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Some Physical and Mechanical Characteristics of Waste Olive Oil Heat-Treated Oriental Beech Wood

Neka fizička i mehanička svojstva kavkaske bukovine pregrijane u otpadnome maslinovu ulju

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ABSTRACT • *This study set out to look into some of the mechanical and physical characteristics of oil-heated oriental beech wood. Waste olive oil was used for oil-heat treatment. Heat treatment of the oil was done at 200 °C and 230 °C for 2 hours and 4 hours, respectively. After oil-heat treatment, physical traits including oven-dry density and water absorption levels, as well as mechanical traits like compression strength parallel to the grain (CSPG), were determined. Oven dry density of wood increased significantly after being heated in oil. Compared to the control groups, waste olive oil heat-treated (WOHT) oriental beech showed lower levels of water absorption. At 200 °C for 4 h, CSPG of waste olive oil heat-treated wood were at their highest, and then they steadily fell as the temperature and treatment time rose.*

KEYWORDS: *waste oil heat-treatment; physical properties; mechanical properties; waste olive oil; oriental beech*

SAŽETAK • *Cilj ovog istraživanja bio je ispitati neka mehanička i fizička svojstva uljem pregrijane bukovine. Za toplinsku je obradu korišteno otpadno maslinovo ulje. Toplinska obrada u ulju provedena je na 200 i 230 °C tijekom dva i četiri sata. Nakon toplinske obrade uljem utvrđena su fizička svojstva bukovine: gustoća apsolutno suhog drva i upijanje vode, kao i mehaničko svojstvo čvrstoće na tlak paralelno s vlakancima (CSPG). Gustoća apsolutno suhog drva znatno se povećala nakon toplinske obrade u ulju. U usporedbi s kontrolnim uzorcima, kavkaska bukovina pregrijana u maslinovu ulju (WOHT) pokazala je nižu razinu upijanja vode. Najveća čvrstoća na tlak paralelno s vlakancima zabilježena je u bukovine pregrijane u otpadnome maslinovu ulju na 200 °C tijekom četiri sata, a zatim se postupno smanjivala kako su se temperatura i vrijeme toplinske obrade povećavali.*

KLJUČNE RIJEČI: *toplinska obrada otpadnim uljem; fizička svojstva; mehanička svojstva; otpadno maslinovo ulje; kavkaska bukva*

