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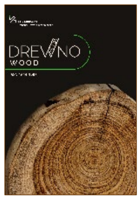

Improving The Surface Quality of Wood After Weathering Through Heat Treatment Using Waste Olive Oil

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Experiments were conducted with the aim of improving the surface properties of Oriental beech (Fagus orientalis Lipsky) wood after weathering, including colour, gloss, and roughness, by means of heat treatment with waste olive oil (WOHT). First, WOHT was applied at 200 °C and 230 °C for 2 and 4 hours. Then, for three months, Oriental beech specimens were exposed to the weather in the Muğla region (Southern Aegean, Türkiye). After weathering, colour, gloss, and roughness tests were performed according to the ASTM D1536-58T (1964), ASTM D 523-14 (2018), and DIN 4768 (1990) standards, respectively. All treatment groups except the control group were found to have positive ΔL* values after weathering. The values of total colour change (ΔE*) for WOHT Oriental beech were better than for the unheated (control) group. The best colour stability was obtained for WOHT Oriental beech heated at 200 °C for 4 hours. The glossiness of all specimens decreased after weathering, but the gloss results for WOHT Oriental beech were better than those obtained for the unheated (control) group. Lower temperatures and durations of heat treatment resulted in smaller decreases in the gloss of WOHT Oriental beech on weathering. The roughness of all specimens was increased by weathering, but lower roughness values after weathering were obtained for WOHT Oriental beech than for the control group.

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Introduction

Wood is the most prevalent structural material in nature, and is often the material of choice for both indoor and outdoor uses. Wood, like all other biological materials, is subject to deterioration in outdoor conditions, as a result of UV light, humidity, temperature, wind, and other atmospheric factors (oxygen, air pollutant gases such as sulphur dioxide and nitrogen dioxide, etc.) [Liu 1997; Temiz et al. 2005]. The most

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significant outdoor factor among these is photodegradation by UV light [Liu 1997; Müller et al. 2003]. These phenomena cause the wood material's surface to age over time, develop cracks, and potentially lose gloss.

Heat treatment is a method of altering wood without the use of hazardous chemicals. In recent years, consumers have become more interested in wood products with improved performance and no toxic preservatives, which has led to an increase in the popularity of heat-treated wood [Jirouš-Rajković and Miklečić 2019]. This provides a good alternative for the production of high-quality materials that can be used for flooring, cladding, windows, doors, floors, garden products, and even saunas or baths. Modification by means of heat treatment is one method of protecting wood material [Militz and Altgen 2014]. Various heat treatment techniques are used globally today, differing in such parameters as applied temperature, processing time, environment, and initial humidity. Wood can be heated in any of the following environments: air, vacuum, nitrogen, steam, or vegetable oil [Dubey et al. 2010]. Normal heat treatment temperatures range from 180 to 260 °C; one study found that lower temperatures did not significantly alter the composition of the wood, whereas higher temperatures severely degraded the wood [Hill 2008]. It is also reported that the colour of heat-treated wood is unstable and fades over time on exposure to UV light [Militz 2002; Ahajji et al. 2009]. Mayes and Oksanen [2002] reported that surface checking and discolouration occurred in the case of heat-treated wood exposed to UV radiation, reducing its aesthetic value.

Recent research has shown that heat treatment in oil is an excellent method for modifying wood. In view of their nontoxicity and environmentally friendly composition, vegetable oils have long been used to protect wood from mould and fungal decay and to lessen the accessibility of moisture to the wood [Yingprasert et al. 2015]. Due to the complementary effects of heat and oil, wood can be improved through oil heat treatment. This technique has been the subject of much research worldwide. However, because the treatment methods and parameters vary between studies, it is challenging to compare the results [Lee et al. 2018].

Industrially, heat treatment and oil heat treatment methods are used to enhance some of the advantageous qualities of wood. As a result of this improvement, wood has begun to be used for exterior cladding and wooden garden furniture [Kesik et al. 2015a]. The durability of wood heat-treated with three different oils – sunflower (Helianthus annuus), linseed (Linum usitatissimum), and rapeseed oil (Brassica napus) – was examined by Bak et al. [2012]. In that research, the woods of poplar (Populus spp.) and black locust (Robinia pseudoacacia) were heated in the vegetable oils at 160 °C and 200 °C for 2, 4, and 6 hours. The specimens were then left outside for a year to weather. The findings showed that the colour change was smaller for the treated wood than for untreated specimens. This results from the decrease in content of some chemical substances, especially hemicelluloses and lignin [Bekhta and Niemz 2003; Huang et al. 2012; Razak et al. 2012]. Pinus radiata specimens were heated to temperatures of 160, 180, and 210 °C in commercial-grade raw linseed oil in a study by Dubey et al. [2010]. They discovered that oil heat-treated wood maintained its colour better than untreated wood. Treated wood did not exhibit any surface checks after weathering, and volumetric swelling was lower than in untreated wood. No colour fading was observed in wood treated at 160 and 180 °C, although some fading was recorded in specimens treated at 210 °C.

There are numerous studies on the changes in colour, gloss, and roughness that occur in heat-treated wood during weathering, but there is less information available on colour changes in oil heat-treated wood. In this study, waste olive oil was chosen for oil heat treatment. This was due to the fact that the use of oils that are generated as waste and have no further purpose is valued both financially and in terms of reducing environmental pollution. In Turkey, 1,500,000 tonnes of vegetable oil are utilised for food purposes every year, leading to approximately 350,000 tonnes of waste oil. When waste oils are disposed of in water or sewers, they cover the water's surface and damage the system. They hinder the transport of oxygen from air to water and, over time, decompose in water, accelerating the loss of oxygen. They also increase the operating costs of wastewater treatment plants. The affected wastewater adheres to channel pipes, causing them to narrow and become clogged. Used vegetable oils account for 25% of waste paper pollution [Cevreonline 2024]. To our knowledge, no research has previously been conducted on how oil heat-treated wood, particularly waste olive oil heat-treated wood, changes in gloss and roughness over time. Therefore, this study examined changes in the colour, gloss, and roughness of Oriental beech that had undergone waste olive oil heat treatment (WOHT).

Materials and methods

1. Materials

Waste olive oil from potato frying was used for the oil heat treatment. The study made use of waste olive oil that was discarded after a single use, obtained from the student cafeteria at Muğla Sıtkı Koçman University. Wood specimens were prepared from Oriental beech wood.

2. Methods

2.1. Preparation of wood specimens

Oriental beech specimens with dimensions of 10 mm × 100 mm × 150 mm (radial, tangential, and longitudinal) were produced for the weathering test.

2.2. WOHT process

In order to prepare the specimens for waste olive oil heat treatment (WOHT), they were dried in an oven at 103 ± 2 °C until they reached a constant weight. Before the oil heat treatment, the specimens were placed in an oil bath and weighted to prevent them from floating. Waste olive oil was then poured onto the specimens at room temperature, and they were heated for 2 and 4 hours at 200 and 230 °C. The wood specimens were then conditioned at 20 °C and 65% relative humidity for two weeks, after which their colour, gloss, and roughness were measured.

2.3. Colour test

The CIEL*a*b* method was used to determine the L*, a*, and b* colour parameters of the specimens. The chromaticity coordinates are represented in this diagram by the a* and b* axes, while brightness is represented by the L* axis. The symbols +a* and –a* stand for the colours red and green, respectively, and yellow and blue are represented by +b* and –b*, respectively. The L* value ranges from 0 (black) to 100 (white) [Zhang 2003]. The total colour difference (ΔE*) was calculated using equations (2)–(5), in accordance with the ASTM D1536-58T [ASTM 1964] standard. Colour analyses were carried out parallel to the fibres.

$$\Delta a^* = a_{final}^* - a_{initial}^* \quad (2)$$
$$\Delta b^* = b_{final}^* - b_{initial}^* \quad (3)$$
$$\Delta L^* = L_{final}^* - L_{initial}^* \quad (4)$$
$$(\Delta E^*) = [(\Delta a^*)\ 2 + (\Delta b^*)2 + (\Delta L^*)2]1/2 \quad (5)$$

where Δa*, Δb* and ΔL* represent the differences between the final and initial values of the respective parameters.

2.4. Gloss test

A Micro-TRI-Gloss instrument was used to calculate the gloss values of Oriental beech in accordance with the ASTM D 523-14 [ASTM 2018] standard. The geometry used corresponds to an incidence angle of 85 degrees. Gloss measurements were taken parallel to the fibres.

