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Surface Roughness of Sliced Veneers in Terms of Defects and Wood Structure Variability – Impact of Mild Hydrothermal Treatment

Hrapavost površine rezanog furnira u smislu nedostataka i varijabilnosti strukture drva – utjecaj blage hidrotermičke obrade

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ABSTRACT • *This study deals with the surface roughness and quality of oak sliced veneers and how these characteristics are influenced by the presence of knots, and other defects associated to knots. The variability of roughness is thoroughly examined along the oak stem, exploring also how it differentiates going from one veneer to the adjacent one, cut in different wood depths of the same sawn wood piece in defect and non-defect areas. The expected vertical variability of morphological characteristics did not influence significantly the surface roughness along the stem, which favors the sliced veneers application and performance. The veneers obtained from the edges of the veneer package presented surfaces of high roughness. The smoothest surfaces were recorded in some of the areas on or peripherally of the living intergrown knots. Apart from the cases of large or dead knots that break and result in detrimental cavities, the small live knots do not influence negatively the roughness and therefore, neither the veneer processing demands, nor the overall quality of the final veneer-based product. In order to improve the surface quality of oak sliced veneers and to investigate the response of both defect- and non-defect areas to the hydrothermal modification, two mild and short-term hydrothermal treatments were applied. Among these treatments, only the mildest one (110 °C) managed to improve significantly the surface quality, concerning both the defect and non-defect areas, while the treatment at 130 °C did not reveal a significant change of the surface roughness of veneers.*

KEYWORDS: *knot; modification; quality; surface property; texture; veneer*

SAŽETAK • *U radu je istraživana hrapavost površine i kvaliteta rezanoga hrastova furnira te utjecaj kvrga i drugih nedostataka povezanih s kvrgama na hrapavost površine i kvalitetu tog furnira. Varijabilnost hrapavosti temeljito je ispitana duž hrastova debla te među susjednim furnirima rezanim na različitim dubinama istog debla u područjima s greškama i bez njih. Očekivana vertikalna varijabilnost morfoloških obilježja drva duž debla nije značajno utjecala na hrapavost površine furnira, što pogoduje primjeni i svojstvima rezanog furnira. Površina furnira uzetih s rubova paketa bila je vrlo hrapava. Površine s najmanjom hrapavošću bile su one s područja zdravih*

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uraslih kvrga ili periferno od njih. Osim velikih ili mrtvih kvrga, koje pucaju i rezultiraju štetnim šupljinama, male zdrave kvrge ne povećavaju hrapavost površine furnira, a time ne utječu na zahtjeve obrade furnira ni na kvalitetu proizvoda od njih. Kako bi se poboljšala kvaliteta površine hrastovih rezanih furnira i istražio utjecaj područja s greškama i bez njih na hidrotermičku modifikaciju, primijenjena su dva blaga i kratkotrajna hidrotermička tretmana. Od tih tretmana samo je blaži (110 ºC) uspio znatnije poboljšati kvalitetu površine, kako područja s greškama, tako i područja bez grešaka, dok tretman pri 130 ºC nije bitno utjecao na promjenu hrapavosti površine furnira.

KLJUČNE RIJEČI: *kvrga; modifikacija; kvaliteta; svojstvo površine; tekstura; furnir*

1 INTRODUCTION
1. UVOD

Wood is a polymeric lignocellulosic, anisotropic, complex material, of a distinct morphology, the structure of which depends on the way of biosynthesis and composition of its cells in the wood tissue. The texture is strongly related to the size (diameter) of the structural elements (cells) of wood, to cells type and distribution within the growth rings, differences in density and structure between early and late wood, earlywood and latewood ratio, with latewood to be much smoother than earlywood (Pinkowski *et al*., 2016), juvenility/maturity of wood, number and distribution of tracheid and vessel elements, etc. As a result, the surface properties of wood depend on the size and distribution of the micro-geometric deviations characterized by the small peaks and valleys of the relief, which constitute the wood surface topography. The surface roughness of wood constitutes a crucial characteristic for its utilization potential in numerous final applications (window frames, furniture manufacturing, benches, table tops, floors, etc.), affecting strongly the structures texture, appearance, surface touch feeling and the subsequent impact on the user's phycology, the manufacturing possibilities, finishing and sanding processes demands, adhesive quantity demands for the achievement of adequate wettability and bonding, wood surfaces bonding strength (Coelho *et al*., 2008; Li *et al*., 2010; Vassiliou *et al*., 2016; Bao *et al*., 2016; Sandak *et al*., 2020). Usually, the rough wood surfaces result in limited contact between the two wood surfaces, poor internal adhesion strength between adhered wood surfaces and consequently, lower mechanical performance of the whole structure (Coelho *et al*., 2008; Bao *et al*., 2016; Kamperidou *et al*., 2020). Furthermore, the phenomenon of adhesive bleeding through the face veneer is much limited in veneers of smooth surfaces (Dundar *et al*., 2008; Bekhta *et al*., 2009). Additionally, the importance of the surface quality in constructions is also proven by the fact that the perfection of the surface manufacturing/machining process and subsequent treatments (finishing, polishing processes) increase the service life of the product (Sandak *et al*., 2020). Excessive roughness tends to create rapid wear and dimensional changes, while surface irregularities, even tiny scratches or grooves, cause stress concentrations, which are the cause of cracks or the onset of fracture (Tsoumis, 2002).

Therefore, surface roughness has received much attention in the previous years. Several studies have been implemented so far, dealing with the surface roughness of wood products, revealing that it is highly influenced by factors, such as the wood species, wood structure, density, moisture content, anisotropy, growth rings width, early to latewood transition, work piece hardness, chemical composition, etc.

The material properties of the tool, concerning the cutting conditions, cutting means, tool wear, angle of knife, number of cutting teeth, cutting speed, cutting depth, feed rate, grain angle, etc., highly influence the surface roughness (Aydin *et al*., 2006; Csanády, 2015; Dobrzynski *et al*., 2018). Another crucial processing treatment, applied aiming to achieve the reduction of surface roughness and increase of sliced veneers quality, is the steaming process that precedes the slicing process of veneers to facilitate the veneer cutting process (Tanritanir *et al*., 2006).

The steaming pre-treatment method strengthens the toughness of wood, reduces the cutting resistance during slicing and therefore decreases the use of energy, damage to cell walls and color variations, improving the overall quality of sliced wood veneer (Aydin *et al*., 2006; Li *et al*., 2015). Additionally, the sanding process that follows the veneers slicing, contributes to the smoothness of wood surface, which depends on the grit number of the sandpaper used (Faust, 1987). The main sanding process of veneer is applied during the veneer-based panels production, using sandpapers of high grit numbers (>180). Other veneer quality criteria, except for the surface roughness, are the veneer thickness (average and variation), and lathe checks presence (depth and frequency) (Wang *et al*., 2006).

Unfortunately, the supply of high-quality wood has become increasingly scarce and therefore the contradiction between wood supply and demand has become increasingly prominent. As a result, research and industrial world recently attempt to evaluate the potential use of low-quality wood species, characterized by a high number of defects, for the preparation of various wood-based panels to meet the urgent needs of the immensely rising population concerning wood material (Yu *et al*., 2020). Defects such as dead (encased) knots, veneers joint zones, holes and cracks on the surface of the wood veneer adversely affect the strength, appearance, and quality class of the product. They make the veneers less attractive to be applied in front face-side surfaces of structures (Bao *et al*., 2016; Kamperidou *et al*., 2020) and determine wood quality classification, as well as to evaluate and determine the cost of manufactured veneer-based products (Sandak *et al*., 2020).

Recently, Sandak *et al*. (2020) tested optimal sensors for refined and accurate enough scanning of the wood surface topography in an industrial environment in-line and on-line, proving their usability and success to access the surfaces of diverse quality and finishing state. The literature review showed a great lack of information as regards the way in which the defects (knots, decay, tensile wood, spiral grain, etc.) affect the smoothness and surface quality of sliced veneer sheets and. subsequently, the quality of veneer-based composites. Furthermore, no data have been found in literature concerning the roughness and surface quality of oak, a species whose veneers are in particular demand in the market, especially the "rustic" oak veneer. This particular type of oak veneer is known and appreciated for its unique appearance characterized by the presence of numerous small live knots and is being sold in the market at higher prices than the typical oak veneers.

Some preservation treatments have been applied so far to rotary cut veneer surfaces, aiming to improve the surface properties of wood, to increase surface activation and enhance the bondability of wood veneers (Kamperidou *et al*., 2012), such as chemical treatments with activating agents, hydrogen peroxide, aluminium persulfate, acetic acid, sodium carbonate, etc. (Bekhta *et al*., 2015) and compression treatments among others. Dudik *et al*. (2020) investigated the surface properties of birch wood rotary cut veneers after heat treatment (170-200 ºC, 1-5 h), namely color, hardness, roughness and wetting, and, in particular, the marketing evaluation of the attractiveness of colored birch wood. The applied heat treatments did not cause any significant changes in a positive or negative direction concerning the surface properties and roughness. As for sawn wood, a variety of results for the surface roughness of thermally modified wood has been demonstrated (Pinkowski *et al*., 2016), depending on many different factors including wood properties and thermal treatment parameters. Budakçı *et al*. (2013) outlined that surface roughness of several soft- and hard-wood species was not at all affected by heat treatment, whereas Gűndűz *et al*. (2008) recorded a lower surface roughness after the modification of black pine wood. Generally, commercial processes tend to first treat and then machine the wood (Gurau *et al*., 2017), and as a result, only few studies and limited information can be found in literature concerning the treatment of already cut (sliced or rotary) veneers. In parallel, there is a lack of information concerning the thermal, hydrothermal or chemical treatment of sliced (decorative) veneers.

Yu *et al*. (2020) investigated the potential of impregnated sliced veneers of poplar with glycidyl methacrylate and ethyleneglycol dimethacrylate, combined with maleic anhydride, as a reactive catalyst and in-situ polymerized and bonded monomers in their mass, through hot pressing method, revealing an impressive increase in bending strength, abrasion resistance, surface bonding strength and smoothness. Peng and Zhang (2019) treated five kinds of typical natural precious decorative veneer (rosewood, teak, black walnut, northeast China ash and red oak) by plasma at different discharge powers and speeds and among other findings, revealed improved surface wettability and increased surface roughness. However, no information or research data have been found concerning the potential of hydrothermal treatment to enhance the sliced veneer surface quality in terms of roughness or decrease of defects presence with an impact on the surface quality.

Therefore, the aim of this study is to examine the surface quality of oak sliced veneers, so that the roughness influenced by the presence of various structural defects (knots, and defects related to knots such as spiral grain, decay and tensile wood around the knots), is compared to non-defect areas of veneer surfaces. The vertical variability of roughness is thoroughly examined along the entire log, while it is also investigated how the surface roughness differentiates among the successively cut veneer sheets from the same batch of material, on different wood depths. In an attempt to improve the surface quality of oak cut (sliced) veneers and to investigate the response of both, defect- and non-defect- areas, to the hydrothermal modification, two mild and short-term hydrothermal treatments were applied.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Collection of veneers and preparation of samples
2.1. Odabir furnira i priprema uzoraka

For the purposes of this experimental work, a package of 17 continuously sliced veneers of European oak (*Quercus robur* L.) wood was obtained from the market. The veneer package was of Balkan region origin (Croatia), produced by one of the most significant manufacturers of sliced veneers in Croatia and was imported to the Greek market, intended to be typically used as raw decorative veneers, applied on particleboards, plywood panels, door frames, etc. The specific company merchandises packages of 17 veneers in the market, which is the reason why we purchased the whole package of 17 veneers. Oak was selected as raw material to be characterized in this study, mainly because it is a significant species typically used in sliced veneers production in the Balkan region, among other species, and as a ring-porous, deciduous species bearing wide rays and vessels (often 3 times wider than adjacent fibers), which can be considered to be more of a rough texture (Zhao *et al*., 2020).

According to the information gathered through the communications with the specific veneer production industry, the tree log used for the production of the specific sliced veneers was of large diameter and approximately at the age of 72 years. It was industrially converted into decorative veneer sheets, using the slicing method, applied in the infrastructures of the above-mentioned industry of sliced veneer production, so that the pre-treatment processes, steaming, mechanical processing conditions, cutting tools, slicing method applied, etc. would be based on industrial conditions and certified practices. The sliced veneer production met the requirements of the industrial sliced veneer production standards applied in this certified industrial unit, in terms of defects elimination, thickness similarity, avoidance of irregularities attributed to mechanical processing errors, such as burning and injuries, among others (stated by the veneer production industry and the collaborating market stores). Prior to the slicing process of veneers, the oak log was initially debarked, naturally dried and exposed to steaming. The slicing device used for the preparation of these decorative flat-cut veneers was of horizontal operation, appropriate for slicing hardwood veneer.

The veneers were sliced in radial direction and there was no visible color difference between heartwood and sapwood and therefore the percentage of sapwood/heartwood has not been considered in the measurements of this study. The growth rings were clearly visible, as expected in a typical ring-porous species, in which there is a clear transition from early- to late-wood. The phenomenon of oak to present the effect of chrysalis in radial section is not so easily seen with the naked eye in the wood veneers examined in the present research. The conical shape of stem is not intense, which may indicate that the tree probably grew in a closed cluster or that pruning had been applied, among other factors. As a tree of medium to high age, with mature wood, it is expected not to present conical shape, since this is a typical characteristic of younger stems (Tsoumis, 2002). The fact that the tree may have grown in narrow space or at a considerably low distance from other trees, is consistent with its narrow growth rings. Of course, the growth rings width depends on various factors, such as age, growing conditions (soil, moisture, sun) and heredity (Tsoumis, 2002).

The package of the continuously sliced veneers (continuous in a row and successively cut) was selected to be characterized (Figure 1), aiming to observe the evolution of the whole defects (mainly knots) as they are encountered in the log mass. The veneers were of (0.53±0.1) mm thickness, cut mainly from the logs heartwood, in dimensions (3130 mm length × 250 mm width), and were left to be conditioned at (20±2) ºC and (65±5) % relative humidity, till constant weight. All veneer sheet samples were conditioned to equilibrium moisture content (EMC), and stayed there until the measurement of roughness. Each roughness measurement area corresponded to a surface of approximately 30 mm × 30 mm. These areas were selected and marked on the surface of veneer samples, so that each of them was in a close proximity to the respective knot/defect examined (Figure 1). Much attention has been paid to ensure the representativeness of the measurements, trying to distribute the 30 mm × 30 mm measurement areas on the whole surface of each veneer to depict the quality of the whole veneer, based also on the distribution pattern of knots. As regards the estima-

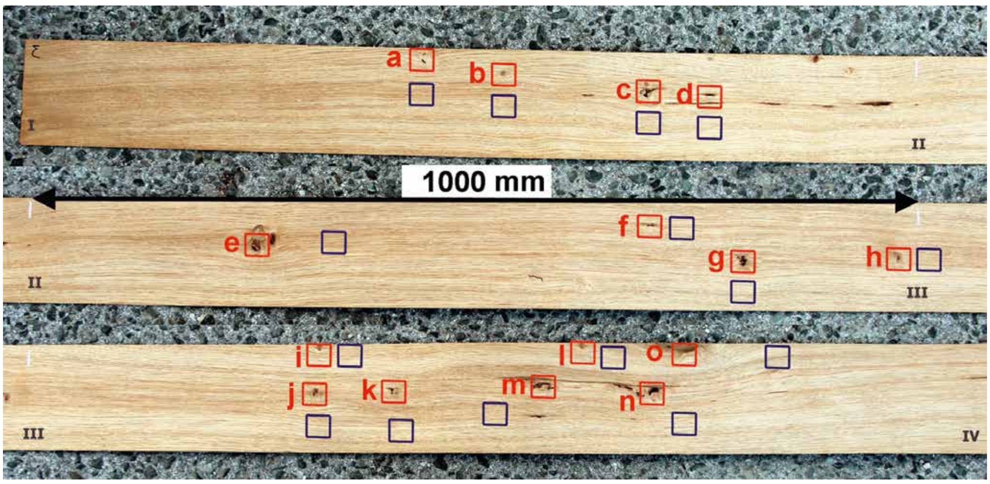


Figure 1 Distribution of 15 studied knots (a-o) on the surface of veneer sample and configuration of roughness measurement areas (30 mm × 30 mm) concerning 15 knot areas (red squares), and respective non-defect areas (blue squares)
Slika 1. Raspodjela 15 proučavanih kvrga (od a do o) na površini uzorka furnira i konfiguracija područja mjerenja hrapavosti (30 × 30 mm) s obzirom na područja od 15 kvrga (crveni kvadrati) i područja bez grešaka (plavi kvadrati)

tion of roughness on the knot areas, several measurements were implemented within surface areas of 30 mm × 30 mm (applying the stylus method in several directions, perpendicular to the veneer length, from circumference of knot to its center and vice versa, etc.), on the knots (when possible), where the orientation of the tissue is perpendicular to the surface, and also, around the examined knots, in their peripheral area, within a radius of 10–20 mm around the knot, including in this way the transition zone from the knot to defect-free wood. In this case, the orientation of the tissue is arbitrarily between 0 and 90 ° and this could influence the surface roughness.

2.2 Roughness measurement
2.2. Mjerenje hrapavosti

In case of areas without defects, the measurements were implemented on an axis perpendicular to the grain (on both directions), recording different growth rings, as encountered on wood surface. This was based on methodology proposed in the respective standard of roughness measurement ISO 4287:1997, as well as the manual instructions of the profilometer used and the practice followed in previous studies (Budakci *et al*., 2013; Kamperidou and Barboutis, 2017; Li *et al*., 2018), aiming to ensure comparability of results. Given the uniqueness of each defect and each knot, it is easily comprehended that some of them constitute live or dead knots, knots accompanied by traces of decay, cavities or deviations of fibers orientation from the stem axis direction, etc. (Figure 2). Although, almost all knots can be considered to be of relatively small dimensions (based on the market considerations and authors' experience), the knots of slightly higher diameter/dimensions were found near the base of the tree, while going towards the canopy, only small knots were detected.

At least 12-15 measurements were implemented on the areas of these 15 knots that were detected on the surface of the veneers (symbolized as knots a-o, going from the canopy to the base of the tree). These roughness measurements were implemented on the differentiated wood structure of knot area, and separately to a respective non-defect area located close to each knot. This approach of clean/defect wood structure pair-points of measurement was applied in order to eliminate the interactive influence of other factors on the surface roughness on different stem heights (the potential of not apparent presence of small injuries/infection/mechanical processing difference, or other cell biosynthesis factors, etc.), allowing the comparison between the roughness values of knot areas and non-defect areas.

All the 17 veneers could not be thoroughly measured (one by one), with such a detailed characterization, examining the 15 knot areas and 15 non-defect areas (x15 measurements on each area of 30 mm × 30 mm). Therefore, some initial measurements had been implemented on all of the 17 veneers to obtain a general idea on the veneers quality and roughness, and finally, we determined to measure thoroughly (as mentioned above) the 1st, 6th, 12th and 17th veneer collectively, in order to provide a representative image of the surface roughness of the whole package of these sliced veneers. In this way, the potential differentiation of roughness as a function of different wood depths on the areas of knot development was investigated. In parallel, attention has been paid to ensure the representativeness of the measurements and therefore the reliability of the results.

The surface roughness of the sliced veneers was examined applying a contact method over the object surface, using a "Mitutoyo Surftest SJ-301" fine stylus

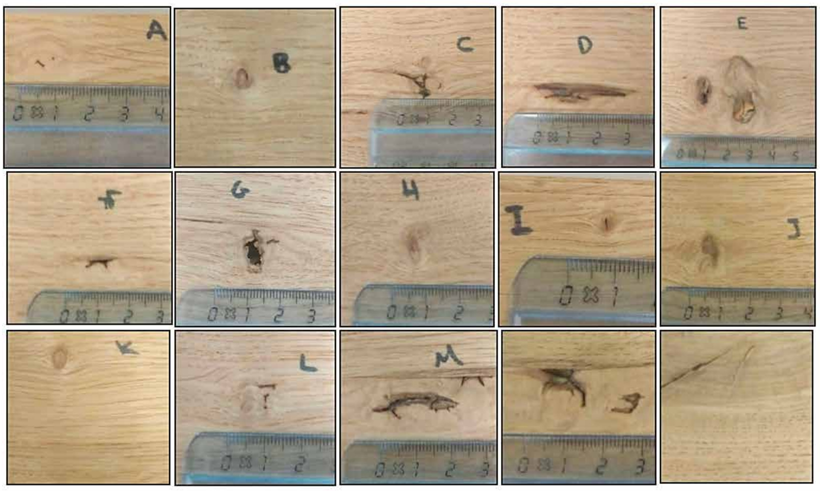
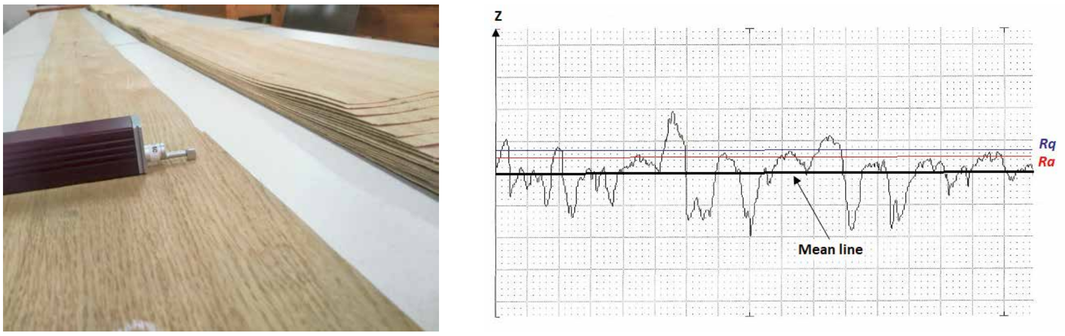


Figure 2 Configuration of 15 knots (a-o) detected on the surface of examined oak decorative veneers, going from canopy to tree base
Slika 2. Konfiguracija 15 kvrga (od a do o) otkrivenih na površini ispitivanih hrastovih dekorativnih furnira, dobivenih s područja od krošnje do baze debla



(a) (b)

Figure 3 Surface roughness characterization using a stylus-type profilometer instrument (a) and surface roughness parameters defined (b)
Slika 3. (a) Karakterizacija hrapavosti površine uz pomoć profilometra s trnom i (b) definirani parametri hrapavosti površine

type profilometer (Figure 3a) according to the standard ISO 4287:1997. This method was chosen as convenient, as it provids accurate results. The measuring speed, the diameter of the pin and the upper angle of the pin tool were 10 mm / min, 4 μm, and 90 °, respectively. The sampling length was of 2.5 mm, and the measurements were implemented in a direction perpendicular to the direction of grain orientation (in areas of clean wood structure).

Three roughness parameters, the mean arithmetic deviation of profile (*Ra*), the mean peak to valley height (*Rz*), and the maximum defect height indicator within the assessed profile, in other words the maximum roughness (*Rq*), were evaluated (Figure 3b). These 3 parameters have been previously used in literature (Budakci *et al*., 2013; Kamperidou and Barboutis, 2017; Li *et al*., 2018), as well employed in veneers roughness assessment (Mummery, 1993), and other wood-based composites. They are specified by the relevant standard ISO 4287:1997. Calibration was a necessary step, implemented before the operation of the profilometer using the calibration standard plate of the device (Mitutoyo 178-601 surface roughness standard), while the measurements were carried out at ambient conditions of (20±2) ºC) (Korkut *et al*., 2008; Korkut and Budakci, 2010).

2.3 Moisture content, density and growth rings width
2.3. Sadržaj vode, gustoća i širina goda

At the end of the measurements of each veneer, 6 specimens of dimensions 20 mm × 20 mm were cut from the edges of each studied veneer (defect-free structure of wood) to measure the veneer moisture content by applying the drying method of the veneer samples according to the respective methodology (ISO 13061-1:2014). The mean value of moisture content of the studied veneers at the time of measurements, which corresponds to the EMC value, was measured to be (9.8 ±0.4) %. For the dry mass measurement, a scale of high accuracy (4 decimals) was used, and for the volume determination, a digital caliper (Mitutoyo 500-196-30) of 0.0005”/0.01 mm resolution was used. On the above specimens, prepared for the moisture content measurement, the mean density of oak wood of 0.721 (± 0.09) g/cm3 was measured based on the respective standard methodology (ISO 13061-2:2014). The mean growth ring width of the examined sliced veneers was found to be (1.2±0.08) mm. This value corresponds to the mean value of measurements in three different points/heights of each veneer (in the middle of veneer length and in the 2 edges of each veneer). Afterwards, using a stereoscope (Nikon SMZ800, Nikon Instruments Inc., NY, USA), the abovementioned examined areas were magnified (X16) and then the growth rings width was recorded using the digital caliper.

2.4 Veneers heat treatment
2.4. Toplinska obrada furnira

After the implementation of the roughness measurements, the four studied veneers were cut in their middle, providing 2 pieces of smaller length (around 1530 mm). They were exposed to heat treatment at 110 ºC (Veneers V6 and V17 – one from the middle and one from the edge of package) and at 130 ºC (V1 and V12– one from the middle and one from the edge of package), in an atmosphere saturated with steam, at a pressure of around 1.5 atm (custom-made chamber, AUTh, Thessaloniki, Greece), for 2 hours from the moment of reaching the final conditions (maximum temperature/pressure). It took approximately 15 min to reach the final conditions inside the chamber at the beginning of the treatment, while at the end of the treatment, the veneer samples were kept for 15 min inside the chamber till the gradual decrease of temperature. Then, the veneers were conditioned till constant weight to EMC, and remained in the conditioning room till the time of roughness measurements (for around 2 weeks).

Both treatments had to be short and mild in order to try to improve the surface quality of these veneers and at the same time to avoid the intensive chemical changes that may take place due to thermal degradation (hemicelluloses, cellulose and lignin depolymerization) (Gonultas and Candan, 2018; Kamperidou, 2019), and the subsequent mechanical strength loss. After the implementation of these short-term hydrothermal treatments and a 2-week conditioning process of the treated veneers, the measurements of surface roughness were conducted again, on the same marked surface areas (30 mm × 30 mm) concerning both defect and non-defect areas, under the same conditions, following exactly the same methodology, in order to get comparable results.

2.5 Statistical analysis
2.5. Statistička analiza

For the statistical analysis of the results, the statistical package SPSS Statistics 25 was used to determine the variability of the mean values of roughness parameters, and the effect of two different independent variables, "Veneers" (referring to the different veneers from V1 to V17), and "Structure" (referring to the defect and non-defect area of wood), and the potential interaction of these two factors upon the dependent variable of roughness parameter *Ra,* chosen as the most commonly used in literature to assess surface quality (Gurau *et al*., 2017), using two way analysis of variance (ANOVA) with a significance level of 0.05 ($p < 0.05$). The homogeneity of variances of the results was tested by means of "Levene´s test of Equality of Error Variance" (the null hypothesis) (Levene, 1960).

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

The progress of roughness parameters (*Ra, Rz* and *Rq*) along the stem, measured following a direction from the canopy to the tree base, concerning areas of defect-free wood structure of the four examined veneers (V1, V6, V12, V17), is presented in Figure 4, 5 and 6.

As regards the roughness parameters along the stem measured on non-defect areas, from the canopy (a) to the tree base (o), even though some statistically significant differences were recorded from point to point among a-o points, a clear tendency of roughness increase or decrease was not depicted along the veneer from the canopy to the tree-base. This is a similar trend as reported for all the examined veneers (V1, V6, V12, V17). Therefore, despite the expected vertical wood structure variability, usually detected along the stems, and the fact that the vessel size may increase by a factor of 3 within the same oak stem (Leal *et al*., 2007),

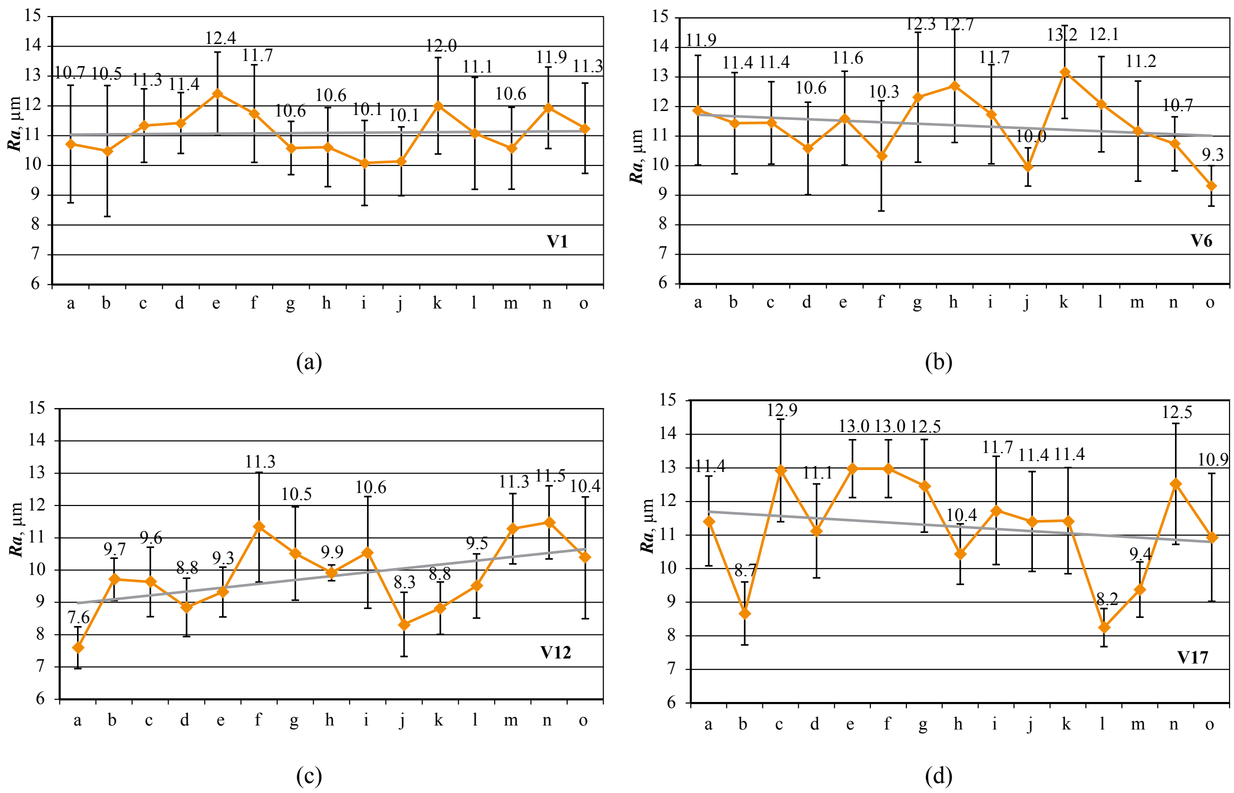


Figure 4 Progress of *Ra* roughness parameter (μm) along the stem, measured on typical structure areas, from the canopy to the lowest part of the tree base, on veneers of (a) V1, (b) V6, (c) V12 and (d) V17. The linear trend line is displayed in gray color.

Slika 4. Povećavanje parametra hrapavosti *Ra* i (μm) duž debla, mjereno na tipičnim strukturnim područjima, od krošnje do najnižeg dijela baze debla, na furnirima (a) V1, (b) V6, (c) V12 i (d) V17. Linija linearnog trenda prikazana je sivom bojom.

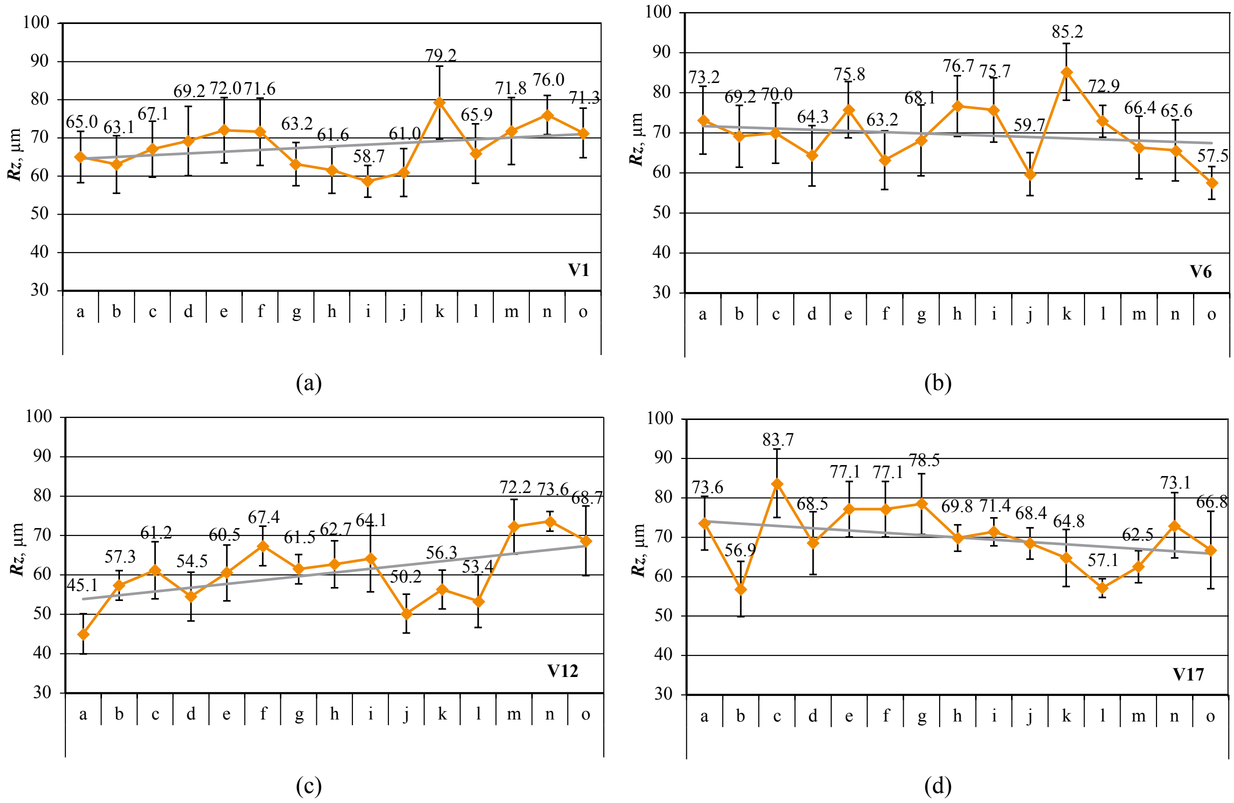


Figure 5 Progress of *Rz* roughness parameter (μm) along the stem, measured on typical wood structure areas, from the canopy to the lowest part of the tree base, on veneers of (a) V1, (b) V6, (c) V12 and (d) V17. The linear trend line is displayed in gray color.
Slika 5. Povećavanje parametra hrapavosti *Rz* i (μm) duž debla, mjereno na tipičnim strukturnim područjima, od krošnje do najnižeg dijela baze debla, na furnirima (a) V1, (b) V6, (c) V12 i (d) V17. Linija linearnog trenda prikazana je sivom bojom.

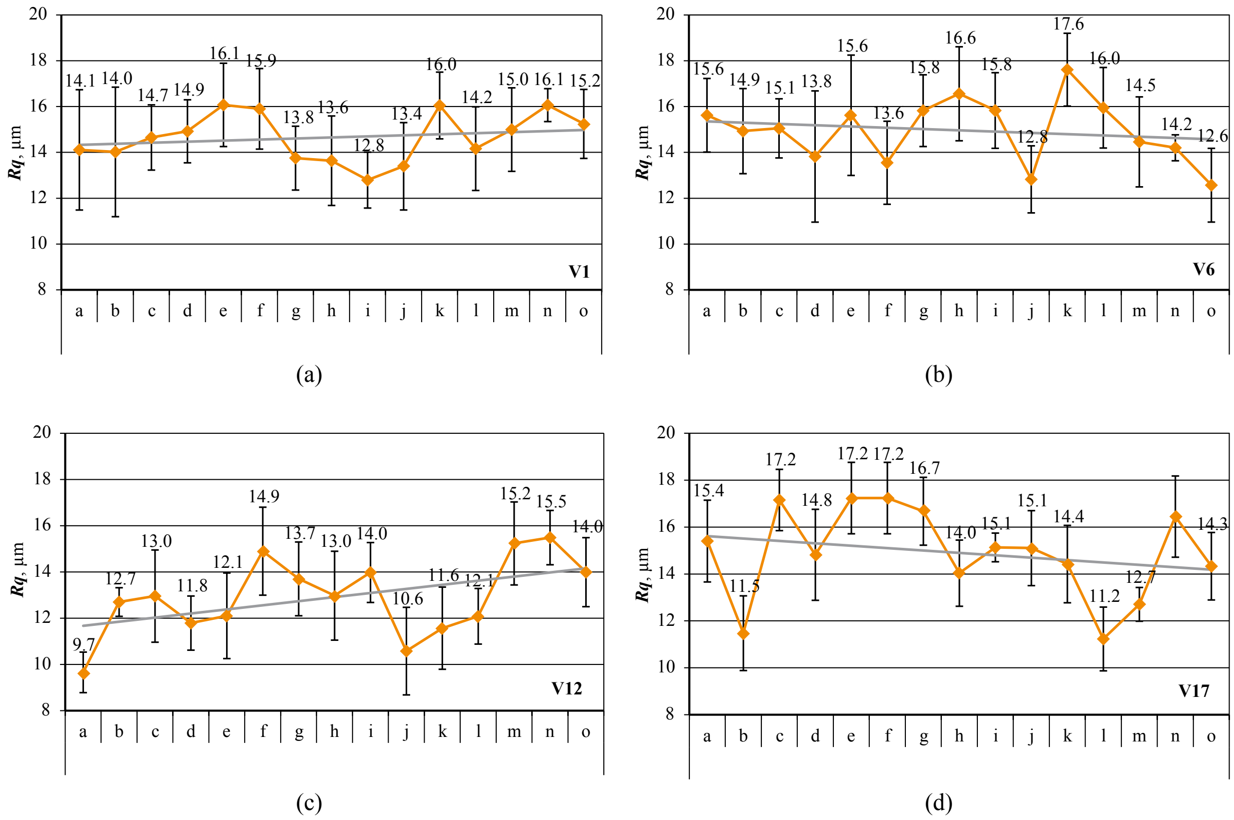


Figure 6 Progress of *Rq* roughness parameter (μm) along the stem, measured on typical structure areas, from the canopy to the lowest part of the tree base, on veneers of (a) V1, (b) V6, (c) V12 and (d) V17. The linear trend line is displayed in gray color.
Slika 6. Povećavanje parametra hrapavosti *Rq* (μm) duž debla, mjereno na tipičnim strukturnim područjima, od krošnje (a) do najnižeg dijela baze debla, na furnirima (a) V1, (b) V6, (c) V12 i (d) V17. Linija linearnog trenda prikazana je sivom bojom.

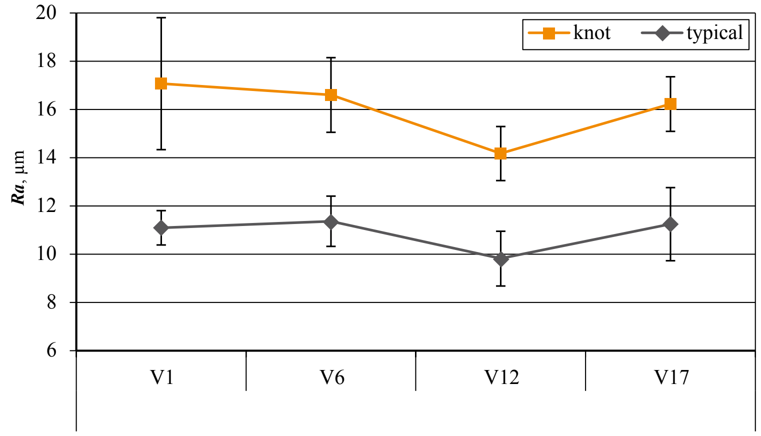


Figure 7 Mean values (μm) of roughness parameter (*Ra*) measured on 15 different points (a-o) along the stem of the examined veneers V1, V6, V12 and V17
Slika 7. Srednje vrijednosti (μm) parametra hrapavosti (*Ra*) izmjerene na 15 različitih točaka (a – o) duž debla, za ispitivane furnire V1, V6, V12 i V17

also increasing the surface roughness, similar surface quality and roughness was recorded along the veneer and the stem. This indicates that the variability of morphological characteristics usually detected on different stem heights was not sufficient to influence the roughness of the surfaces. This characteristic of roughness and quality uniformity in the surface of veneers could highly favor their performance and utilization.

Nevertheless, statistically significant differences were recorded between V12 and the other values of veneer roughness, with V12 to record the lowest surface roughness value, both on non-defect wood surfaces and knot areas (Figure 7) and the lowest standard deviation values compared to the rest of examined veneers. Veneer sheet V1 presented the highest roughness values. V1 and V17 were the first and last veneers of the package, respectively, and therefore their higher surface roughness could be partly attributed to the fact that they may have experienced some intensive changes of moisture content, during an earlier stage that preceded the experimental work, during their transfer or storage, that may have resulted in dimensional changes, which could have led to fibers detachment and to wilder/rougher surfaces.

According to Figures 8 and 9 that present the percentage of differences between roughness parameters *Ra, Rz* and *Rq* of defect-free wood structure veneer surfaces and defect-wood structure areas on/around the knots (a-o), it is obvious that concerning all the veneers and 14 out of 15 cases of knots examined, the surface roughness parameters were significantly lower, from a statistical point of view, than the respective values measured on defect-free wood structure surfaces very close to knot areas. This finding of lower roughness around the knots could be attributed mainly to the fact that in hardwoods, in the lower part of the knot, tensile wood usually appears. It can be recognized by its lighter color and higher gloss, a slightly higher axial shedding (up to 1.5 %), with more cells of smaller diameters, resulting in 2-20 % higher density of wood in these areas (Tsoumis, 2002; Dundar *et al*., 2008). Another factor contributing to the lower roughness, could be the fact that in these areas the fibers usually bear a gelatinous layer inside the fiber walls, which is rich in cellulose and of a high crystallinity degree. **Tensile** wood bears more fibers, and smaller and fewer vessels, as well as more rays. Therefore, the differences in density and structure of tensile wood areas may have a high impact on surface roughness (Tsoumis, 2002).

Another reason could be the presence, number and size of vessels found in defect-free wood structure surfaces of such a ring-porous species. Since the roughness measurements in the non-defect areas were conducted on an axis perpendicular to the grain, at least 2 growth rings were scanned by the stylus of the profilometer, taking into account the area of vessels. Lower roughness was also recorded in areas around the knot (till 20 mm), in the transition zone from knot to defect-free wood areas, where irregularities of annual rings or spiral grain phenomena were also present. This is of great importance for the performance of oak sliced veneer in various applications, since evidently these areas of spiral grain (surrounding the knot) are usually of a larger area than the knot itself.

It is observed that in V12, not only the lowest roughness parameters values were recorded on non-defect wood surface, but at the same time the highest difference between the surface roughness of the areas around the knots and the respective non-defect areas was detected (table 1). In V6 and V17, high differences of roughness were recorded between wood structure of non-defect areas and different wood structures on and around the knots areas, with knots (especially the small live knots) to constitute smoother areas compared to defect-free wood surfaces. Of course, in some cases of firm or loose knots (c, d, g, m, n), where a cavity had

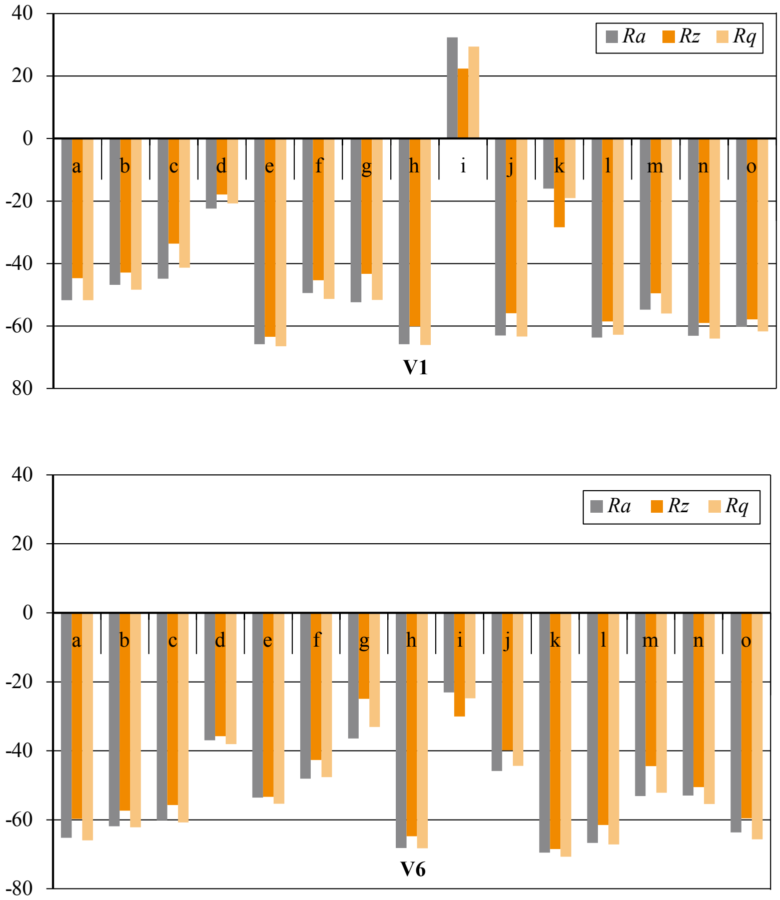


Figure 8 Percentage values depicting the decrease of roughness parameters (*Ra, Rz, Rq*) recorded on knot areas (a-o), compared to corresponding areas of non-defect surfaces in veneer V1 and V6
Slika 8. Postotne vrijednosti koje pokazuju smanjenje parametara hrapavosti (*Ra, Rz, Rq*) zabilježene na područjima s kvrgama (a – o) u usporedbi s odgovarajućim područjima bez kvrga na furniru V1 i V6

been generated because of a breaking knot or decay, especially in the case of large or dead knots, the resultant wood tissue discontinuity is proven detrimental to the surface quality, and the veneer requires special pretreatment, use of resin or substitution of the knot part with a non-defect veneer piece and sanding, thus also increasing the use of energy and cost of production. In case of veneer V1, as regards the defect-free wood structure surfaces, the highest surface roughness values were observed, even though without marking statistically significant difference, as well as the lowest roughness parameters difference values between defect-free wood structure and defect-wood structure (knot areas). This may be partly attributed to the potential frequent changes of relative humidity and the subsequent moisture absorption-desorption of wood during transport or storage that could deteriorate the surface quality of veneers, increasing the demands of sanding or the need of higher amounts of finishing, painting or adhesive agents applied to the surfaces. In this case, the necessity to protect the sliced veneers from frequent changes of climatic conditions would be highlighted.

The results of Levene's test (table based on two-way analysis of ANOVA, SPSS) showed that the null hypothesis cannot be rejected in a significance level of 0.05 (*p* value 0.213), and therefore the 6th requirement of ANOVA is fulfilled. The factor "Veneers" presented a statistically significant effect on surface roughness parameters, affecting their variability by 13 % (sig. 0.001). The factor of "Structure", referring to defect-free wood structure of non-defect areas or knot areas of different wood structure, demonstrated the statistically significant effect on roughness, marking an influence of 80.1 % on roughness variability (sig. 0.000). The interaction between these two factors, veneers and

Table 1 Mean percentage values depicting the decrease of roughness parameters *Ra, Rz* and *Rq* of defect areas, compared to respective non-defect wood structure veneer surfaces, recorded on examined veneers
Tablica 1. Srednje postotne vrijednosti koje pokazuju smanjenje parametara hrapavosti *Ra, Rz i Rq* na područjima s greškama u usporedbi s odgovarajućim područjima furnira bez grešaka strukture drva zabilježene na ispitivanim furnirima

Veneer / *Furnir*	*Ra*	*Rz*	*Rq*
V1	-45.82	-42.53	-46.33
V6	-53.67	-49.90	-54.08
V12	-55.50	-50.97	-55.62
V17	-54.90	-52.27	-56.02

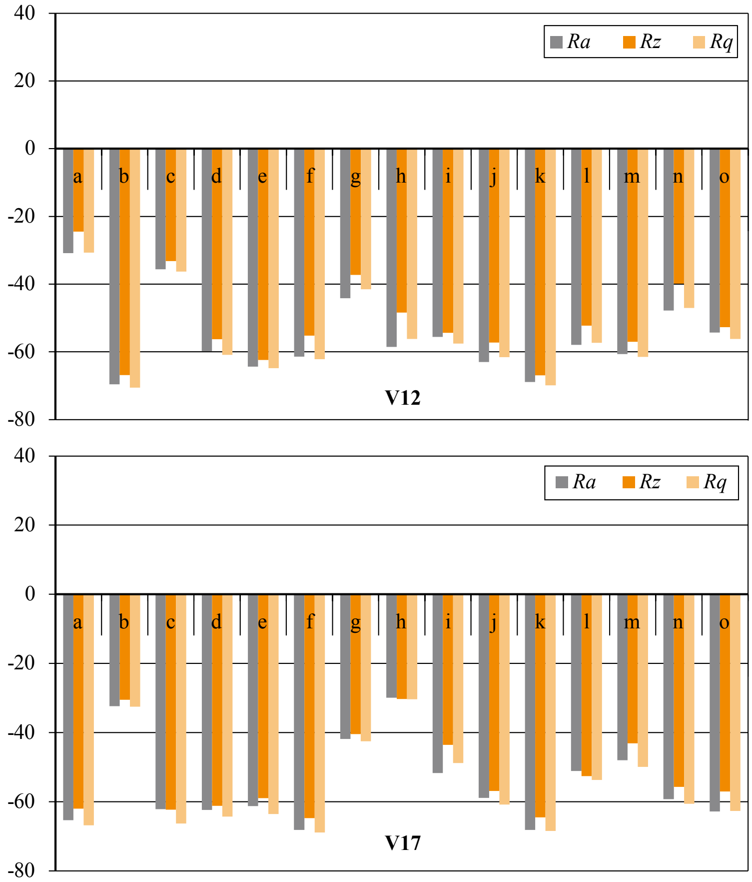


Figure 9 Percentage values depicting the decrease of roughness parameters (*Ra, Rz, Rq*) recorded on knot areas (a-o), compared to corresponding areas of non-defect surfaces in veneer V12 and V17
Slika 9. Postotne vrijednosti koje predočuju smanjenje parametara hrapavosti (*Ra, Rz, Rq*) zabilježene na područjima s kvrgama (a – o) u usporedbi s odgovarajućim područjima bez kvrga na furniru V12 i V17

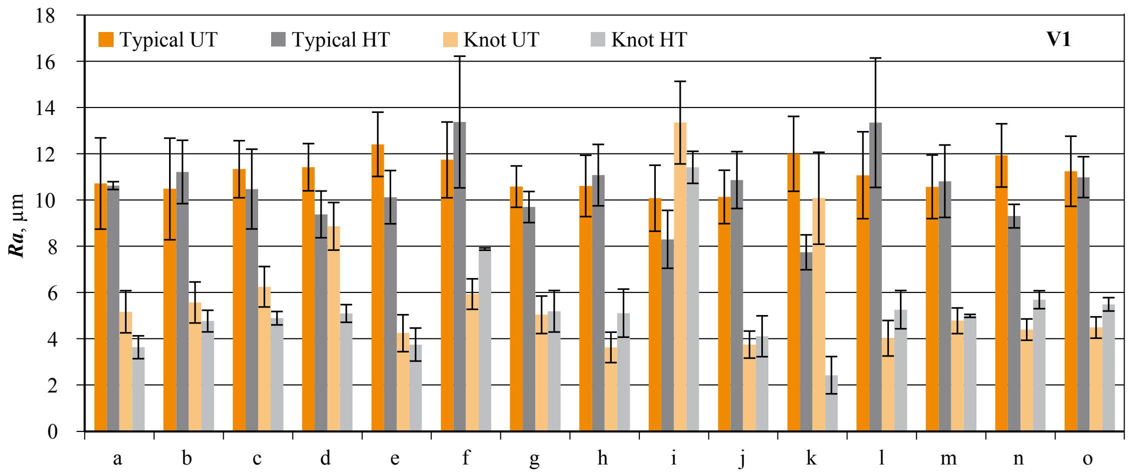


Figure 10 Mean values (µm) and respective standard deviation values of roughness parameter (*Ra*) measured on 15 different points (a-o) along the stem, concerning both knot areas and defect-free areas, on the surface of veneer V1, before (UT- untreated) and after (HT – treated) hydrothermal treatment (130 ºC-2h)
Slika 10. Srednje vrijednosti (µm) i odgovarajuće vrijednosti standardne devijacije parametra hrapavosti (*Ra*) izmjerene na 15 različitih točaka (a – o) duž debla, koje se odnose na područje s kvrgama i na područje bez grešaka, na površini furnira V1, prije hidrotermičke obrade (130 ºC, 2h) (UT – neobrađeno) i nakon obrade (HT – obrađeno)

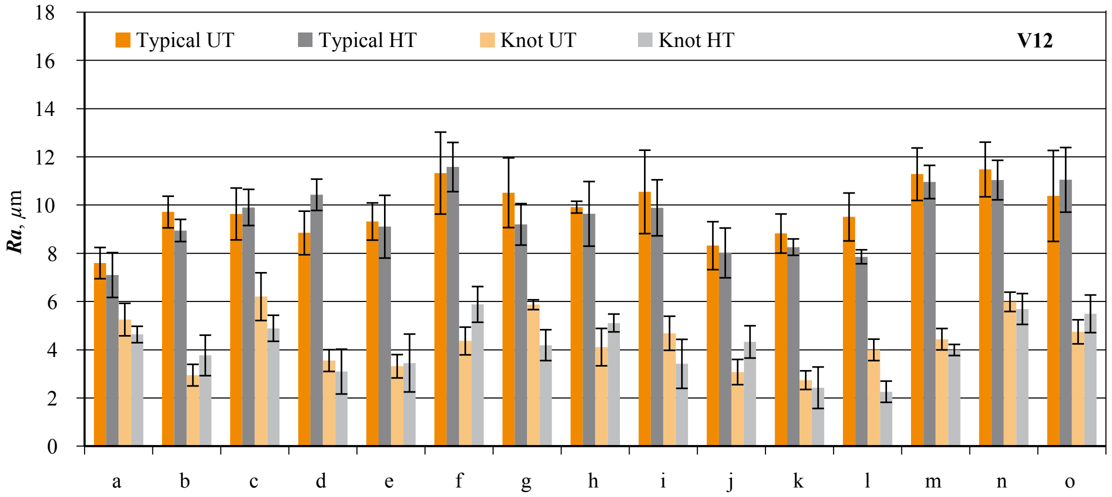


Figure 11 Mean values (μm) and respective standard deviation values of roughness parameter (*Ra*) measured on 15 different points (a-o) along the stem, concerning both knot areas and defect-free areas, on the surface of veneer V12, before (UT- untreated) and after (HT – treated) hydrothermal treatment (130 ºC-2h)
Slika 11. Srednje vrijednosti (μm) i odgovarajuće vrijednosti standardne devijacije parametra hrapavosti (*Ra*) izmjerene na 15 različitih točaka (a – o) duž debla, koje se odnose na područje s kvrgama i na područje bez grešaka, na površini furnira V12 prije hidrotermičke obrade (130 ºC, 2h) (UT – neobrađeno) i nakon hidrotermičke hidrotermičke obrade (HT – obrađeno)

structure, did not record a statistically significant impact on roughness parameters.

In an attempt to improve the surface quality of the oak sliced veneers and to investigate the response of both, defect-free wood structure areas and defect-areas, to the hydrothermal modification process, two short-term treatments were performed (max. temperature of 110 ºC and 130 ºC). According to the results, the hydrothermal treatment of 130 ºC did not show a clear tendency of impact (a negative or positive one) on the surface roughness of wood veneers, and in most of the cases, the recorded differences were not statistically significant, as demonstrated in Figures 10 and 11 for the veneers V1 and V12. It can be observed that in most of the cases, concerning both the non-defect and the defect-areas, the roughness of heat treated veneers was not found to differ significantly from the roughness values of the corresponding areas of untreated veneers.

The slightly milder hydrothermal treatment of 110 ºC, more favorable to the surface quality improvement of sliced veneers, was found in most of the study areas marking a statistically significant decrease of surface roughness in both wood structure of non-defect areas and defect areas, as presented in Figures 12 and 13 for veneers V6 and V17, respectively. This indicates that the hydrothermal modification could act beneficially on the surface quality (smoothness) of oak sliced veneers, only if it is applied at quite low temperatures (100-110 ºC) for short durations. This could be explained by the geometry and dimensions. To be specific, the very low thickness of the sliced veneers allows the entire cross-section to reach faster the temperature of the medium and therefore leaves the wood tissue vulnerable to thermo-degradation phenomenon and oxidative reactions. Treatments of higher intensity (higher temperatures or durations) can cause the loss of volatile extractives, generation of new extractives from the hydrolysis of polysaccharides or polymerization of some extractives, partial depolymerization of hemicelluloses and amorphous parts of cellulose, etc. also affecting the structure and surface properties of wood (Filipou, 2014; Kamperidou, 2019). However, according to the findings of Dudík *et al.* (2020), the heat treatment of birch wood veneers at 170 ºC, 190 ºC and 200 ºC (much higher temperatures than those applied in the present study), and duration of 1, 3, 5 hours, did not cause any significant negative or positive impact on the surface roughness of the veneers, but this different response could be probably attributed to the fact that the veneers were not sliced cut, but rotary cut, and were of different dimensions (500 mm x 500 mm, with thickness of 1.5 mm) than those of the present study. Concerning the surface roughness of thermally treated sawn wood/timber (assessed on samples of higher dimensions), most of the studies have revealed a decrease in surface roughness of wood after its exposure to heat treatment (Korkut and Budakci, 2010; Baysal *et al.*, 2014).

Thermal or hydrothermal modification process is made of cost-effective and environmentally-friendly treatments that provide many benefits to wood and wood-based products (veneers and others), such as improved dimensional stability, lower moisture absorption, increased biological durability, higher color homogeneity, etc. (Kamperidou, 2019). As regards the aesthetics of wood material, these treatments tend to darken wood and confer a reddish color that helps it to imitate more expensive exotic species. Concerning the

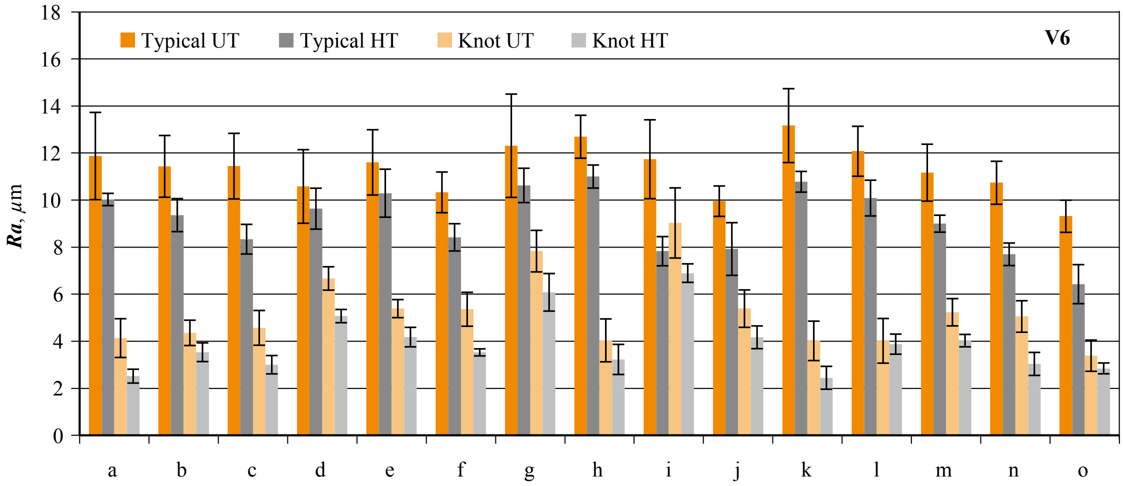


Figure 12 Mean values (μm) and respective standard deviation values of roughness parameter (*Ra*) measured on 15 different points (a-o) along the stem, concerning both knot areas and defect-free areas, on the surface of veneer V6, before (UT- untreated) and after (HT – treated) hydrothermal treatment (110 ºC-2h)

Slika 12. Srednje vrijednosti (μm) i odgovarajuće vrijednosti standardne devijacije parametra hrapavosti (*Ra*) izmjerene na 15 različitih točaka (a – o) duž debla, koje se odnose na područje s kvrgama i na područje bez grešaka, na površini furnira V6 prije hidrotermičke obrade (110 ºC, 2h) (UT - neobrađeno) i nakon hidrotermičke obrade (HT – obrađeno)

surface quality of wood, these treatments seem to enhance the smoothness of its surfaces (Korkut and Budakci, 2010; Baysal *et al*., 2014), even though the response of very thin sheets of wood, such as the sliced veneers, is not very clear. According to the findings of this experimental work, a mild hydrothermal treatment (around 100-110 ºC, for 2h) could improve significantly the surface quality of oak sliced veneers, decreasing the surface roughness of veneers, concerning both the wood structure of defect-free areas and the wood of defect areas. This response of the oak sliced veneers to hydrothermal treatment, presenting an enhanced smoothness in combination with the darkening of the surface color, could highly increase the range of applications of these products, allowing them to compete with other hardwoods of higher quality (mainly exotic) that have been preferably applied so far. Therefore, the issue of optimization of the hydrothermal treatment conditions, aiming to improve even more the surface quality of sliced veneers, is expected to attract high research interest and will be investigated thoroughly in the coming years. This paper provides the preliminary

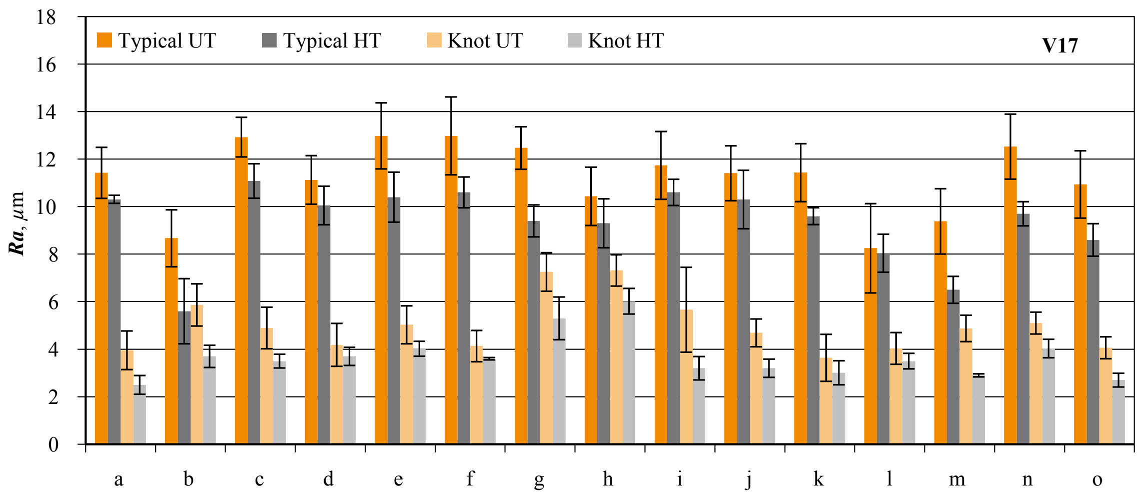


Figure 13 Mean values (μm) and respective standard deviation values of roughness parameter (*Ra*) measured on 15 different points (a-o) along the stem, concerning both knot areas and defect-free areas, on the surface of veneer V17, before (UT- untreated) and after (HT – treated) hydrothermal treatment (110 ºC-2h)

Slika 13. Srednje vrijednosti (μm) i odgovarajuće vrijednosti standardne devijacije parametra hrapavosti (*Ra*) izmjerene na 15 različitih točaka (a – o) duž debla, koje se odnose na područje s kvrgama i na područje bez grešaka, na površini furnira V17, prije hidrotermičke obrade (110 ºC, 2h) (UT – neobrađeno) i nakon hidrotermičke obrade (HT – obrađeno) results of a more extensive experimental work as part of a research project intended to be implemented in the years to come. The specific data provided will be expanded, taking into consideration all the mentioned approaches, and correlated to other crucial properties assessed (color, density, etc.). A more thorough analysis of the structure will also be made.

4 CONCLUSIONS
4. ZAKLJUČAK

Similar surface quality and roughness was found along the oak veneers and stem. This roughness uniformity highly favors their performance and utilization potential.

The significantly lowest surface roughness, referring both to non-defect areas and knot areas were recorded by veneer V12, obtained from the middle of the package, while the edge veneers of the package presented the highest roughness, highlighting the necessity of the sliced veneers to be protected from frequent changes of climatic conditions, from the production time till the final application. Smoothness was recorded in areas on and around the knots, as well as other defects relevant to knots, possibly attributed to the presence of tensile wood, higher density and wider growth rings. This reveals that the wood structure differences in the area of live knots, as well as in the transition zone from knot to defect-free wood areas, do not influence negatively the surface quality. Therefore, the veneers processing is not more demanding because of such defects. The required energy and the cost of veneer production do not increase, while the overall quality of the final products and productivity is not deteriorated. Therefore, veneers bearing several small/live knots or other defects could be considered as candidate material of high potential to be utilized in a wide range of applications, e.g. as table-tops, benches, floors, cupboards, wardrobe back side or front side surface, highlighting the unique natural appearance of wood in the structures.

A short hydrothermal treatment at low temperatures (100-110 °C) significantly favors the surface quality of oak sliced veneers, providing smoother surfaces concerning both defect-free areas and defect-areas of veneers. This could further increase the utilization potential of this product in applications where other exotic hardwoods have been traditionally used so far. Further research is highly recommended to comprehend thoroughly the impact of different defects on the surface properties of sliced veneers, to optimize the hydrothermal treatment conditions, as well as other surface modification methods, and to improve even more the surface quality, bonding strength and performance of the sliced veneers, and veneer-based composites.

5 REFERENCES
5. LITERATURA

1. Aydin, I.; Colakoglu, G.; Hiziroglu, S., 2006: Surface characteristics of spruce veneers and shear strength of plywood as a function of log temperature in peeling process. International Journal of Solids and Structures, 43 (20): 6140-6147. https://doi.org/10.1016/j.ijsolstr.2005.05.034
2. Bao, M.; Huang, X.; Zhang, Y.; Yu, W.; Yu, Y., 2016: Effect of density on the hygroscopicity and surface characteristics of hybrid poplar compreg. Wood Science and Technology, 62: 441-451. https://doi.org/10.1007/s10086-016-1573-4
3. Baysal, E.; Kart, S.; Toker, H.; Degirmentepe, S., 2014: Some physical characteristics of thermally modified Oriental-Beech wood. Maderas. Ciencia y tecnología, 16 (3): 291-298. DOI:10.4067/S0718-221X2014005000022
4. Bekhta, P.; Hiziroglu, S.; Shepelyuk, O., 2009: Properties of plywood manufactured from compressed veneer as building material. Materials & Design, 30 (4): 947-953. https://doi.org/10.1016/j.matdes.2008.07.001
5. Bekhta, P.; Sedliačik, J.; Tymyk, D., 2015: The effect of chemical treatment of wood veneer surfaces on their bondability. Acta Facultatis Xylologiae Zvolen, 57 (2): 71-79. https://doi.org/10.17423/afx.2015.57.2.07
6. Budakci, M.; Cemil Ilce, A.; Gurleyen, T.; Uter, M., 2013: Determination of the surface roughness of Heat-treated wood materials planed by the cutters of the horizontal milling machine. BioResources, 8: 3189-3199.
7. Coelho, C. L.; Carvalho, L. M. H.; Martins, J. M.; Costa, C. A. V.; Masson, D.; Meausoone, P. J., 2008: Method for evaluating the influence of wood machining conditions on the objective characterization and subjective perception of a finished surface. Wood Science and Technology, 42, 181-195. https://doi.org/10.1007/s00226-007-0166-1
8. Csanády, E.; Magoss, E.; Tolvaj, L., 2015: Surface roughness of wood. in quality of machined wood surfaces. Springer International Publishing: Cham, Switzerland, 2015; pp. 183-236. ISBN 978-319-22418-3
9. Dobrzynski, M.; Orlowski, K.; Biskup, M., 2018: Comparison of surface quality and tool-life of glulam window elements after planing. Drvna industrija, 70 (1): 7-18. https://doi.org/10.5552/drvind.2019.1741
10. Dudík, R.; Boruvka, V.; Zeidler, A.; Holecek, T.; Riedl, M., 2020: Influence of site conditions and quality of birch wood on its properties and utilization after heat treatment. Part II: Surface properties and marketing evaluation of the effect of the treatment on final usage of such wood. Forests, 11: 556. https://doi.org/10.3390/f11050556
11. Dundar, T.; Akbulut, T.; Korkut, S., 2008: The effects of some manufacturing factors on surface roughness of sliced Makoré (*Tieghemella heckelii Pierre* Ex A. Chev.) and rotary-cut beech (*Fagus orientalis* L.) veneers. Building and Environment, 43 (4): 469-474. https://doi.org/10.1016/j.buildenv.2007.01.002
12. Faust, T. D., 1987: Real time measurement of veneer surface roughness by image analysis. Forest Products Journal, 37: 34-40.
13. Gonultas, O.; Candan, Z., 2018: Chemical characterization and FTIR spectroscopy of thermally compressed eucalyptus wood panels. Maderas. Ciencia y tecnología, 20 (3): 431-442. http://dx.doi.org/10.4067/S0718-221X2018005031301
14. Gűndűz, G.; Korkut, S.; Korkut, D. S., 2008: The effects of heat treatment on physical and technological proper-

ties and surface roughness of Camiyanı Black Pine (*Pinus nigra* Arn. subsp. pallasiana var. pallasiana) wood. Bioresource Technology, 99: 2275-2280. https://doi.org/10.1016/j.biortech.2007.05.015
15. Gurau, L.; Irle, M.; Campean, M.; Ispas, M.; Buchner, J., 2017: Surface quality of planed beech wood (*Fagus sylvatica* L.) thermally treated for different durations of time. BioResources, 12 (2): 4283-4301. https://doi.org/10.15376/biores.12.2.4283-4301
16. Small ClearWood Specimens. Part 2: Determination of Density for Physical and Mechanical Tests; ISO: Geneva, Switzerland.
17. ***ISO 4287: 1997: Geometrical Product Specifications (GPS) – Surface Texture: Profile Method-Terms, Definitions and Surface Texture Parameters; ISO: Geneva, Switzerland.
18. Kamperidou, V.; Aidinidis, E.; Barboutis, I., 2020: Impact of structural defects on the surface quality of hardwood species sliced veneers. Applied Sciences, 10 (18): 6265. https://doi.org/10.3390/app10186265
19. