted in better surface properties of wood after natural weathering.

REFERENCES

1. Ahajji, A., Diouf, P. N., Aloui, F., Elbakali, I., Perrin, D., Merlin, A., George, B., 2009: Influence of heat treatment on antioxidant properties and colour stability of beech and spruce wood and their extractives. Wood Science and Technology 43(1-2): 69-83.
2. Aksoy, A., Deveci, M., Baysal, E., Toker, H., 2011: Colour and gloss changes of Scots pine after heat modification. Wood Research 56(3): 329-336.
3. ASTM D1536–58, 1964: Tentative method of test color difference using the colormaster differential colorimeter.
4. ASTM D, 358-55, 1970: Standard specification for wood to be used panels in weathering tests of paints and varnishes.
5. ASTM D523-08, 2008: Standard test method for specular gloss.
6. Ayadi, N., Lejeune, F., Charrier, F., Charrier, B., Merlin, A., 2003: Color stability of heat treated wood during artificial weathering. Holz als Roh und Werkstoff 61: 221-226.

7. Baysal, E., Kart, S., Toker, H., Degirmentepe, S., 2014: Some physical characteristics of thermally treated Oriental beech wood. Maderas Ciencia y Tecnologia 16(3): 291-298.
8. Cakicier, N., Korkut, S., Korkut, D.S., 2011: Varnish layer hardness, scratch resistance, and glossiness of various wood species as effected by heat treatment. Bioresources 6(2): 1648-1658.
9. De Meijer, M., 2001: Review on the durability of exterior wood coatings with reduced VOC-content. Progress in Organic Coatings 43(4): 217-225.
10. Deka, M., Humar, M., Rep, G., Kričej, B., Šentjurc, M., Petrič, M., 2008: Effects of UV light irradiation on colour stability of thermally modified, copper ethanolamine treated and non-modified wood: EPR and DRIFT spectroscopic studies. Wood Science and Technology 42(1): 5-20.
11. Denes, A.R., Young, R.A., 1999: Reduction of weathering degradation of wood through plasma-polymer coating. Holzforschung 53(6): 632-640.
12. DIN 4768, 1990: Determination of values of surface roughness parameters R_a, R_z, R_{max} using electrical contact (stylus) instruments, concepts and measuring conditions.
13. Esteves, B.M., Pereira, H.M., 2009: Wood modification by heat treatment: A review. Bioresources 4(1): 370-404.
14. Garcia, R. A., de Oliveira Lopes, J., do Nascimento, A. M., de Figueiredo Latorraca, J. V., 2014: Color stability of weathered heat-treated teak wood. Maderas Ciencia y Tecnologia 16(4): 453-462.
15. Hiziroglu, S., 1996: Surface roughness analysis of wood composites: A stylus method. Forest Product Journal 46: 67-72.
16. Hiziroglu, S., Graham, S., 1998: Effect of press closing time and target thickness on surface roughness of particleboard. Forest Product Journal 48: 50-54.
17. Huang, X., Kocaefe, D., Kocaefe, Y., Boluk, Y., Pichette, A., 2012: Study of the degradation behavior of heat treated jack pine (*Pinus banksiana*) under artificial sunlight irradiation. Polymer Degradation and Stability 97(7): 1197-1214.
18. Johansson, D., 2008: Heat treatment of solid wood: Effects on absorption, strength and colour. PhD Thesis, Luleå University of Technology, Skelleftea, Sweden, 142 pp.
19. Kocaefe, D., Younsi, R., Poncsak, S., Kocaefe, Y., 2007: Comparison of different models for the high-temperature heat-treatment of wood. International Journal of Thermal Sciences 46(7): 707-716.
20. Korkut, S., Alma, M.H., Elyildirim, Y.K., 2009: The effects of heat treatment on physical and technological properties and surface roughness of European Hophornbeam (*Ostrya carpinifolia* Scop.) wood. African Journal of Biotechnology 8(20): 5316-5327.
21. Olărescu, C.M., Câmpean, M., Varodi,A., 2014: Colour and dimensional modifications of solid wood panels made from heat treated spruce wood after three months of outdoor exposure. Pro Ligno 10(3): 46-54.
22. Ozgenc, O., Hiziroglu, S., Yildiz, U.C., 2012: Weathering properties of wood species treated with different coating applications. BioResources 7(4): 4875-4888.
23. Sevim Korkut, D., Korkut, S., Bekar, I., Budakci, M., Dilik, T., Cakicier, N. 2008: The effects of heat treatment on the physical properties and surface roughness of Turkish Hazel (*Corylus colurna* L.) wood. International Journal of Molecular Sciences 9(9): 1772-1783.
24. Sevim Korkut, D., Hiziroglu, S., Aytin, A., 2013: Effect of heat treatment on surface chracteristics of wild cherry wood. Bioresources 8(2): 1582-1590.
25. Srinivas, K., Pandey, K.K., 2012: Photodegradation of thermally modified wood. Journal of Photochemistry and Photobiology B: Biology 117: 140-145.

26. Su, W.Y., 1997: Development of fire retardant wood composites using boron compounds and their evaluation methods. M.Sc. Thesis, Kyoto University, Kyoto, Japan, 126 pp.
27. Turkish State Meteorological Service Database, 2014. Meteorological data of Mugla, Regional Meteorological Observation Station of Mugla, Turkey.
28. Turkoglu, T., Baysal, E., Toker, H., 2015: The effects of natural weathering on color stability of impregnated and varnished wood materials. Advances in Materials Science and Engineering, vol. 2015, Article ID 526570, 9 pages, doi:10.1155/2015/526570.
29. Vukas, N., Horman, I., Hajdarević, S., 2010: Heat treated wood. In: 14th International Research/Expert Conference "Trends in the Development of Machinery and Associated Technology" TMT 2010, 11-18 September, Mediterranean Cruise.
30. Williams, R.S., Kanaebe, M.T., Sotos, P.G., Feist, W.C., 2001: Erosion rates of wood during natural weathering. Part 1. Effects of grain angle and surface texture. Wood and Fiber Science 33(1): 31-42.
31. Yalinkilic, M.K., Ilhan, R., Imamura, Y., Takahashi, M., Demirci, Z., Yalinkilic, A.C., Peker, H., 1999: Weathering durability of CCB-impregnated wood for clear varnish coatings. Journal of Wood Science 45: 502-514.
32. Yildiz, S., Yildiz, U.C., Tomak, E.D., 2011: The effects of natural weathering on the properties of heat treated alder wood. Bioresources 6(4): 2504-2521.
33. Yildiz, S., Tomak, E.D., Yildiz, C., Ustaomer, D., 2013: Effect of artificial weathering on the properties of heat treated wood. Polymer Degradation and Stability 98(8): 1419-1427.
34. Zhang, X., 2003: Photo-resistance of alkylammonium compound treated wood. MS.c. Thesis. The University of British Colombia Vancouver, Canada.
35. Zhong, Z.W., Hiziroglu, S., Chan, C.T.M. 2013: Measurement of the surface roughness of wood based materials used in furniture manufacture. Measurement 46: 1482-1487.

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