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# Weathering Performance of Oriental Beech (*Fagus orientalis* L.) Wood Impregnated with Glycerol and Glyoxal

# Posljedice izlaganja vremenskim utjecajima drva kavkaske bukve (*Fagus orientalis L.*) impregnirane glicerolom i glioksalom

**ORIGINAL SCIENTIFIC PAPER**

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**ABSTRACT •** *This study aimed to improve some surface properties such as color, gloss, and surface roughness changes of Oriental beech (Fagus orientalis L.) wood impregnated with some water repellent chemicals such as glycerol (GR) and glyoxal (GX) after weathering. Oriental beech wood specimens were impregnated with a 4 % aqueous solution of GR, GX, and a mixture of GR and GX (1:1; weight : weight) (GR+GX) and then exposed to weathering in Muğla Province in Turkey. Results showed that ΔL* values of all wood specimens were decreased after weathering. Moreover, the decreases in the control specimen were higher than in the impregnated wood specimens. Oriental beech wood specimens showed a greenish and yellowish tendency, giving -Δa* and +Δb* values, respectively. Total color changes of GR impregnated Oriental beech was the lowest after weathering. The gloss of all Oriental beech test specimens decreased after weathering. The control specimen gave the lowest value in all three surface roughness parameters ($R_a$, $R_z$ and $R_q$) after weathering. Among the impregnated specimens, the groups impregnated with GR had, in general, the highest value in all three roughness degrees and showed the most negative results in surface roughness.*

**KEYWORDS:** *glycerol, glyoxal, oriental beech, surface properties, impregnation*

**SAŽETAK •** *Cilj ovog istraživanja bilo je poboljšanje nekih svojstava, npr. promjene boje, sjaja i hrapavosti površine drva kavkaske bukve (Fagus orientalis L.) impregnirane vodoodbojnim kemikalija kao što su glicerol (GR) i glioksal (GX) nakon izlaganja vremenskim utjecajima. Uzorci drva kavkaske bukve impregnirani su 4 %-tnom vodenom otopinom glicerola, glioksala i mješavine glicerola i glioksala (1 : 1; v : v) (GR + GX) te su zatim izloženi vremenskim uvjetima u provinciji Muğla u Turskoj. Rezultati su pokazali da su vrijednosti ΔL* svojstava svih uzoraka drva nakon izlaganja vremenskim uvjetima smanjene. Nadalje, smanjenje tih vrijednosti na kontrolnim je uzorcima bilo veće nego na impregniranima. Uzorci drva kavkaske bukve pokazali su tendenciju povećanja zelenoga (-Δa*) i žutog tona (+Δb*). Nakon izlaganja vremenskim utjecajima ukupne promjene boje ispitivanog drva kavkaske bukve impregniranoga glicerolom bile su najmanje. Sjaj svih uzoraka ispitivanog drva smanjio se nakon izlaganja vremenskim utjecajima. Pri izlaganju vremenskim uvjetima i nakon toga kontrolni je uzorak imao najmanju hrapavost površine za sva tri parametra hrapavosti (Ra, Rz i Rq). Od impregniranih uzoraka najveće*

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*vrijednosti svih triju parametara hrapavosti imali su uzorci impregnirani glicerolom, koji su pokazali i najlošije rezultate hrapavosti površine.*

**KLJUČNE RIJEČI:** *glicerol, glioksal, drvo kavkaske bukve, svojstva površine, impregnacija*

## 1 INTRODUCTION
## 1. UVOD

Many elements add value to wood, which is a renewable resource. Wood is environmentally friendly, widely available, has low energy consumption during preparation, good heat and sound insulation, superior weight/resistance ratio compared to other building materials (Tomak, 2011). As a result of all these features, wooden material has found thousands of uses from past to present (Bozkurt and Göker, 1996). Although wood material has all these positive features, it also has some undesirable negative features. For wood material, outdoor conditions are one of these negative features; in other words, «weathering» is seen as an important risk factor. Weathering is defined as the color change, surface roughness, and cracks that occur on the surface with the effect of sunlight (UV), humidity (rain and snow), and temperature. As a result of these effects, some changes occur in the color, chemical, and physical structure of the wood material (Feist and Hon, 1984; Williams, 2005; Kılıç and Hafızoğlu, 2009). Since untreated wood material does not have a resistant structure against weathering, wood impregnation is highly recommended. Although wood species with high biological durability remain intact for many years at the place of use, tree species with low biological durability must be impregnated to increase their lifetime (Kartal and Imamura, 2004). The negative properties of wood material can be reduced with some protective measures and impregnation techniques. The wood material can become resistant to these effects to some extent with precautions that can be taken without the use of chemicals, but if the risk factors are severe and continuous, chemical measures are needed (Kartal and Imamura, 2004).

