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Physical, Mechanical and Weathering Characteristics of Oriental beech Heat Treated with Waste Engine Oil

Fizička i mehanička svojstva te otpornost na vremenske utjecaje drva kavkaske bukve toplinski tretirane otpadnim motornim uljem

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ABSTRACT • *In general, vegetable oils are chosen for oil heat treatment. Oil heat treatment with waste engine oil, which is quite limited in the literature, was used in this study. After the wood material was subjected to oil heat treatment with waste motor oil, several physical parameters such as oven-dry and air-dry density, water absorption (WA) levels, and mechanical properties such as compression strength parallel to the grain (CSPG) were examined. The color changes of waste engine oil heat treated (WEOHT) specimens were examined after three months of weathering.*

The results showed that when oven-dry and air-dry density of WEOHT specimens increased, WA levels decreased. The WEOHT specimens had greater CSPG values than the control group. WEOHT specimens and control group revealed negative ΔL, Δa*, and Δb* values following weathering. The WEOHT specimens had smaller total color changes (ΔE*) than the control group after weathering. Our results showed that higher temperature and durations resulted in lower WA, and higher air-dry density and total color changes of WEOHT specimens.*

KEYWORDS: *oil heat treatment; oriental beech; physical properties; mechanical properties; color; waste engine oil; weathering*

SAŽETAK • *Za toplinski tretman drva uljem najčešće se biraju biljna ulja. U ovom je radu za toplinski tretman drva upotrijebljeno otpadno motorno ulje, o čemu postoji malo podataka u literaturi. Nakon što je drvo toplinski tretirano otpadnim motornim uljem, ispitano je nekoliko njegovih fizičkih svojstava kao što su gustoća apsolutno suhog drva i drva sušenog na zraku, upijanje vode (WA) te mehanička svojstva poput čvrstoće na tlak paralelno s vlakancima (CSPG). Osim toga, promatrana je promjena boje uzoraka toplinski tretiranih otpadnim motornim uljem (WEOHT) nakon tri mjeseca izlaganja vremenskim utjecajima. Rezultati su pokazali da se pri povećanju gustoće toplinski tretiranih uzoraka apsolutno suhog drva i drva sušenog na zraku smanjilo upijanje vode. Toplinski tretirani uzorci imali su veće vrijednosti čvrstoće na tlak paralelno s vlakancima nego kontrolni. Nakon*

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izlaganja vremenskim utjecajima toplinski tretirani i kontrolni uzorci pokazali su negativne vrijednosti ΔL, Δa* i Δb*. Nakon izlaganja vremenskim utjecajima toplinski tretirani uzorci imali su manje promjene boje (ΔE*) od kontrolnih uzoraka. Rezultati istraživanja pokazali su da su viša temperatura i dulje trajanje toplinskog tretmana rezultirali nižim upijanjem vode, većom gustoćom uzoraka drva sušenog na zraku i ukupnim promjenama boje toplinski tretiranih uzoraka.*

KLJUČNE RIJEČI: *toplinski tretman uljem; drvo kavkaske bukve; fizička svojstva; mehanička svojstva; boja; otpadno motorno ulje; izlaganje vremenskim utjecajima*