2.5. Roughness test

A Mitutoyo Surftest SJ-301 instrument was used to measure the roughness in accordance with the DIN 4768 [1990] standard. This device was used to profile the protrusions and indentations on the sample surface by rotating the 5 mm diamond tip up and down. The measuring environment is protected from vibration sources, as is the table where the instrument is placed. The temperature was maintained between 18 and 22 °C. After confirming that the device and specimens were parallel to the ground plane, Ra, Rz, and Rq values were established. Measurements were made of the profile's mean arithmetic deviation (Ra), mean peak-to-valley height (Rz), and root mean square (Rq) roughness parameters. The surface characteristics of wood and materials made from wood have previously been extensively evaluated using these parameters [Hızıroğlu 1996; Hızıroğlu and Graham 1998]. Measurements of roughness were taken parallel to the fibres.

2.6. Weathering test

The ASTM D 358-55 [ASTM, 1970] standard states that specimens of wood panels should be tested by exposure to weathering. The specimens were weathered for three months (September–November 2022) in panels located in the province of Muğla in the South Aegean Region of Türkiye (Table 1). The specimens faced south at a 45° angle and were set up on panels about 50 cm above the ground (Figure 1).

Table 1. Meteorological data for September–November 2022, Muğla Region

	September	October	November
Maximum monthly temperature (°C)	35.2	34.1	27.4
Average monthly temperature (°C)	22.6	17.1	11.4
Monthly minimum temperature (°C)	6.9	2.8	1.7
Monthly average relative humidity (%)	48.1	54.7	76.3
Number of rainy days per month	1	3	10

Fig. 1. Weathering test apparatus

2.7. Statistical evaluations of test results

The outcomes of the experiment were examined statistically using the Duncan test and analysis of variance. The Duncan test results for gloss, roughness, and total colour change were evaluated with a 95% confidence level using a computerised statistical program. Homogeneity groups (HG) were used in determining the statistical significance of the findings.

Results and discussion

1. Colour changes

Table 2 provides the colour and total colour change values for the unheated (control) group and WOHT Oriental beech specimens before and after weathering. Figure 2 also displays the specimens' total colour change values after weathering. Before weathering, the L* value for the control group was measured at 65.42. The values for WOHT Oriental beech ranged from 42.69 to 52.84, lower than that of the control group. The L* values of WOHT Oriental beech decreased as the temperature and duration of treatment increased. This indicates that Oriental beech specimens became darker due to the oil heat treatment. The darkening of wood after heating may be caused by a decrease in holocellulose content as the temperature rises, as reported by Bourgios et al. [1991]. The breakdown of lignin and other non-cellulosic polysaccharides may accelerate the darkening of wood [Grelier et al. 2000; Hon and Chang 1985; Petrič et al. 2004]. Heat treatment-related hemicellulose degradation, changes in extractive composition, and the formation of oxidation products are the main causes of colour change [Bekhta and Niemz 2003; Dubey et al. 2012]. Non-toxic and affordable vegetable oils include palm, linseed, rapeseed, coconut, soybean, and sunflower.

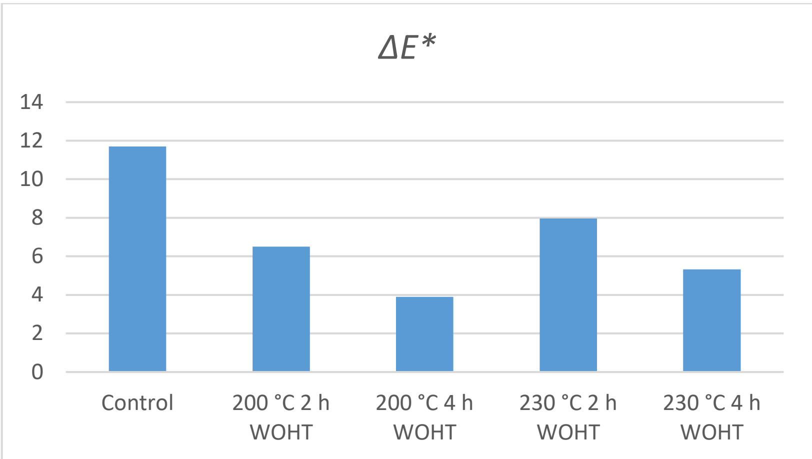

Fig. 2. Total colour change (*Δ*E*) values of unheated and WOHT Oriental beech before and after weathering