Chemicals containing toxic biocides such as arsenic and chromium in their compositions have negative effects on the environment at the point of disposal of wood materials that have completed their useful life, as well as their toxicity during the life of wood, and this causes environmental pressures (Gezer, 2003; Humar *et al.,* 2005). The use of arsenic-containing CCA wood material and its re-use while at rest have been limited since 2003 by the Waste Management and Regulatory Authority (PMRA) in Canada and the Environmental Protection Organization (EPA) in the United States, and this decision has been made by the European Union Countries and Western European Wood Protection Agency. It has also been accepted by the Institute (WEI-IEO) (Gezer, 2003; Tomak, 2011). According to the studies of the Forest Products Laboratory (FPL) in the U.S. state of Wisconsin, based on average 30-year service life, approximately 6 million $m^3$ of impregnated solid wood is involved in the solid waste cycle (Humar *et al.,* 2005). The evaluation or disposal of such a large amount of impregnated wood material that has completed its service life requires serious and costly studies (Felton and De Groot, 1996). Considering all these problems and increasing environmental concerns in recent decades, the use of impregnation materials that have toxic effects on the environment, humans, and all living things has been limited and the wood protection industry has been compelled to develop new and environmentally friendly alternatives of impregnation methods (Kartal and Imamura, 2004). Newly developed impregnation agents include boron compounds, alkyl ammonium compounds (quats), and copper-based systems. In addition, there are isothiazolinone, chlorothalonil, thiazole, carbamate, triazole, copper naphthenate, and oxine copper and water repellent substances among the oily impregnation substances (Kartal and Imamura, 2004).

Water repellents are intended to control or prevent the water uptake of wood. By creating a water-repellent barrier in the wood, the water uptake rate can be significantly reduced. Depending on the materials used and their amounts, water-repellent substances fill the cell spaces and are stored on the outer surfaces and partially on the inner surfaces. Thus, the wood surface shows hydrophobic properties, and the water uptake rate is reduced (Koski, 2008). Specimens impregnated with water-repellent substances, when exposed to water, swell over time like untreated wood. However, the swelling time is 5-6 times longer than that of normal wood (Yıldız, 1988). Although water repellants do not completely reduce water absorption, they are one of the most effective materials for using wood in outdoor conditions. Water-repellent substances protect the wood against fungi and discoloration by reducing the amount of moisture needed for the growth of fungi and microorganisms in the wood (Williams and Feist, 1999). Temiz *et al.,* (2007) determined that the impregnation of wood surfaces with linseed and tall oil reduced the color change caused by external weather conditions and the leaching of lignin with rainwater. Hansmann *et al.,* (2006) stated that wood impregnated with different melamine-formaldehyde resins after accelerated weathering showed a more positive effect in terms of color stability compared to the control specimen. In this study, glycerol and glyoxal were preferred as water repellents. The chemical company Sigma Aldrich supplied the glycerol (GR; 99.5%) and glyoxal (GX; 40 wt% in $H_2O$) used as chemicals to resist water. A substance called glycerol (GR) has three functional groups that can interact with carboxylic acids to generate ester linkages. The dialdehyde glyoxal (GX), which has two aldehyde groups, is extremely reactive. Glyoxal is one of the intriguing dialdehydes as a crosslinking agent for wood in relation to the issue of formaldehyde release (Nakano, 1993).Glycerol finds use in a wide range of areas, depending on the purity of the glycerine produced by the breakdown of triglycerides. It can also be used as a paint and resin additive and antifreeze raw material. It is a sugar alcohol, and the hydrophilic alcoholic hydroxyl groups it contains allow it to dissolve easily in water. It has a high boiling point. It is used as a consistency and viscosity regulator, brightener, moisture retainer in industry and is one of the main inputs in many industrial chemicals. In addition, it has anti-freeze properties (Beser Kimya, 2022). On the other hand, Glyoxal is a linear aliphatic dialdehyde containing two aldehyde groups, and it participates in the synthesis of glyoxylic acid. It can be prepared by oxidizing ethanol or acetaldehyde with nitric acid. It is very commonly used in textile and paper production (Merck, 2022).