1 INTRODUCTION
1. UVOD

Compared to other materials, wood has a number of advantages, such as a high strength-to-weight ratio, high impact resistance, the ability to be used in a variety of technical processes, etc (Popescu and Popescu, 2013). Wood chemical structure contains a lot of hydroxyl groups, which makes it vulnerable to atmospheric influences. These influences can cause wood to change in size and perform differently, as well as significantly shorten product service lives and cause biological decomposition (Korkut and Hızıroğlu, 2014; Okon *et al.,* 2017; Li *et al.,* 2015; Kasemsiri *et al.,* 2012). Enhancing these characteristics makes thermally treated wood suitable for outdoor use (Németh *et al.,* 2016). One of the best methods for reducing the hygroscopicity of wood is thermal treatment in an inert atmosphere, which involves treating the wood at temperatures between 160 °C and 260 °C (Esteves and Pereira, 2008; Candelier *et al.,* 2016). Making long-lasting wood products without the use of biocides is crucial (La Mantia and Morreale, 2011). Oil heat treatment (OHT), which uses oil as the heating medium, is thought to be a slightly different approach to wood modification and a more cost-effective, sustainable, and ecologically friendly way to treat wood. OHT, which combines heat treatment and oil impregnation, has proven to be the most effective method for enhancing wood qualities (Sailer *et al.,* 2000). Linseed, rapeseed, palm, soy, and coconut oils are among the industrial vegetable oils that are used for thermal treatments. (Welzbacher and Rapp, 2005; Wang and Cooper, 2005). OHT is commonly conducted at temperatures ranging from 180 to 260 °C using rapeseed, linseed, or sunflower oil as the heat transfer medium. These oils have exceptional heat transmission properties and effectively exclude oxygen from the wood during treatment (Militz, 2002). Typically, OHT process is conducted in a closed vessel with hot oil circulating around the wood. According to recent studies, heating wood with oil is a perfect substitute for it. Because of their non-toxicity and environmentally benign composition, plant oils have long been used to preserve wood against fungal and mold deterioration as well as to minimize the accessibility of moisture to the wood (Yingprasert *et al.,* 2015). According to Tomak *et al.* (2011), oil absorption during treatment produces a protective layer on the wood surface that improves the treated wood dimensional stability. According to Tang *et al.* (2019), tung oil improved the structural stability and hydrophobicity of bamboo after oil heat treatment by being evenly distributed across the cell walls and lumens. Wood can also be improved for outdoor use and have its surface uniformly colored with oil heat treatment (Sailer *et al.,* 2000). Bak and Németh (2012) heated sunflower, rapeseed, and linseed oils to 160 °C and 200 °C for two hours, four hours, and six hours, respectively, to cure Poplar (*Populus* × *euramericana* Pannónia) and Robinia (*Robinia pseudoacacia* L.) woods. It is noteworthy to observe that poplar wood treated with oil heat treatment has a 15 % – 25 % improvement in compression strength. Additionally, black locust wood compression strength rose by 5 % to 15 % at 160 °C; however, it began to decrease by 5 % to 10 % at 200 °C. Mastouri *et al.* (2021) investigated the water absorption rates of eastern cotton (*Populus deltoides*) wood for four hours at 190 °C using silicone and rapeseed oil. The results show that heat treatment using silicon has a higher potential to improve the water-related qualities of wood than heat treatment using rapeseed oil. Özkan (2013) heated Turkish fir (*Abies nordmanniana* subsp. *bornmulleriana* Mattf.) wood to 150 °C, 180 °C, and 200 °C for two, four, and six hours, allowing the wood to naturally weather. Consequently, it was shown that an oil heat treatment given for two hours at 150 °C increased water absorption by 76 % and weathering color stability by 35 %. While coal oils and creosote are classified as highly hazardous materials, waste engine oil is classified as a moderately hazardous waste under the Russian Federation current criteria (Belchinskaya *et al.,* 2021). Research on the application of waste engine oil as preservative, anticorrosive and stabilizing agents to produce the hydrophobizing composition required for impregnation of railway sleepers is limited (Belchinskaya *et al.,* 2020).

Waste engine oil may pose some problems if it leaches. The Regulation on the Control of Waste Oils intends to record waste engine oils that are hazardous to the environment and human health, collect them under proper conditions, and dispose of them in accordance with European Union standards. If waste oils are not handled properly, they can damage the environment, injure living animals, and cause harm when tossed into soil or water. Furthermore, heavy metal and chlorine compounds in waste oils are discharged into the atmosphere, contaminating the air and endangering human health (CSB, 2024).

This study used waste engine oil, which is not often used in the literature instead of vegetable oils, for oil heat treatment of Oriental beech wood. The main aim of this study is to examine certain physical and mechanical properties of Oriental beech wood, thermally modified with waste engine oil, and color changes of this material after weathering.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Materials
2.1. Materijali

Wood specimens were prepared from Oriental beech (*Fagus orientalis* L.) wood. The oven-dry and air-dry density of Oriental beech wood is 0.645 g/cm^3 and 0.669 g/cm^3, respectively. In this study, waste engine oil was used for the oil heat treatment. Engine oils that have exceeded their useful life and can no longer be reused are called waste engine oil. Waste engine oil was supplied from the oils drained after the engine maintenance of the vehicles of different auto mechanics in the auto industry site in Muğla city of Turkey.

Compared to unused oils, waste engine oils can become contaminated by mixing with dirt, metal friction, water or chemicals during use. Furthermore, the 20W-50 engine oil used in the study is in viscosity class and is a high-performance engine oil that provides proven protection for diesel engines operating in harsh road and off-road applications (Mobil, 2024). The density of the original engine oil (20W/50) is 0.87 g/cm^3 at 15 degrees, its viscosity is 91.0 at 40 degrees (Vural, 2020). In our study, the viscosity of waste engine oil at 15 degrees was found to be 108.24 and its density was 0.9387 g/cm^3 at 40 degrees

2.2 Methods
2.2. Metode

2.2.1 Preparation of wood specimens
2.2.1. Priprema uzoraka drva

Oriental beech (*Fagus orientalis* L.) was cut to the measurements found in the tests and subjected to oven-dry density, air-dry density, *WA*, *CSPG*, and color tests.

2.2.2 Treatment process
2.2.2. Postupak modifikacije

To be prepared for waste engine oil heat treatment (WEOHT), specimens were dried in an oven at (103±2) °C until they reached a constant weight. Before the oil heat treatment, the test specimens were immersed in an oil bath and weighted to keep them from floating in the oil. The specimens were then poured with waste engine oil at room temperature and heated for 3 and 6 hours at 160 and 220 °C, respectively. Following their removal from the oil bath, the specimens were wrapped in aluminum foil and left to cool. Following the therapy, weight percent gain (WPG) of specimens was determined using Equation 1:

$$WPG\,(\%) = \frac{m_2 - m_1}{m_1} \cdot 100 \qquad (1)$$

Weights before and after oil heat treatment by m_1 and m_2, respectively.

Then, wood specimens were conditioned at 20 °C and 65 % relative humidity for two weeks before physical, mechanical and weathering tests.

2.2.3 Oven-dry density test
2.2.3. Ispitivanje gustoće uzoraka drva u apsolutno suhom stanju

The TS ISO 13061-2 2472 (TS ISO, 2021) standard was used to ascertain the oven-dry density of the specimens. In this test, specimen were prepared with the dimensions of 20 mm × 20 mm × 20 mm. A total of 50 specimens were prepared, 10 from each specimen group. The test specimens needed to be dried at (103±2) °C in order to reach a consistent weight. The specimens were allowed to cool before measuring their diameters with a 0.01 mm fine calliper, estimating their volumes with the stereo metric method, and recording their weights with an analytical balance to the accuracy of 0.01 g.

The oven-dry density (δ_0), oven-dry weight (M_0), and oven-dry volume (V_0) were then determined using Formula 2:

$$\delta_0 = \frac{M_0}{V_0}\left(\mathrm{g/cm^3}\right) \qquad (2)$$

2.2.4 Air-dry density test
2.2.4. Ispitivanje gustoće uzoraka drva sušenih na zraku

The air-dry density values of specimens were computed using TS ISO 13061-2 (2021). In this test, specimens were prepared in dimensions of 20 mm × 20 mm × 20 mm. A total of 50 specimens were prepared, 10 from each specimen group. Until they reached a constant weight, specimens were maintained in the cabinet at 20 °C and 65 % relative humidity. Following that, an analytical balance with a sensitivity of 0.01 g was used to weigh the air-dry density, which was then determined using the stereometric method and the dimensions measured with a calliper with a sensitivity of 0.01 mm. Next, using the air-dry weight (M_{12}) and volume (V_{12}) data, the air-dry density (δ_{12}) was calculated from Equation 3.

$$\delta_{12} = \frac{M_{12}}{V_{12}}\left(\mathrm{g/cm^3}\right) \qquad (3)$$

2.2.5 Water absorption test
2.2.5. Ispitivanje upijanja vode

In this test, specimen were prepared in dimensions of 20 mm × 20 mm × 20 mm. A total of 50 specimens were prepared, 10 from each specimen group. Specimens were stored in distilled water for 5, 10, 20, 40, 60, 80, 100, and 120 hours in a room setting. Specimens were taken out of the water, wiped dry with paper, and weighed following each soaking time. The *WA* of each specimen was therefore determined using Formula 4.

$$WA = \frac{M_f - M_{oi}}{M_{oi}} \cdot 100 \quad (4)$$

In this section;

WA – water absorption (%),

M_f – specimen's weight following absorption of water (g),

M_{oi} – the specimen's oven-dry weight following impregnation (g).