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1 INTRODUCTION
1. UVOD

Wood has been used in residential building since the beginning of time, due to its very good qualities such as thermal insulation and transportation, high specific strength and easy workability (Su, 1997). However, wood is adversely affected by environmental factors such as biological creatures, fire, light, and water compared to many other materials (Kiguchi and Evans, 1998). Therefore, it is important to treat wood so as to extend its useful life and enhance some of its qualities necessary for its use (Srinivas and Pandey, 2012). Wood modification refers to improving the quality of wood through biological, chemical, or physical processes (Hill, 2007; Esteves and Pereira, 2009; Thybring, 2013). Heat treatment is an alternative approach to wood modification. Heat-treated wood has new characteristics including increased dimensional stability and greater decay resistance, while its resistance is noticeably reduced (Türkoğlu *et al.,* 2015). Heat-treated wood performs better than untreated wood in terms of aesthetic quality (effective and uniform color change) and performance in accordance with technical standards (much less shrinkage and swelling, enhanced strength to fungus) (Vukas *et al.,* 2010; Türkoğlu *et al.,* 2015). Recent research has shown that heating wood with oil is a great replacement for it. Due to their non-toxicity and being environmentally friendly, plant oils have long been used to protect wood from mold and fungal degradation as well as to drop the accessibility of moisture to the wood (Yingprasert *et al.,* 2015). Without the use of any long-lasting, dangerous chemicals, hot oil heat-treatment can improve the dimensional stability and toughness of wood, especially of plantation wood that develops quickly (Cheng *et al.,* 2014). Additionally, compared to the wood heated in other gaseous atmospheres, oil heat-treated wood has slightly better mechanical characteristics (Rapp and Sailer, 2001). One of these techniques, oil-heat treatment (OHT), was developed and first used for garden furniture in Germany in the 2000s. This technique involves adding plant oils, such as sunflower oil, rapeseed or linseed to a closed tank at a specific temperature for a predetermined amount of time (Kesik *et al.,* 2015). As oil is used as the heating medium, the process is thought to be more ecologically sustainable, eco-friendly, cost-effective, and heat treatment using oil (OHT) is seen as a slightly different approach to wood modification. Linseed, rapeseed, palm, soybean, and coconut oils are industrial vegetable oils used for heat treatment (Welzbacher and Rapp, 2005; Wang and Cooper, 2005). By combining the beneficial effects of heat with oil, a process known as “oil heat treatment” or “oleothermal treatment” can enhance the quality of wood. Researchers from all over the world have conducted a great deal of research on oil heat treating wood (Lee *et al.,* 2018). Wang *et al*. (2014) investigated the density of wood treated with hot air and hot oil from *Paulownia tomentosa* and wood from *Pinus koraiensis*. Mostly because oil was absorbed during treatment, wood from both species that had been heat-treated with oil showed noticeably higher density than wood heated with air. Var *et al.* (2021) sought to ascertain the density values of red pine treated with hot-cold bio-oil. The findings showed that the density of test samples rose by 40.38 % to 78.85 %. Mastouri *et al.* (2021) used silicone and rapeseed oil to study the water absorption rates of eastern cotton (*Populus deltoides*) wood for 4 h at 190 °C. According to the findings, heat treatment with silicon has a greater potential to enhance water-related properties of wood than heat treatment with rapeseed oil. According to Lee *et al*. (2018), heat-induced changes to the chemical composition of wood cell wall components result in changes of wood strength after oil heat treatment. Hemicellulose, cellulose, and lignin, the three main components of the cell wall, each contribute in a unique way to the characteristics of wood strength. They stated that other factors, besides an oxygen-free environment, contribute to the comparatively good mechanical characteristics of wood during oil heat treatment. In addition, more oil uptake than provided by other heat treatment techniques also improves the wood mechanical strength. Linseed oil considerably reduced the compression strength of coastal pine when samples were heated to 200 °C for 6 hours, according to Taşdelen *et al*. (2019). In contrast to vacuum heat treatment alone, other linseed oil treatments typically yielded excellent strength values, notably for 180 °C. Bak and Németh (2012) treated Poplar (*Populus × euramericana* Pannónia) and Robinia (*Robinia pseudoacacia* L.) woods by heating sunflower, rapeseed, and linseed oils to 160 °C and 200 °C for 2 h, 4 h, and 6 h, respectively. It is interesting to note that oil heat treatment of poplar wood increased the compression strength by 15 % to 25 %. In addition, when treated at 160 °C, black locust wood compression strength increased by 5 % to 15 %; however, when treated at 200 °C, it started to decline by 5 % to 10 %.

The physical and mechanical characteristics of wood that had been heat-treated with oil were explored from a variety of angles in earlier investigations. There has not been much research on the use of oils, particularly olive oil as heating oil. In order to better understand the properties of oriental beech that had been heated using waste olive oil, this study looked at its oven-dry density, water absorption (WA), and compressive strength parallel to the grain. In addition, one of the aims of the study is to enhance physical and mechanical characteristics of oriental beech with an organic material by contributing to recycling with the use of waste olive oil.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Materials
2.1. Materijali

Wasted olive oil used for fried potatoes was used for the oil heat treatment. Wood samples were prepared from oriental beech wood.

2.2 Methods
2.2. Metode

2.2.1 Preparation of wood samples
2.2.1. Priprema uzoraka drva

Wood samples were prepared according to TS ISO 3129:2021 standard. Oriental beech (*Fagus orientalis* L.) samples were cut into rectangles with radial, tangential, and longitudinal dimensions of 20 mm × 20 mm × 20 mm, 20 mm × 20 mm × 20 mm, and 20 mm × 20 mm × 30 mm, respectively, for the oven-dry density, *WA*, and *CSPG* test samples. One hundred fifty wood samples overall, each made of ten wood samples, were prepared as control and test samples for this investigation.

2.2.2 Treatment process
2.2.2. Postupak toplinske obrade

The samples were dried in an oven at 103 ± 2 °C until they reached a consistent weight in preparation for oil heat treatment (m_1). The samples were then processed in a high temperature oven before being submerged in the oil bath at room temperature. When the oil bath reached 200 °C and 230 °C, the treatment times were 2 h and 4 h, respectively. After being removed from the oil bath, the samples were covered in aluminium foil and allowed to cool.

The weight percentage gain (WPG) of samples after the treatment were calculated by Eq. 1:

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

Where:
m_1 – mass before oil heat treatment,
m_2 – mass after oil heat treatment.

An electric furnace was used to heat the air (KD 200 model drying cabinet.). The temperature was raised from ambient to the desired temperatures of 200 °C and 230 °C for 2 and 4 h, respectively. Wood samples were conditioned at 20 °C and 65 % relative humidity for two weeks before *CSPG*, oven-dry density, and *WA* tests.

2.2.3 Oven-dry density test
2.2.3. Ispitivanje gustoće apsolutno suhog drva

Oven-dry density of samples was measured in accordance with the TS ISO 13061-2 2472 (TS ISO, 2021) standard. Test samples were required to be dried at (103±2) °C until they reached a consistent weight. The samples were then allowed to cool before being weighed on an analytical balance with an accuracy of 0.01 g; their diameters were measured with a delicate calliper with an accuracy of 0.01 mm, and their volumes estimated using the stereo metric method. The oven-dry density (δ_o), oven-dry weight (M_o), and oven-dry volume (V_o) were then determined using Eq. 2:

$$\delta_0 = \frac{M_0}{V_0}\ (\text{g/cm}^3) \quad (2)$$

Where:
M_o – Oven-dry weight of specimen (g)
V_o – Oven-dry volume of specimen (cm^3)

2.2.4 Water absorption test
2.2.4. Ispitivanje upijanja vode

In a room environment, wood samples were kept in distilled water for 2, 8, 24, 48, 72, 96, 120, 144, and 168 h. After each soaking interval, samples were removed from the water, patted dry with spotting paper, and then weighed. As a result, each specimen's *WA* was calculated using Eq. 3:

$$WA = \frac{M_f - M_{oi}}{M_{oi}} \cdot 100\ (\%) \quad (3)$$

Where:
WA – Water absorption (%),
M_f – Weight of specimen after water absorption (g),
M_{oi} – Oven-dry weight of specimen after impregnation (g).

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

According to the TSE 2595:1977 standard, the compression strength parallel to the grain test was carried out using a universal test machine with a 4000 kp capacity and a 6 mm/min loading period. The universal test device was produced by MATEŞ Electronic company located in Ankara province of Turkey.

2.2.6 Statistical evaluation
2.2.6. Statistička procjena

After the test results were acquired, the SPSS computer assessed the variance analysis and Duncan test, which was covered at a 95 % confidence level. Homogeneity groups (HG) were subjected to statistical analyses, where different letters denote statistical significance.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 *WPG* of WOHT oriental beech wood
3.1. Povećanje mase kavkaske bukovine pregrijane u otpadnome maslinovu ulju

WPG of WOHT oriental beech wood is given in Table 1. *WPG* of WOHT oriental beech ranged from 39

Table 1 Weight percent gain (*WPG*) of waste olive oil heat-treated (WOHT) oriental beech
Tablica 1. Povećanje mase (*WPG*) kavkaske bukovine pregrijane u otpadnome maslinovu ulju (WOHT)

Treatment type *Vrsta tretmana*	**Temperature, °C** *Temperatura, °C*	**Duration, h** *Trajanje, h*	***WPG*, %**	Standard deviation *Standardna devijacija*
Control kontrolni uzorak	-	-	-	-
WOHT	200	2	39	4.85
WOHT	200	4	44	6.60
WOHT	230	2	54	7.75
WOHT	230	4	60	7.30

Table 2 Oven-dry density values of waste olive oil heat-treated (WOHT) oriental beech
Tablica 2. Vrijednosti gustoće apsolutno suhe kavkaske bukovine pregrijane u otpadnome maslinovu ulju (WOHT)

Treatment type* *Vrsta tretmana**	**Temperature, °C** *Temperatura, °C*	**Duration, h** *Trajanje, h*	**Mean** *Srednja vrijednost*	**Standard deviation** *Standardna devijacija*	**Homogeneity group** *Homogene grupe*	**Compared to control, %** *Usporedba s kontrolnim uzorkom, %*
Control *kontrolni uzorak*	-	-	0.658	0.03	A	-
WOHT	200	2	0.941	0.03	B	+43.0
WOHT	200	4	1.041	0.03	B	+55.2
WOHT	230	2	1.030	0.04	B	+56.5
WOHT	230	4	1.025	0.04	B	+55.7

*Ten samples were used for each treatment group. / *Za svaki tretman korišteno je deset uzoraka.*

% to 60 %. Higher duration and temperatures resulted in higher *WPG* of WOHT oriental beech.

3.2 Oven-dry wood density
3.2. Gustoća apsolutno suhog drva

The oven-dry density values of the waste olive oil heat-treated (WOHT) oriental beech are given in Table 2.

WOHT oriental beech has significantly higher oven dry density values, increasing from 43 % to 56.5 %. For WOHT oriental beech, the oven-dry density values increased from 0.941 g/cm^3 to 1.041 g/cm^3. WOHT oriental beech oven-dry density values increased at 200 °C for 2 h and 4 h, while they dropped at 230 °C for the same amount of time. There was a statistical difference in oven-dry density values between control and WOHT oriental beech. It might be the result of the treatment oil intake (Suri *et al.*, 2022). Okon *et al.* (2018) found that the density of *Cunninghamia lanceolata* wood heated with oil increased to 75 % during the first stage of the treatment due to oil uptake, but then decreased as the temperature and treatment time increased. They clarified that the decrease in density is caused by the pyrolysis and degradation of the cell wall polymers during oil heat treatment. In our investigation, treatments carried out at 230 °C for 2 h and 4 h resulted in lower oven-dry density values for WOHT oriental beech. According to Dubey *et al.* (2016), the density of *Pinus radiata* wood after oil heat treatment was noticeably enhanced to a level of about 80 % greater than that of the untreated control group. Our findings generally agree well with those of these researchers.

3.3 Water absorption levels
3.3. Razine upijanja vode

Water absorption (*WA*) levels of the waste olive oil heat-treated (WOHT) oriental beech are presented in Table 3 and Figure 1.

According to the findings, *WA* levels were greater in the early stages of *WA*, particularly within 2 h, 8 h,

Table 3 Water absorption levels of waste olive oil heat-treated (WOHT) oriental beech
Tablica 3. Razine upijanja vode kavkaske bukovine pregrijane u otpadnome maslinovu ulju (WOHT)

Treatment type* *Vrsta tretmana**	**Temperature, °C** *Temperatura, °C*	**Duration, h** *Trajanje, h*	**Water absorption levels** / *Razine upijanja vode, %*																	
			After 2 h	H.G**	After 8 h	H.G	After 24 h	H.G	After 48 h	H.G	After 72 h	H.G	After 96 h	H.G	After 120 h	H.G	After 144 h	H.G	After 168 h	H.G
Control *kontrolni uzorak*	-	-	34.23	B	54.80	C	64.91	C	68.59	C	77.80	C	80.73	C	82.02	C	83.42	C	83.82	C
WOHT	200	2	6.70	A	15.01	B	22.85	B	26.15	B	31.02	B	32.86	B	33.93	B	35.22	B	35.30	B
WOHT	200	4	4.59	A	8.52	AB	13.42	A	16.99	AB	20.35	AB	23.21	AB	24.68	AB	26.20	AB	27.18	AB
WOHT	230	2	3.59	A	7.91	AB	13.92	A	17.56	AB	22.36	AB	24.88	AB	26.42	AB	28.41	AB	28.93	AB
WOHT	230	4	2.33	A	5.05	A	8.79	A	11.23	A	14.05	A	16.72	A	18.08	A	20.41	A	21.81	A

*Ten samples were used for each treatment group. / *Za svaki tretman korišteno je deset uzoraka.*
**Homogeneity group / *Homogene grupe*

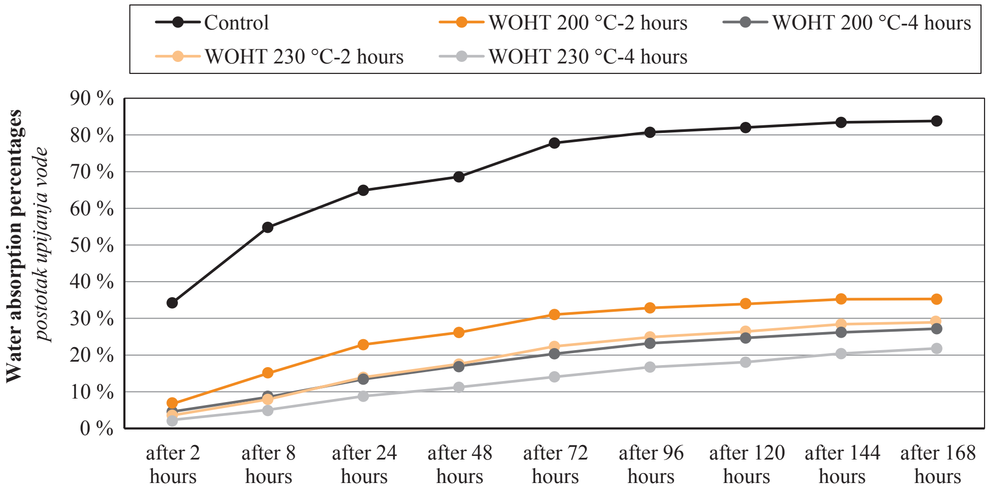

Figure 1 Water absorption percentages of oriental beech samples
Slika 1. Postotak upijanja vode uzoraka kavkaske bukovine

and 24 h, which is in line with the previous data (Alma, 1991; Hafızoğlu *et al*., 1994; Yıldız, 1994). These outcomes could be the consequence of *WA* being injected into wood empty hollow at the beginning of wetting and those spaces being smaller with time (Yalınkılıç *et al.*, 1995). In comparison to WOHT oriental beech, the water absorption (*WA*) levels of control samples were higher throughout both the initial and subsequent leaching periods. It might be because waste olive oil molecules can permeate into the water-swollen cell wall and stop or hinder the ability of treated wood samples to absorb water. The usage of waste olive oil has a water-repellent and bulking effect, which contributes significantly to the reduction of *WA*. According to a claim, the mass loss resulting from the breakdown of hemicellulose, the component of the cell wall that is most hydrophilic, after the thermal treatment of wood is the cause for the reduction in hygroscopicity of the material (Bourgois and Guyonnet, 1988). Some authors explained how vegetable oils can improve wood water repellency, while reducing water absorption. Vegetable oils produce a mechanical barrier function that prevents water from entering wood without forming any chemical bonds (Panov *et al*., 2010), and they also make wood water-repellent by permeating the tracheid lumen and parenchyma cells (Ulvcrona *et al.*, 2006). Plant oil that fills the cell lumen is stored on the exterior and partially on the interior surfaces of the wood, increasing the hydrophobicity of the surface. As a result, water absorption level is decreased because water enters wood pores through capillary action (Koski, 2008). Wang and Cooper (2005) found that soybean oil can bond in wood after analyzing the samples lowering water absorption rates after being heated with palm, soybean, and wax oils. The quality of the oil, the quantity absorbed, and the rate at which the oil is leached from the wood, all affect the success of oil treatments. It has been claimed that heat treatments under various atmospheric conditions, such as oil, steam, air, nitrogen, and vacuum have improved several wood qualities (Hakkou *et al*., 2005; Tjeerdsma and Militz, 2005; Welzbacher *et al*., 2008; Surini *et al*., 2012; Dubey *et al*., 2012; Boonstra *et al*., 2007a). Oriental beech that had been heated using waste olive oil (WOHT) had less WA than the control. These data show that lower values of *WA* were obtained (21.81 %) when the treatment temperature was 230 ºC for 4 hours, and the maximum *WA* was found in the control samples (83.82 %) after 168 hours of *WA*, indicating that a 62.01 % reduction had taken place. Our findings demonstrated that, for the total duration ranging from 2 to 168 hours, *WA* of control samples maintained a higher trend than oil heat-treated samples. A statistical difference between the control and WOHT oriental beech was seen in every period. According to Dubey *et al*., (2012), higher temperatures caused some chemical changes that had an impact on dimensional stability, and hydrophobic oils in the lumens prevented the walls from absorbing water. Hygroscopicity and water absorption in wood treated with oil heat decreased, according to several studies (Hofland and Tjeerdsma, 2005; Hyvonen *et al*., 2005). Some dry oils, like flaxseed oil, have molecules that are too big to pass through cell membranes, according to other studies. However, according to their claims, such oils mostly remained in the cell lumens and seeped into the wood to form a water-repellent outer layer (Olsson *et al.*, 2001; Hill, 2007; Wang, 2007). According to Hyvonen *et al*., (2005) and Hofland and Tjeerdsma (2005), wood heated with tall oil and rapeseed oil reduced the intake of water. Linseed oil-heated aspen wood levels in *WA* were investigated by Bazyar (2012). He discovered that, whereas the WA levels in control samples were 99.99 %, they were only 22.9 % in aspen wood that had been heated in linseed oil. Our results are in good agreement with the above findings. According to our

Table 4 *CSPG* levels of waste olive oil heat-treated (WOHT) oriental beech
Tablica 4. *CSPG* razine za kavkasku bukovinu pregrijanu u otpadnome maslinovu ulju (WOHT)

Treatment type* Vrsta tretmana*	**Temperature** *Temperatura* °C	**Duration** *Trajanje* h	***CSPG*** N/mm²	**Standard deviation** *Standardna devijacija*	**Homogeneity group** *Homogene grupe*	**Compared to control** *Usporedba s kontrolnim uzorkom* %
Control *kontrolni uzorak*	-	-	56.01	7.40	A	-
WOHT	200	2	57.11	6.56	A	+1.96
WOHT	200	4	59.62	8.49	A	+6.44
WOHT	230	2	55.73	7.08	A	-0.49
WOHT	230	4	54.03	5.84	A	-3.53

*Ten samples were used for each treatment group. / *Za svaki tretman korišteno je deset uzoraka.*

investigation, the water absorption levels of the control samples climbed to 83.82 % after 168 hours of *WA*, whereas it changed from 21.81 to 35.30 % for WOHT oriental beech.

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

The compression strength parallel to the grain (*CSPG*) values of the waste olive oil heat-treated (WOHT) oriental beech is presented in Table 4.

In our study, the greatest *CSPG* for WOHT oriental beech was 59.62 N/mm² at 200 °C for 4 h, while the *CSPG* value of the control was 56.01 N/mm²; the values for WOHT oriental beech were modified from 54.03 to 59.62 N/mm². The *CSPG* values between the control group and WOHT oriental beech showed no statistical differences at 95 % confidence levels. In comparison to the control, WOHT oriental beech had higher *CSPG* values for 2 and 4 hours at 200 °C. Oil is thought to fill the lumen, thicken the cell wall, and improve the lateral stability of the wood (Tomak *et al.,* 2011). Cheng *et al.* (2014) discovered that, after oil heat treatment, the *CSPG* for poplar wood increased primarily because of the high oil uptake, which thickened the fibers and improved their longitudinal strength. According to Suri *et al.* (2022), samples heated in oil exhibited significantly higher axial compressive strength than samples heated in air, with *Pinus koraiensis* exhibiting a bigger rise in compressive strength than *Paulownia tomentosa*. The increase in axial compressive strength following oil heat treatment may be attributed to several factors, including the higher density of samples that had undergone oil heat treatment, as well as the oil thickening and filling of cell wall lumens. According to Hao *et al.* (2021), as the temperature of the oil heat treatment increases, the compressive strength parallel to grain initially rises before falling. The compressive strength parallel to grain of the oil heat-treated samples is lower than that of the untreated samples at temperatures up to 200 °C. In our investigation, WOHT oriental beech heated at 230 °C for 2 hours and 4 hours exhibited lower *CSPG* values than WOHT oriental beech heated at 200 °C for 2 hours, 4 hours, and the control group. As a result, our results are in line with the previous research.

4 CONCLUSIONS
4. ZAKLJUČAK

Oven-dry density, water absorption (*WA*) levels, and compression strength parallel to the grain (*CSPG*) of WOHT wood were studied.

The WOHT oriental beech had higher oven-dry density than the control group. Our findings demonstrated that WOHT oriental beech oven-dry densities were lowered at 230 °C for 2 h and 4 h. For all *WA* periods, the *WA* of WOHT wood was lower than that of the control group. The *CSPG* values of WOHT oriental beech heated at 200 °C for 2 h and 4 h were greater than those of the control group. However, WOHT oriental beech *CSPG* levels decreased during 2 h and 4 h treatments at 230 °C.

In summary, the mechanical and physical characteristics of WOHT oriental beech wood have been generally improved. They lead to increased oven dry density values as well as reduced *WA* levels. Moreover, except for at 230 °C for 2 h and 4 h, *CSPG* values of oriental beech at 200 °C for 2 h and 4 h were higher than those of the control group. Thus, WOHT oriental beech may be a substitute structural material for exterior and interior application, depending on the level of mechanical and physical requirements.

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