This study investigated the changes in color, gloss, and surface roughness that occur as a result of exposure of Oriental beech test specimens impregnated with glycerol and glyoxal to natural-weathering conditions for 1 month. Furthermore, glycerol and glyoxal are impregnating agents that reduce the expansion of wood. Therefore, the aim of this study is to determine various surface performance properties of wood treated with these impregnation materials in weathering conditions.

## 2 MATERIALS AND METHODS
## 2. MATERIJALI I METODE

### 2.1 Materials
### 2.1. Materijali

In this study, Oriental beech (Fagus orientalis L.) was used as wood material, and glycerol and glyoxal were used as impregnation materials.

#### 2.1.1 Preparation of test specimens
#### 2.1.1. Priprema ispitnih uzoraka

Oriental beech wood (*Fagus orientalis* L.) specimens measuring 10 mm (radial) × by 100 mm (tangential) × 150 mm (longitudinal) were made from air-dried wood. Before the experiments, wood specimens were maintained for two weeks at 20 °C and 65 % relative humidity. A total of 40 wooden specimens were prepared, 10 of which were from control and impregnated specimens. The average density of oriental beech wood used in the study is 0.59 g/cm$^3$. In addition, there is no significant difference within the whole annual ring in terms of the size and distribution of the trachea in the wood material used in the study. So the annual ring boundaries are not very clear.

### 2.2 Methods
### 2.2. Metode

#### 2.2.1 Impregnation procedure
#### 2.2.1. Postupak impregnacije

The Oriental beech (*Fagus orientalis* L.) wood specimens were impregnated with a 4 % aqueous solution of GR, GX, and a combination of GR and GX (1:1; weight: weight). Oriental beech wood was impregnated in accordance with ASTM D 1413-07el (2007). A total of 30 specimens were impregnated with each aqueous solution. Test specimens were allowed to diffuse in the solution at room temperature for 30 minutes after a pre-vacuum of 760 mm Hg was applied for 30 minutes in accordance with the impregnation method. The following equation was used to compute the retention value of the impregnated Oriental beech:

$$R = \frac{G \cdot C}{V} \cdot 10^3 \text{ (kg/m}^3\text{)} \quad (1)$$

Where;

$G$ – mass of impregnating solution absorbed by wood specimen (g)

Where;

$G – T_2 - T_1$

$T_2$ – Wood mass after impregnation (g)

$T_1$ – Wood mass before impregnation (g)

$V$ – Wood volume (cm$^3$)

$C$ – Solution concentration (%)

#### 2.2.2 Color test
#### 2.2.2. Mjerenje boje

The *CIEL*a*b** technique was used to calculate the color parameters $L^*$, $a^*$, and $b^*$. Additionally, an X-Rite SP Series Spectrophotometer was used to measure the color parameters $a^*$, $b^*$, and $L^*$. 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. While $a^*$ and $b^*$ are the chromaticity coordinates, the $L^*$ axis controls brightness. Red and green are displayed by the values $+a^*$ and $-a^*$, respectively. Blue is represented by the $-b^*$ parameter, while yellow is represented by the $+b^*$ value. The $L^*$ value ranges from zero (black) to 100 (white) (Zhang, 2003). The color difference, ($\Delta E^*$) was determined for each wood according to ASTM D1536-58T (1964). Color measurements were made parallel to the fibers. Three measurements were taken for each specimen from 3 different points. Equations 2, 3, 4, and 5 were used to determine the changing of colors.

$$\Delta a^* = a_f^* - a_i^* \quad (2)$$

$$\Delta b^*= b_f^*-b_i^* \quad (3)$$
$$\Delta L^*= L_f^*-L_i^* \quad (4)$$
$$\Delta E^*=[(\Delta a^*)^2+(\Delta b^*)^2+(\Delta L^*)^2]^{1/2} \quad (5)$$

Where;
$\Delta a^*$, $\Delta b^*$, and $\Delta L^*$ represent the changes between the initial and final interval values. Ten replicates were made for each treatment group.

### 2.2.3 Gloss test
### 2.2.3. Mjerenje sjaja

A measuring tool was used to determine the gloss values of Oriental beech in accordance with ASTM D523-14 (2018). (Micro-TRI-Gloss). Incidence angle of 85 degrees was the selected geometry. Each treatment group received ten replications. Gloss measurements were made parallel to the fibers. A total of 3 measurements were made from 3 different points for each specimen.

### 2.2.4 Surface roughness
### 2.2.4. Hrapavost površine

Roughness was tested using the Mitutoyo Surftest SJ-301 device in line with DIN 4768 (1990) specifications. The three roughness measures are the mean arithmetic deviation of the profile (*Ra*), mean peak-to-valley height (*Rz*), and root mean square (*Rq*). The average distance between the profile and the mean line over the period of the evaluation is known as the $R_a$. The parameter *Rz* can be derived from the five equal lengths of the peak-to-valley values of the profile, and *Rq* is the square root of the arithmetic mean of the squares of the profile deviations from the mean line (Mummery, 1993). Using a stylus with a diamond tip that had a 5 µm radius and a 90° conical angle, the surface roughness profile was examined. The stylus feed rate was 0.5 mm/$s^1$ throughout an 8 mm specimen length (Zhong *et al*., 2013). For each treatment group, ten replications were made. Surface roughness measurements were made parallel to the fibers. A total of 3 measurements were made from 3 different points for each specimen.

### 2.2.5 Natural weathering test
### 2.2.5. Izlaganje vremenskim uvjetima

10 wood specimens were grouped together in each group. The specimens were exposed to the weathering conditions of Muğla province in December 2021. Table 1 shows the meteorological data of Muğla province in December 2021 (State Meteorological Services Database, 2021). In accordance with ASTM D 358-55 (1970), wood panels were also prepared for exposure to the elements.

### 2.2.6 Statistical analysis
### 2.2.6. Statistička analiza

As a result of the measures, test results were acquired and then examined using the statistical program SPSS. The computer was used to upload the test results and run a variance analysis. At a 95 % statistical level of confidence, the Duncan test was used. The experimental data homogeneity groups (HG) were used for statistical analysis. Statistically significant differences are denoted by different letters in HG (Günbekler *et al*., 2021; Baysal *et al*., 2021; Türkoğlu *et al*., 2020).

## 3 RESULTS AND DISCUSSION
## 3. REZULTATI I RASPRAVA

### 3.1 Color changes
### 3.1. Promjene boje

Color changes values of Oriental beech wood specimens impregnated with GR, GX, and GR+GX are given in Table 2.

Before weathering, the $L^*$ value of the control specimen was found to be 64.42. In the impregnated specimens, the highest $L^*$ value was obtained at 63.63 in the Oriental beech test specimens impregnated with GR+GX, while the lowest $L^*$ value was determined in the Oriental beech test specimens impregnated with GX at 61.60. The $L^*$ values of the impregnated specimens decreased compared to the control specimen. Before weathering, the Oriental beech test specimens showed a tendency to turn reddish and yellowish, giving $+a^*$ and $+b^*$ values, respectively. After natural weathering, the $\Delta L^*$ values of the control and impregnated Oriental beech test specimens decreased. While the maximum reduction was obtained in the control specimens (-3.87), the least decrease was detected in the specimens impregnated with GR+GX. Negative values in $\Delta L^*$ are an indication of depolymerization of lignin in wood (Temiz *et al.,* 2003). Wood specimens become darker due to the decrease in $L^*$ value (Baysal

**Table 1** Weather conditions of Muğla for December 2021
**Tablica 1.** Vremenski uvjeti u provinciji Muğla za prosinac 2021.

| **Weather conditions** / *Vremenski uvjeti* | **December** / *Prosinac* |
|---|---|
| Average temperature, °C / *prosječna temperatura,* °C | 6.7 |
| Maximum temperature, °C / *najviša temperatura,* °C | 16.4 |
| Minimum temperature, °C / *najniža temperatura,* °C | -4.4 |
| Number of rainy days per month / *broj kišnih dana po mjesecu* | 21 |
| Rainfall per month, kg/$m^2$ / *količina padalina po mjesecu,* kg/$m^2$ | 368.7 |
| Average humidity per month, % / *prosječna vlažnost zraka po mjesecu,* % | 87.7 |

**Table 2** Color change values of test specimens after natural weathering
**Tablica 2.** Vrijednosti promjene boje ispitnih uzoraka nakon prirodnog izlaganja vremenskim uvjetima

| **Specimens** *Uzorci* | **Retention, kg/m³** *Retencija, kg/m³* | **Color values before natural weathering** *Vrijednosti boje prije prirodnog izlaganja vremenskim uvjetima* | | | | | | **Color changes values after natural weathering** *Vrijednosti promjene boje nakon prirodnog izlaganja vremenskim uvjetima* | | | **Total color changes** *Ukupna promjena boje* | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *L** | | *a** | | *b** | | | | | | |
| | | **Mean** *Srednja vrijednost* | **Standard deviation** *Standardna devijacija* | **Mean** *Srednja vrijednost* | **Standard deviation** *Standardna devijacija* | **Mean** *Srednja vrijednost* | **Standard deviation** *Standardna devijacija* | $\Delta L^*$ | $\Delta a^*$ | $\Delta b^*$ | $\Delta E^*$ | **Homogeneity group** *Homogene grupe* |
| Control *kontrolni uzorak* | - | 64.42 | 9.66 | 10.97 | 1.64 | 10.83 | 3.13 | -3.87 | -1.48 | 11.85 | 12.55 | A |
| GR | 15.38 | 63.27 | 9.49 | 11.22 | 1.68 | 11.75 | 3.20 | -2.30 | -1.99 | 10.98 | 11.39 | A |
| GX | 21.71 | 61.60 | 9.24 | 10.36 | 1.55 | 10.59 | 3.21 | -1.78 | -1.53 | 11.45 | 11.68 | A |
| GR+GX | 19.54 | 63.63 | 9.54 | 11.05 | 1.65 | 11.99 | 3.26 | -0.39 | -1.43 | 11.56 | 11.65 | A |

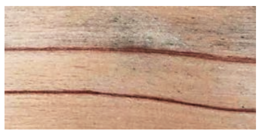
| **Impregnated and non-impregnated test specimens** *Impregnirani i neimpregnirani ispitni uzorci* | **Before natural weathering** *Prije prirodnog izlaganja vremenskim uvjetima* | **After 1 month of natural-weathering** *Nakon mjesec dana prirodnog izlaganja vremenskim uvjetima* |
|---|---|---|
| **Control** *kontrolni uzorak* |  |  |
| **GR** |  |  |
| **GX** |  |  |
| **GR+GX** |  |  |

**Figure 1** Color change images of Oriental beech wood specimens impregnated with GR, GX, and GR+GX before and after 1 month of natural weathering
**Slika 1.** Fotografije promjena boje uzoraka drva kavkaske bukve impregniranih s GR, GX i GR+GX prije i nakon prirodnog izlaganja vremenskim uvjetima tijekom jednog mjeseca

*et al.,* 2014). After natural weathering, all specimens showed a greenish and yellowish tendency, giving $-\Delta a^*$ and $+\Delta b^*$ values, respectively. Changes in some chromophoric groups of lignin may be the cause of the rise in the chromaticity coordinate ($\Delta b^*$) (Grelier *et al.*, 2000). According to the results of the total color change ($\Delta E^*$), Oriental beech test specimens impregnated with GR gave the best color stability. However, there was no statistical difference between impregnated Oriental beech specimens. In our study, impregnated specimens showed less discoloration than control specimens after weathering.

Color change images of Oriental beech wood specimens impregnated with GR, GX, and GR+GX before and after natural weathering are given in Figure 1. Additionally, Figure 1 clearly shows that the Oriental beech wood surface is overgrown with mold fungi.

## 3.2 Gloss changes
## 3.2. Promjene sjaja

Values of gloss changes of Oriental beech wood specimens impregnated with GR, GX, and GR+GX are given in Table 3.

In this study, before natural weathering, the highest gloss value was obtained in the control specimens, while the lowest gloss value was obtained in the GR impregnated Oriental beech specimens. With the impregnation process before weathering, the gloss of the specimens was lower than that of the control specimens. After natural weathering, the gloss of all specimens decreased. While the maximum decrease was obtained in the control specimens with -10.49, the least decrease was obtained in the specimens impregnated with GR+GX with -6.33. The gloss reduction in the impregnated specimens was lower than in the control specimens. The deterioration of wood surfaces is caused by the sunlight UV component, temperature and relative humidity (RH) fluctuations throughout the year, air pollution, oxygen levels, and human activities (Williams, 2005). The chemical, physical, and optical properties of wood change over time, resulting in discoloration, gloss loss, and surface roughening. In addition, the three main mechanical qualities of wood are impacted (Denes and Young, 1999). Additionally, it has been suggested that poor glossiness values in impregnated specimens may be the result of the addition of impregnation materials with their chemical structures to the surface of the wood material (Soylamış, 2007). According to Özdemir *et al.* (2015), increased fibers reduce the gloss value and water-based wood treatments enhance surface porosity. In the present study, the surface gloss of the impregnated wood specimens decreased. For this reason, this study is supported by the study of Özdemir *et al.,* (2015).

## 3.3 Surface roughness changes
## 3.3. Promjene hrapavosti površine

Surface roughness changes of Oriental beech wood specimens impregnated with GR, GX, and GR+GX are given in Table 4.

In this study, before natural weathering, the highest value of *Ra* roughness was obtained in specimens impregnated with GR (6.10 µm), while the lowest value was obtained in control specimens (3.65 µm). While the highest value in *Rz* roughness was obtained in specimens impregnated with GR (34.19 µm), the lowest value was obtained in control specimens (21.88 µm). While the highest value in *Rq* roughness was obtained in the specimens impregnated with GX (7.41 µm), the lowest value was obtained in the control specimens (4.58 µm). The impregnation process before natural weathering had an effect on increasing the surface roughness of the specimens in all three roughness values (*Ra*, *Rz*, and *Rq*). Surface roughness is an important factor in determining wood surface. In addition, wood is affected by many factors (Yıldız *et al.,* 2013). The roughness of all specimens increased at *Ra*, *Rz* and *Rq* roughness values after natural weathering. While there was no statistical difference between the control specimens and the specimens impregnated with GX in *Ra* and *Rz* roughness values, a statistical difference was determined compared to the other specimens. While there was no statistical difference in *Rq* roughness value between control specimens and the specimens impregnated with GR, a statistical difference was observed compared to other specimens. Generally, after weathering, the impregnated specimens caused a rougher surface on the wood material. Rough surface wood materi-

**Table 3** Values of gloss changes of test specimens after natural weathering
**Tablica 3.** Vrijednosti promjene sjaja ispitnih uzoraka nakon prirodnog izlaganja vremenskim uvjetima

| **Specimens** *Uzorci* | **Retention, kg/m³** *Retencija,* kg/m³ | **Gloss values before natural weathering** *Vrijednosti sjaja prije prirodnog izlaganja vremenskim uvjetima* 85° | | **Gloss values after natural weathering** *Vrijednosti sjaja nakon izlaganja vremenskim uvjetima* 85° | | **Values of gloss changes after natural weathering, %** *Vrijednosti promjene sjaja nakon prirodnog izlaganja vremenskim uvjetima, %* | |
|---|---|---|---|---|---|---|---|
| | | **Mean** *Srednja vrijednost* | **Standard deviation** *Standardna devijacija* | **Mean** *Srednja vrijednost* | **Standard deviation** *Standardna devijacija* | **85°** | **Homogeneity group** *Homogene grupe* |
| Control *kontrolni uzorak* | - | 5.81 | 0.87 | 5.20 | 1.03 | -10.49 | A |
| GR | 15.38 | 1.13 | 0.16 | 1.03 | 0.21 | -8.84 | AB |
| GX | 21.71 | 1.25 | 0.18 | 1.16 | 0.31 | -7.20 | B |
| GR+GX | 19.54 | 1.42 | 0.21 | 1.33 | 0.69 | -6.33 | B |

Note: GR: Glycerol, GX: Glyoxal, Homogeneity group at 95 % confidence level
*Napomena: GR – glicerol, GX – glioksal; homogene grupe na razini pouzdanosti od 95 %*

**Table 4** Values of surface roughness change of test specimens after natural weathering
**Tablica 4.** Vrijednosti promjene hrapavosti površine ispitnih uzoraka nakon prirodnog izlaganja vremenskim uvjetima

| **Speci-mens** *Uzorci* | **Retention, kg/m³** *Retencija, kg/m³* | **Surface roughness values before natural weathering** *Vrijednosti hrapavosti površine prije prirodnog izlaganja vremenskim uvjetima* | | | | | | **Surface roughness values after natural weathering** *Vrijednosti hrapavosti površine nakon prirodnog izlaganja vremenskim uvjetima* | | | | | | **Surface roughness values after natural weathering, %** *Vrijednosti hrapavosti površine nakon prirodnog izlaganja vremenskim uvjetima, %* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ***Ra*, μm** | | ***Rz*, μm** | | ***Rq*, μm** | | ***Ra*, μm** | | ***Rz*, μm** | | ***Rq*, μm** | | *Ra* | H.G | *Rz* | H.G | *Rq* | H.G |
| | | Mean | Std. dev. | Mean | Std. dev. | Mean | Std. dev. | Mean | Std. dev. | Mean | Std. dev. | Mean | Std. dev. | | | | | | |
| Control | - | 3.65 | 0.54 | 21.88 | 3.28 | 4.58 | 0.68 | 3.68 | 1.88 | 23.45 | 4.15 | 5.12 | 1.85 | 0.82 | A | 7.17 | A | 11.79 | B |
| GR | 15.38 | 6.10 | 0.91 | 34.19 | 5.12 | 7.14 | 1.07 | 6.87 | 1.93 | 39.79 | 3.53 | 8.24 | 2.69 | 12.62 | C | 16.37 | B | 15.40 | B |
| GX | 21.71 | 5.75 | 0.85 | 33.80 | 5.07 | 7.41 | 1.11 | 5.90 | 1.41 | 36.22 | 4.99 | 9.12 | 3.56 | 2.60 | A | 7.15 | A | 23.07 | C |
| GR + GX | 19.54 | 5.31 | 0.79 | 33.34 | 5.03 | 6.85 | 1.02 | 5.77 | 0.89 | 38.12 | 3.40 | 7.23 | 1.47 | 8.66 | B | 14.33 | B | 5.54 | A |

als require much more sanding than smooth-surfaced wood materials, which causes a decrease in the thickness of the material and thus increases the losses from sanding (Dündar *et al.,* 2008). Wood roughness, however, is a complicated issue. For the evaluation of the surface roughness of wood, a number of parameters, including its anatomical structure, machining properties, growth characteristics, and pre-treatments before machining, should be taken into account (Aydın and Çolakoğlu, 2003; Aydın and Çolakoğlu, 2005; Temiz *et al*., 2005). According to Miklei *et al.* (2017), light irradiation largely caused the middle lamella, which sits between two cell walls and binds the cells together, to deteriorate. This deterioration makes the wood surface more uneven. (Tolvaj *et al.,* 2014).

## 4 CONCLUSIONS
## 4. ZAKLJUČAK

The surface properties such as color, gloss, and surface roughness of Oriental beech wood impregnated with GR, GX, and GR+GX mixtures were investigated after natural weathering. The $L^*$ values of all specimens decreased after natural weathering. All specimens showed a tendency to greenish and blueish, giving negative $\Delta a^*$ and positive $\Delta b^*$ values, respectively. Our results showed total color changes of impregnated Oriental beech was improved compared to the control group, but there were no statistical differences in total color changes between all test specimens and control specimens. In terms of gloss changes, impregnated Oriental beech wood specimens gave better results than the control group after natural weathering.

In conclusion, while total color changes and gloss changes of impregnated Oriental beech were lower than those of the control specimen after weathering, impregnated Oriental beech specimens gave rougher surface compared to the control specimens after natural weathering.

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