2.2.6 Compression strength parallel to the grain (CSPG)
2.2.6. Čvrstoća na tlak paralelno s vlakancima (*CSPG*)

A universal test machine with a 4000 N capacity and a 6-mm/min loading period was used to execute the *CSPG* test in compliance with TS 2595 (TS, 1977) standard. All specimens were conditioned at 20 °C and 65 % relative humidity for 2 weeks before *CSPG* test. In this test, specimens dimensions were prepared as 20 mm × 20 mm × 30 mm. A total of 50 specimens were prepared, 10 from each specimen group. *CSPG* was calculated using Formula 5.

$$\sigma_B = \frac{P}{a \cdot b} \quad (5)$$

In this section:

σ_B – *CSPG* (N/mm^2),

P – load at break (N),

a, *b* – specimen cross-section dimensions (mm)

2.2.7 Color test
2.2.7. Ispitivanje boje

In this test, specimen were prepared in dimensions of 10 mm × 100 mm × 150 mm. A total of 50 specimens were prepared, 10 from each specimen group. The *L**, *a**, and *b** color characteristics of the specimens were ascertained for the color test using the CIEL*a*b* method. The *a** and *b** axes in this diagram stand for the chromaticity coordinates, and the *L** axis for darkness (black-white axis). In addition, the hues red and green are represented by the symbols +*a** and -*a**, respectively. Furthermore, the variables +*b** and -*b** stand in for yellow and blue, respectively. Zhang (2003) states that the *L** value ranges from 0 (black) to 100 (white). The overall color difference (ΔE^*) was determined using equations 6 through 9 in accordance with ASTM D1536-58T (ASTM 1964) standards. Color analysis was performed in the radial direction of wood.

$$\Delta a^* = a_{final}^* - a_{initial}^* \quad (6)$$

$$\Delta b^* = b_{final}^* - b_{initial}^* \quad (7)$$

$$\Delta L^* = L_{final}^* - L_{initial}^* \quad (8)$$

$$(\Delta E^*) = \left[(\Delta a^*)^2 + (\Delta b^*)^2 + (\Delta L^*)^2\right]^{1/2} \quad (9)$$

Where:

The discrepancies between the values of the first and last intervals are represented by the symbols Δa^*, Δb^*, and ΔL^*, respectively.

2.2.8 Weathering test
2.2.8. Izlaganje vremenskim utjecajima

The ASTM D 358-55 (ASTM, 1970) standard states that wood panels should expose specimens to weathering. The specimens were then weathered for three months (10 November 2023–10 February 2024) in panels located in the province of Muğla in the South Aegean Region of Turkey (Table 1). The specimens

Table 1 Meteorological data of Muğla
Tablica 1. Meteorološki podatci za Muğlu

Muğla	**10 November-10 December 2023** *10. studenog-10. prosinca 2023.*	**11 December-10 January 2024** *11. prosinca-10. siječnja 2023.*	**11 January-10 February 2024** *11. siječnja-10. veljače 2023.*
Average temperature per month, °C *prosječna mjesečna temperatura,* °C	10.51	8.61	6.21
Average humidity per month, % *prosječna mjesečna vlažnost zraka,* %	90.00	92.00	78.00
Average wind speed per month, m/s *prosječna mjesečna brzina vjetra*, m/s	1.00	1.20	0.97
Average sun exposure time per month, hours *prosječno mjesečno vrijeme izloženosti suncu,* h	0.42	0.15	0.87
Total rainfall per month, mm = kg/m^{-2} *ukupna mjesečna količina padalina,* mm = kg/m^{-2}	10.46	4.88	7.19

faced south at a 45° angle and were set up on panels about 50 cm above the ground.

2.2.9 Statistical evaluation
2.2.9. Statistička obrada rezultata

The Duncan test, at a 95 % confidence level, and variance analysis were evaluated by the SPSS computer once the test results were obtained. Statistical studies were performed on homogeneity groups (HG), with various letters indicating statistical significance.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Weight percent gain of treated oriental beech wood
3.1. Postotno povećanje mase toplinski modificiranog drva kavkaske bukve

Weight percent gain (*WPG*) values of WEOHT specimens are given in Table 2. *WPG* values of WEOHT specimens were ranged from 23 % to 44 %. Higher duration and temperatures resulted in higher *WPG* of WEOHT specimens.

Table 2 *WPG* of WEOHT specimens
Tablica 2. *WPG* za WEOHT uzorke

Treatment type *Vrsta tretmana*	**Temperature, °C** *Temperatura, °C*	**Duration, h** *Trajanje, h*	***WPG*, %**	**Std. dev.**
Control	-	-	-	-
WEOHT	160	3	23	5.1
WEOHT	160	6	26	4.2
WEOHT	220	3	37	4.8
WEOHT	220	6	44	6.3

WEOHT – Waste engine oil heat treatment; *WPG* – Weight percent gain; Std. dev. – Standard deviations
WEOHT – toplinski tretman otpadnim motornim uljem; WPG – postotno povećanje mase; Std. dev. – standardna devijacija

3.2 Oven-dry density
3.2. Gustoća apsolutno suhog drva

The oven-dry density and and air-dry density values of the WEOHT specimens are given in Table 3.

Compared to the control group, the oven-dry density values of the WEOHT specimens are higher. While the volume of wood either stays the same or only slightly changes, the density may rise as a result of the WEOHT specimens increased mass and oil filling in the wood cells (Azis *et al.,* 2020). A longer heating period will result in a greater amount of oil filling the wood cells, raising the wood density (Daud and Coto, 2009). In contrast to the control group, which had the lowest oven-dry density, the specimens heat treated at 220 °C for six hours had the highest oven-dry density, according to the study. The specimens heat treated at 160 °C and 220 °C for 6 hours showed statistically significant differences in oven dry density values when compared to the control group.

The WEOHT specimens had a higher air-dry density than the control group. The study discovered that specimens heated for six hours at 220 °C had the highest air-dry density, whereas the control group had the lowest. The air dry density values of the specimens that were heat treated at 220 °C for 3 and 6 hours differed statistically significantly from the control group. Azis *et al.,* (2020) investigated the density variations of bulk oil-heated candlenut wood (*Aleurites moluccanus* (L.) Willd.). The average density of the control group was 0.38 g/cm^3. The density of the oil-heated wood increased dramatically from 18.85 % to 25.13 % when compared to the control. Bayraktar and Pelit (2022) investigated the air dry density values of European beech and Scots pine linseed oil heated to three different temperatures (170 °C, 190 °C, and 210 °C). They discovered that European beech and Scots pine specimens heat-treated with linseed oil increased their air dry density values by 29 % and 31 %, respectively.

During our examination, the oven dry and air dry density values of WEOHT Oriental beech increased by 16.66 % to 39.39 % and 22.05 % to 44.11 %, respectively. Overall, our findings are consistent with past research.

3.3 Water absorption
3.3. Upijanje vode

The water absorption (*WA*) values of WEOHT specimens and decreases of *WA* values of WEOHT specimens compared to the control group (%) are given in Table 4 and Table 5, respectively.

The results confirmed previous finding (Yalınkılıç *et al.,* 1995) and demonstrated that throughout the early stages of *WA*, particularly within 5, 10 and 20 hours, *WA* levels of the control group were significantly higher. This may be a result of water being absorbed by wood during the initial soaking period and gradually decreasing wood gaps (Richardson, 1987). The *WA* levels of the control group were higher during the first and subsequent *WA* periods when compared to WEOHT specimens. The application of waste engine oil provides a thickening and water-repellent quality that greatly lowers *WA*. The results of the *WA* test indicate that as the temperature and length of the oil heat treatment increase, the *WA* of all wood decreases. This is consistent with the claim made in (Hidayat *et al.,* 2015; Jamsa and Viitaniemi, 2001) that wood loses water absorption as treatment duration and temperature increase because the cell walls become more hydrophobic due to a decrease in hydroxyl groups as a result of chemical reactions during heat treatment. Wood dimensional stability will rise as a result of its decreased capacity to absorb water (Ma'ruf *et al.,* 2021). The wood external and partially inner surfaces retain waste engine oil, which fills the cell lumen and increases the surface hydrophobicity. Water enters wood pores

Table 3 Oven- and air-dry density values of WEOHT specimens
Tablica 3. Vrijednosti gustoće WEOHT uzoraka u apsolutno suhom stanju i sušenih na zraku

Treatment type *Vrsta tretmana*	**Temperature, °C** *Temperatura, °C*	**Duration, h** *Trajanje, h*	**Oven-dry density, g/cm³** *Gustoća apsolutno suhog drva, g/cm³*	**Increase compared to control, %** *Povećanje u odnosu prema kontrolnim uzorcima, %*	**Std. dev.**	**H.G.**	**Air-dry density, g/cm³** *Gustoća drva sušenog na zraku, g/cm³*	**Std. dev.**	**H.G.**	**Increase compared to control, %** *Povećanje u odnosu prema kontrolnim uzorcima, %*
Control	-	-	0.66	-	0.05	A	0.68	0.05	A	-
WEOHT	160	3	0.77	16.66	0.06	AB	0.83	0.05	AB	22.05
WEOHT	160	6	0.87	31.81	0.08	B	0.84	0.08	AB	23.52
WEOHT	220	3	0.78	18.18	0.02	AB	0.92	0.07	B	35.29
WEOHT	220	6	0.92	39.39	0.10	B	0.98	0.09	B	44.11

WEOHT – Waste engine oil heat treatment; Std. dev. – Standard deviation; H.G. – Homogeneity group
WEOHT – toplinski tretman otpadnim motornim ulje; Std. dev. – standardna devijacija; H.G. – grupe homogenosti

Table 4 Water absorption values of WEOHT specimens
Tablica 4. Vrijednosti upijanja vode WEOHT uzoraka

Treatment type *Vrsta tretmana*	**Temperature, °C** *Temperatura, °C*	**Duration, h** *Trajanje, h*	**Water absorption** / *Upijanje vode*, %															
			5 h	H.G	10 h	H.G	20 h	H.G	40 h	H.G	60 h	H.G	80 h	H.G	100 h	H.G	120 h	H.G
Control	-	-	32.41	A	37.59	A	47.35	D	57.26	C	59.80	C	63.14	C	63.31	C	64.33	C
WEOHT	160	3	9.60	B	11.89	B	17.97	C	27.24	B	31.72	B	33.12	B	34.55	B	36.06	B
WEOHT	160	6	7.46	B	9.91	B	16.46	BC	24.85	B	29.80	B	31.31	B	32.87	B	34.68	B
WEOHT	220	3	7.34	B	9.27	B	14.61	AB	21.28	A	26.60	A	28.83	AB	30.64	AB	31.87	AB
WEOHT	220	6	6.46	B	8.86	B	12.83	A	19.45	A	24.07	A	26.43	A	28.27	A	29.83	A

WEOHT – Waste engine oil heat treatment H.G – Homogeneity group / *WEOHT – toplinski tretman otpadnim motornim uljem; H.G. – grupe homogenosti*

Table 5 Decreases of water absorption values of WEOHT specimens compared to control group
Tablica 5. Smanjenje vrijednosti upijanja vode WEOHT uzoraka u usporedbi s kontrolnim uzorcima

Treatment type *Vrsta tretmana*	**Temperature, °C** *Temperatura, °C*	**Duration, h** *Trajanje, h*	**Decrease in water absorption values compared to the control, %** *Smanjenje vrijednosti upijanja vode u odnosu prema kontrolnim uzorcima, %*							
			5 h	10 h	20 h	40 h	60 h	80 h	100 h	120 h
Control	-	-	-	-	-	-	-	-	-	-
WEOHT	160	3	70.4	68.4	62.0	52.4	47.0	47.5	45.4	43.9
WEOHT	160	6	77.0	73.6	65.2	56.6	50.2	50.4	48.1	46.1
WEOHT	220	3	77.3	75.3	69.1	62.8	55.5	54.3	51.6	50.5
WEOHT	220	6	80.1	76.4	72.9	66.0	59.7	58.1	55.3	53.6

WEOHT – Waste engine oil heat treatment / *toplinski tretman otpadnim motornim uljem* through capillary action, which lowers the amount of water absorption (Koski, 2008). Our results proved that *WA* of control group maintained a stronger trend than WEOHT specimens for total durations ranging from 5 hours to 120 hours. Every phase showed a statistically significant difference between the WEOHT specimens and the control group. Dubey *et al.* (2012) stated that higher temperatures led to various chemical alterations that affected dimensional stability, and hydrophobic oils in the lumens stopped water from penetrating the walls. According to studies conducted in Hyvonen *et al.* (2005) and Hofland and Tjeerdsma (2005), heating wood with tall oil or rapeseed oil, respectively, reduced the water absorption properties of wood. Our findings and those of the previously cited researcher are fairly consistent. According to our research, after 120 hours of *WA*, the *WA* levels of the control group increased to 64.33 %, while WEOHT specimens showed a shift from 29.83 to 36.06 %. Therefore, after 120 hours *WA* period, WEOHT specimens took up 43.9 to 53.6 % less water than the control group (Table 5)

3.4 Compression strength parallel to grain (*CSPG*)
3.4. Čvrstoća na tlak paralelno s vlakancima (*CSPG*)

The *CSPG* values of WEOHT specimens are given in Table 6.

The highest *CSPG* values in our study were 46.04 N/mm^2 for WEOHT specimens at 220 °C for three hours, compared to 39.57 N/mm^2 for the control group; the values for WEOHT specimens were changed from 43.56 to 46.04 N/mm^2. After oil heat treatment, the wood strength properties are impacted because heat causes the chemical structure of the wood cell wall components to change. The strength quality of wood is influenced by the contributions of hemicellulose, cellulose, and lignin, the three primary components of the cell wall, in distinct ways (Lee *et al.,* 2018). Our results proved that WEOHT specimens had higher *CSPG* values than the control group, ranging from 10.08 % to 16.35 %. However, there were no statistically significant differences between the WEOHT specimens and the control group at the 95 % confidence level. Cheng *et al.* (2014) found that following oil heat treatment, poplar wood *CSPG* rose. The high oil uptake thickened the fibers and increased their longitudinal strength, which was primarily responsible for this. The results were ascribed by Windeisen *et al.* (2009) to the rise in lignin condensation caused by heat treatment. The increase in compression strength may be explained by a number of factors, including reduced bound water content in heat-treated wood, an increase in crystalline cellulose, and restricted movement perpendicular to the grain as a result of increased lignin polymer network cross-linking (Boonstra *et al.,* 2007). Our findings are consistent with the previously cited research. However, it has been reported in the literature that the compression strength decreases in oil heat treated wood, especially at temperatures of 200 °C (Bak and Németh 2012). In our study, *CSPG* values were higher in a 3 h heat time at 160 °C compared to a 6 h heat time; For 220 °C, 6 h of heat time gave lower CSPG values than 3 hours of heat time.

3.5 Color changes
3.5. Promjene boje

The color and total color change values of the WEOHT specimens are shown in Table 7 both before and after weathering. The specimens' total color change values upon weathering are also shown in Figure 1.

Consideration should be given to the hardwood color in addition to its durability, as it plays a significant role in defining both its aesthetic appeal and market value (Baar and Gryc, 2012). The chemical components of wood material, such as extractives, interact with light to determine its hue. The surface color of the wood material varies depending on the abundance, scarcity, or modification of the extractives effects (Hon and Minemura, 2001). The *L** value for the control group was found to be 65.85 before weathering. The *L** values of the WEOHT specimens' ranged from 28.14 to 32.24. Because of this, WEOHT specimens' *L** values were lower than those of the control group. Furthermore, WEOHT specimens *L** values declined with increasing duration. As a result of the oil heat treatment process, the Oriental beech specimens darkened. It is more likely that the darkening effect in the oxygen-excluded treatment medium, such as oil, is

Table 6 *CSPG* values of WEOHT specimens
Tablica 6. *CSPG* vrijednosti WEOHT uzoraka

Treatment type *Vrsta tretmana*	**Temperature, °C** *Temperatura, °C*	**Duration, h** *Trajanje, h*	***CSPG*, N/mm^2**	**Standard deviation** *Standardna devijacija*	**Homogeneity group** *Grupe homogenosti*	**Increase compared to control, %** *Povećanje u odnosu prema kontrolnim uzorcima, %*
Control	-	-	39.57	6.81	A	-
WEOHT	160	3	45.67	7.31	A	15.41
WEOHT	160	6	44.20	5.44	A	11.70
WEOHT	220	3	46.04	5.79	A	16.35
WEOHT	220	6	43.56	6.92	A	10.08

WEOHT – Waste engine oil heat treatment / *toplinski tretman otpadnim motornim uljem*

Table 7 Color and total color differences of WEOHT specimens as a result of weathering
Tablica 7. Boja i ukupne promjene boje WEOHT uzoraka kao posljedica izlaganja vremenskim utjecajima

Treatment type *Vrsta tretmana*	Temperature, °C *Temperatura, °C*	Duration, h *Trajanje, h*	**Color differences before weathering** *Vrijednosti boje prije izlaganja vremenskim utjecajima*			**Color differences after weathering** *Vrijednosti boje nakon izlaganja vremenskim utjecajima*			**Total color differences** *Ukupne promjene boje*	
			L^*	a^*	b^*	ΔL^*	Δa^*	Δb^*	ΔE^*	H.G
Control	-	-	65.85	11.69	22.07	-16.82	-9.67	-12.59	23.12	B
WEOHT	160	3	30.28	3.66	6.74	-2.31	-1.62	-0.04	2.82	A
WEOHT	160	6	29.95	4.12	7.30	-1.98	-2.08	-0.82	2.98	A
WEOHT	220	3	32.24	4.35	8.83	-1.96	-2.67	-1.31	3.56	A
WEOHT	220	6	28.14	3.77	7.35	-3.29	-2.22	-1.09	4.11	A

WEOHT – Waste engine oil heat treatment; Std. dev. – Standard deviation / *WEOHT – toplinski tretman otpadnim motornim uljem; Std. dev. – standardna devijacija*

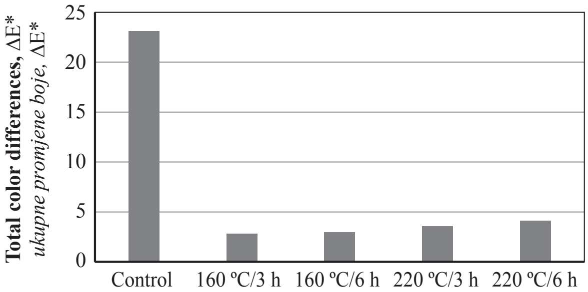

Figure 1 Total color differences of WEOHT specimens
Slika 1. Ukupne promjene boje WEOHT uzoraka

caused by the caramelization of soluble sugars and heat treatment, which forms an oil coating on the wood surface (Lee *et al.,* 2018). According to Németh *et al.* (2016), the level of darkening is strongly influenced by the extractive content of wood. The effect of further darkening generated by the oxidation process is more noticeable in wood with a higher extractive content. According to our research, WEOHT specimens had lower a^* and b^* values than the control group before weathering. The WEOHT and control groups experienced negative ΔL^* values due to weathering. The best parameter to describe the color evolution of a wood surface is ΔL^*. Consequently, the wood surface became rougher and darker with age. In Oriental beech, photodegradation and leaching of lignin and other noncellulosic polysaccharides result in weathering-related darkening (Sönmez *et al.*, 2011; Petric *et al.*, 2004; Hon and Chang, 1985). Both the WEOHT and control groups saw negative Δa^* and Δb^* values due to weathering. The surfaces of oriental beech have negative values for Δa^* and Δb^*, corresponding to greenish and blueish tones. Our study found that WEOHT specimens thermally treated at 160 °C for 3 hours had the lowest total color change value (2.82), while the control group had the highest total color change value (ΔE^*). Our findings indicated that there were substantial differences in overall color changes between WEOHT specimens and the control group. Németh *et al.,* (2016) studied the photostability of sunflower oil heat-treated locust and poplar wood when subjected to short-term UV radiation. They discovered that oil heat treated wood specimens had better photostability than the control group. Our findings are consistent with data from Németh *et al.* (2016). Given that a low total color change value is sought, WEOHT specimens heated at 160 °C for 3 hours demonstrated the best color stability.

In our investigation, the control group had the highest total color change value (ΔE^*) while the WEOHT specimens, which were thermally treated for three hours at 160 °C, had the lowest (1.82). Based on our research, the control group and WEOHT specimens had significantly different overall color alterations. Short-term UV radiation treatment of locust and poplar wood treated with sunflower oil was investigated by Németh *et al.* (2016) for photostability. Compared to the control group, the wood specimens that had undergone oil heat treatment demonstrated superior photostability. The data from Németh *et al.* (2016) agrees with our conclusions. The maximum color stability was achieved by WEOHT specimens heat treated at 160 °C for three hours; this is because a low total color change value is required.WEOHT specimens higher color stability could be explained by the increased lignin stability caused by oil heat treatment (Ayadi *et al.,* 2003; Deka *et al.,* 2008). In our study, the total color changes of WEOHT specimens increased as the temperatures and durations increased.

4 CONCLUSIONS
4. ZAKLJUČAK

This study was designed to recycle engine oils, which are widely used in the automotive industry, and use them in the wood preservation industry. In the study, some physical, mechanical and color changes of Oriental beech wood specimens heat treated with waste engine oils were evaluated.

According to the results obtained, oven-dry and air-dry density values of WEOHT specimens increased compared to the control group. After all *WA* periods, all WEOHT specimens absorbed less water than the control group. Additionally, a statistically significant difference was found in *WA* levels between WEOHT specimens and the control group. Higher duration and temperature values resulted in lower *WA* levels of WEOHT specimens. Although the *CSPG* values of WEOHT specimens were increased compared to the control group, no statistically significant difference was found between all specimens. Our results showed that weathering caused darkening and reduced *a** and *b** values in WEOHT specimens and the control group. Additionally, the total color change of WEOHT specimens was lower than that of the control group.

In summary, the physical and mechanical properties of WEOHT specimens improved. Color stability of WEOHT specimens were higher than those of the control group after weathering. While there were statistically significant differences in oven-dry density, air-dry density, and *WA* levels between WEOHT specimens and the control group, there was no statistical difference in *CSPG* values between WEOHT specimens and the control group. Increased air-dry densities as well as total color changes, were seen in WEOHT specimens with decreased *WA* at higher temperatures and durations. As a result, WEOHT specimens are an alternate structural material that can be used outside when especially physical properties and color stability are needed.

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