Table 2. Colour and total colour change values of unheated and WOHT Oriental beech specimens before and after weathering

Treatment	Temperature (°C)	Duration (hours)	Colour values before weathering						Colour change values after weathering			Total colour changes after weathering	
			*L**		*a**		*b**						
			Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Δ_L*	Δ_a*	Δ_b*	Δ_E*	H.G.
Control	-	-	65.42	4.21	10.88	1.09	20.70	0.98	–8.53	–6.31	–4.95	11.70	E
WOHT	200	2	52.84	3.48	15.02	1.92	25.52	2.83	3.32	–2.66	4.93	6.51	BC
WOHT	200	4	51.45	3.79	15.49	2.67	24.87	2.32	0.34	–0.26	3.88	3.90	A
WOHT	230	2	50.63	3.14	16.10	0.87	26.35	3.21	6.18	–4.99	0.66	7.97	CD
WOHT	230	4	42.69	3.18	15.48	0.93	21,85	2.63	0.87	–1.20	5.12	5.33	AB

Note: Ten specimens were used for each treatment group. WOHT: Waste olive oil heat treatment. Std. dev.: Standard deviation, H.G.: Homogeneity groups

Furthermore, these oils are good heat transmission media with high boiling points, making them suitable for heat treatment of wood [Umar et al. 2016]. Bal [2016] heated Taurus fir wood at 160 °C, 180 °C, 200 °C, and 220 °C using sunflower oil. The wood's colour characteristics were identified after processing. The L* values of the oil heat-treated specimens decreased with increasing temperature. The findings of our study are in agreement with those of Bal [2016]. According to our findings, the WOHT Oriental beech had higher a* and b* values than the control group. Radiata pine wood heated with commercial grade raw linseed oil at 160 °C, 180 °C, and 210 °C for 1, 3, and 6 hours was the subject of a study by Dubey et al. [2012]. They discovered that heating oil increased the reddish and yellowish hues of Radiata pine wood. Our findings are in accordance with those of Dubey et al. [2012], as in our study the WOHT Oriental beech specimens also displayed a tendency towards red and yellow. On weathering, the WOHT Oriental beech produced positive ΔL* values, while those of the control group were negative. After weathering, every WOHT Oriental beech specimen had negative a* and positive b* values, indicating that the surface of WOHT Oriental beech wood took on a greenish and yellowish hue. Our findings demonstrated that the total colour change value (ΔE*) was highest (11.70) for the control group, and lowest (3.90) for the WOHT Oriental beech heated at 200 °C for 4 hours. Low total colour change is a desirable characteristic, indicating that the best colour stability was provided by WOHT Oriental beech heated at 200 °C for 4 hours. The increase in lignin's stability following oil heat treatment may help to explain why WOHT Oriental beech has better colour stability [Ayadi et al. 2003; Deka et al. 2008]. According to Ayadi et al. [2003], the presence of antioxidant compounds in lignin can reduce oxidative and radical damage after heating. On weathering, there was a statistically significant difference in the total colour change values between the unheated (control) group and the WOHT Oriental beech wood. In a study by Suri et al. [2022], Paulownia tomentosa and Pinus koraiensis woods were heat-treated in palm oil (OHT) and air (AHT) at 180 °C, 200 °C, and 220 °C for two hours, and an artificial weathering test was conducted on untreated and heat-treated specimens. In that test, heat-treated wood from both species exhibited a smaller total colour change than control specimens. The findings from our study coincided with those of Suri et al. [2022]. However, those authors reported that the total colour change decreased as the treatment temperature was raised, but in our study the total colour changes of WOHT Oriental beech increased with increasing temperatures, although they decreased with increasing durations.

2. Gloss changes

Table 3 and Figure 3 display the changes in gloss of the unheated (control) group and WOHT Oriental beech specimens before and after weathering. Coated wood surfaces must be glossy, or have the capacity to reflect light like a mirror, in order to have a decorative and alluring appearance [Aksoy et al. 2011]. Prior to weathering, WOHT reduced the gloss of Oriental beech wood. The gloss value of the unheated (control) group was 6.42, but for the WOHT Oriental beech it

Table 3. Gloss and gloss change values for unheated and WOHT Oriental beech specimens before and after weathering

Specimens	Temperature (°C)	Duration (hours)	Gloss values before weathering		Gloss values after weathering		Gloss change values after weathering (%)	
			85°		85°		85°	H.G.
			Mean	Std. dev.	Mean	Std. dev.		
Control	-	-	6.42	2.35	1.58	0.36	−75	A
WOHT	200	2	4.38	1.85	2.27	0.89	−48	CD
WOHT	200	4	6.32	2.85	2.90	1.10	−54	BC
WOHT	230	2	5.86	1.52	2.31	0.83	−61	B
WOHT	230	4	6.12	2.75	2.13	0.74	−65	B

Note: Ten specimens were used for each treatment group. WOHT: Waste olive oil heat treatment. Std. dev.: Standard deviation, H.G.: Homogeneity groups

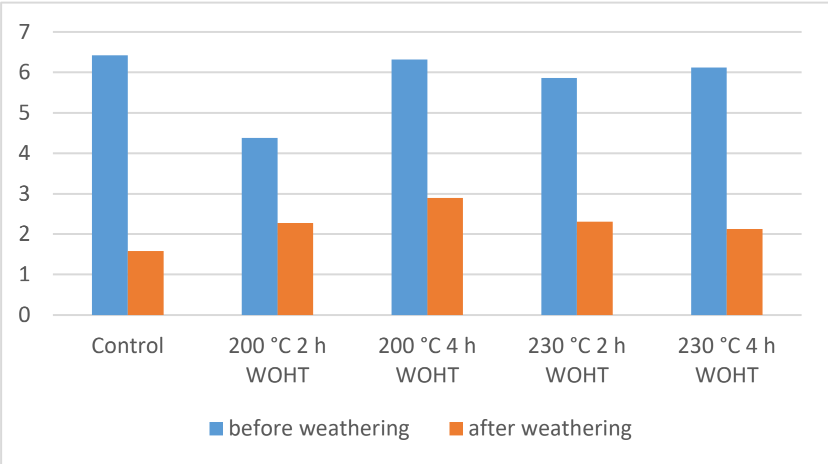

Fig. 3. Gloss values of unheated and WOHT Oriental beech before and after weathering

ranged from 4.38 to 6.32 This outcome is in line with previous reports on the reduction of wood gloss by heat treatment [Aksoy et al. 2011; Baysal et al. 2014a,b; Türkoğlu et al. 2015; Toker et al. 2016]. The gloss values of the Oriental beech specimens were somewhat reduced by weathering. The oxidation and degradation of the main constituents of wood (cellulose, hemicelluloses, and lignin) by UV light appear to be sped up by modifications in chemical and optical properties, which are inherent properties of wood and cause discolouration, a loss of gloss, and roughening of the surface [Denes and Young 1999]. According to Yalınkılıç et al. [1999], erosion and abrasion on wood surfaces both contribute to gloss degradation. Additionally, Bucur [2011] reported that cracks are to blame for gloss losses, with physical and biological degradation taking place on the surface of the wood. Türkoğlu et al. [2015] and Baysal et al. [2016] both reported similar findings for the reduction in gloss after weathering and accelerated weathering. The loss of gloss on weathering for the unheated (control) group was 75%, but for the WOHT Oriental beech it ranged from 48% to 65%. There was a statistically significant difference between the values for gloss loss on weathering between the unheated (control) group and WOHT Oriental beech wood. According to our findings, WOHT Oriental beech experienced greater gloss losses on weathering when treatment was carried out at higher temperatures and for a longer period of time.

3. Roughness changes

Table 4 shows values of the roughness parameters Ra, Rz, and Rq for the unheated (control) group and WOHT Oriental beech. They are also depicted in Figures 4, 5, and 6, respectively. Before weathering, the average Ra, Rz, and Rq values for the unheated (control) group were 2.82, 17.84, and 3.66, respectively. Our findings showed that the roughness of the unheated (control) group was lower than that of the WOHT

Table 4. Roughness and roughness change values for unheated and WOHT Oriental beech specimens before and after weathering

Specimens	Temperature (°C)	Duration (hours)	Roughness values before weathering						Roughness change values after weathering (%)					
			R_a (µm)		R_z (µm)		R_q (µm)							
			Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	R_a	*H.G*	R_z	*H.G*	R_q	*H.G*
Control	-	-	2.82	1.18	17.84	7.44	3.66	1.58	101	F	73	F	93	F
WOHT	200	2	3.80	1.26	23.07	7.62	4.92	1.53	17	A	7	A	15	A
WOHT	200	4	3.30	2.83	18.90	5.09	4.16	3.57	31	AB	48	CD	38	B
WOHT	230	2	3.24	0.99	20.97	5.51	4.19	1.15	44	BC	29	B	41	BC
WOHT	230	4	3.25	1.02	19.80	6.73	4.15	1.39	71	DE	57	DE	70	DE

Note: Ten specimens were used for each treatment group. WOHT: Waste olive oil heat treatment. Std. Dev.: Standard deviation, H.G.: Homogeneity groups

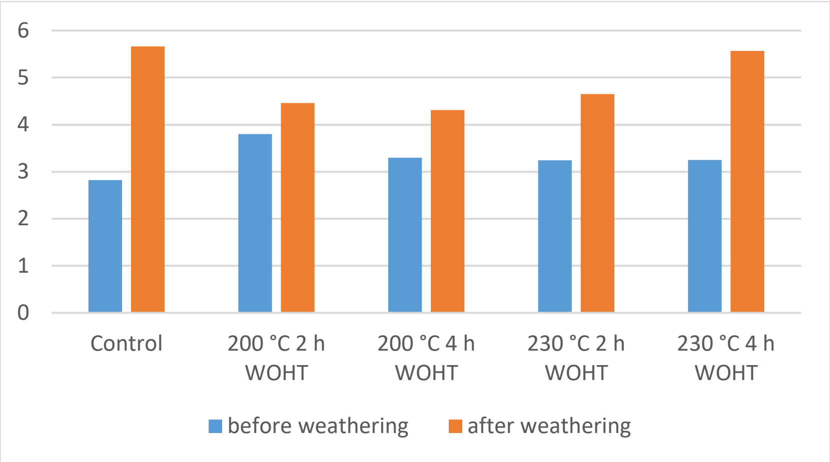

Fig. 4. *Ra* values of unheated and WOHT Oriental beech (*Fagus orientalis*) before and after weathering

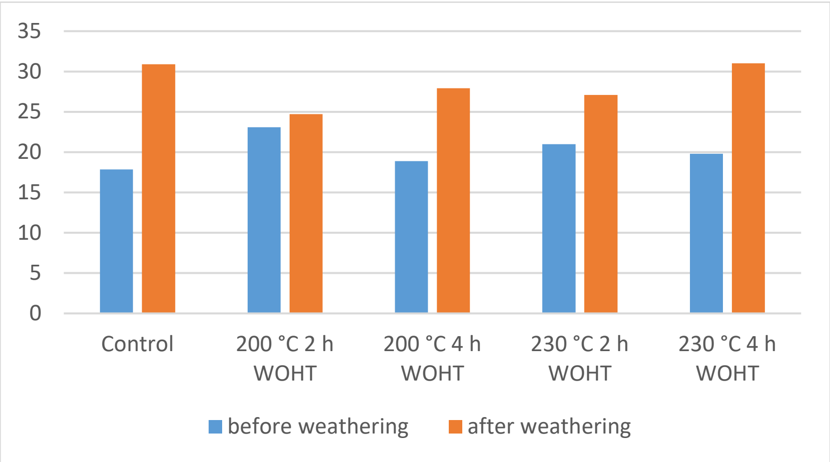

Fig. 5. *Rz* values of unheated and WOHT Oriental beech (*Fagus orientalis*) before and after weathering

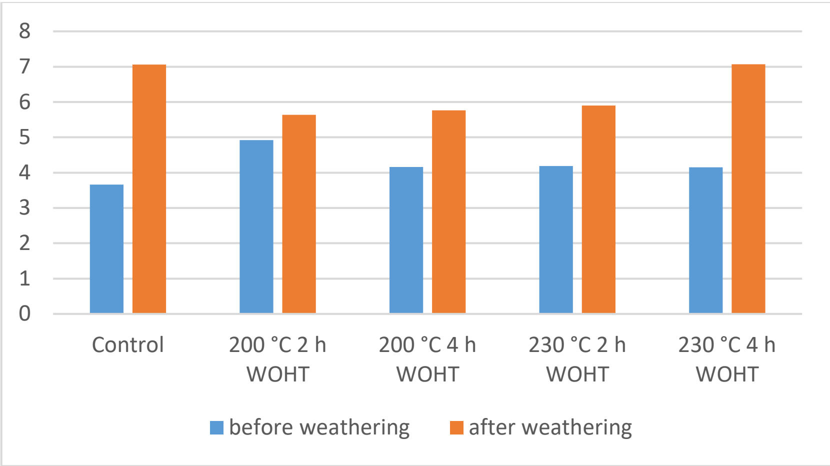

Fig. 6. *Rq* values of unheated and WOHT Oriental beech (*Fagus orientalis*) before and after weathering

Oriental beech wood before weathering. This implies that WOHT had an impact on the roughness values of Oriental beech. This increase in roughness is critical for many applications of solid wood. Rough-surfaced wood requires significantly more sanding than smooth-surfaced wood, which reduces the thickness of the material and, as a result, increases sanding process losses [Dündar et al. 2008]. Wood is anisotropic, heterogeneous, and brittle. The anatomical structure of the wood (vessels, cell lumen, annual ring width, hardness, etc.), machine conditions (feed rate, spindle speed, etc.), and cutting characteristics are a few of the variables that influence the roughness of wood products [Karagöz et al. 2011]. The surface roughness of both WOHT and unheated Oriental beech increased with weathering. According to Williams et al. [2001], weathering of wood is mostly a surface phenomenon that causes the surface to slowly erode and lose wood fibres [Williams et al. 2001]. According to Denes and Young [1999] and Özgenç et al. [2012], the first effects of weathering are discolouration and gloss loss, which are then followed by surface checking and an increase in the wood's roughness. Our results showed that the control group experienced the greatest increase in each of the three roughness parameters. The increases in the Ra, Rz, and Rq values for WOHT Oriental beech were smaller than those for the control group. While the increases in Ra, Rz, and Rq for the unheated (control) group on weathering were 101%, 73%, and 93%, respectively, the increases in Ra, Rz, and Rq for WOHT Oriental beech ranged from 17% to 71%, 7% to 57%, and 15% to 70%, respectively. There was a statistically significant difference between the roughness increases for the unheated (control) group and WOHT Oriental beech wood. Roughness increased in WOHT specimens as treatment duration and temperature increased. WOHT wood heated at 200 °C for 2 hours produced the smallest increases in all three roughness parameters. According to Yıldız et al. [2013], heat treatment for softwood appeared to prevent the surface from becoming rougher after weathering. Türkoğlu et al. [2015] looked into how weathering affected the roughness of Oriental beech that had undergone thermal treatment, and reported that specimens that had been heated acquired less roughness as a result of weathering. According to Baysal et al. [2014a], after artificial weathering, unheated Scots pine (Pinus sylvestris) wood obtained a rougher surface than heat-treated Scots pine wood. The results of this study agree with those of the aforementioned researchers.

These results show that after weathering, WOHT Oriental beech had smoother surfaces than the unheated (control) group. Surface smoothing and roughness reduction may be related to alterations in cell wall constituents [Bakar et al. 2013]. This improvement in smoothness is crucial for a variety of applications of solid wood. Additionally, planing machine losses are reduced, and high-quality surfaces are achieved [Ünsal and Ayrılmış 2005].

Conclusions

This study has focused on how the surface properties of WOHT Oriental beech, including colour, gloss, and roughness, changed as a result of weathering. After weathering, WOHT Oriental beech exhibited superior surface qualities to those of the unheated (control) specimens. WOHT Oriental beech had lighter colouration than the control group after weathering, and underwent smaller total colour changes. Weathering caused losses of gloss in all treatment groups and the unheated (control) group, but the losses were highest in the control group.

Also, higher temperature and duration of treatment resulted in higher gloss losses for WOHT Oriental beech after weathering. The findings demonstrate that weathering softened the surface of the wood and increased its roughness, but WOHT Oriental beech wood displayed better roughness values after weathering than the control group.

The results of this investigation suggest that WOHT Oriental beech has superior surface characteristics when compared with unheated wood.

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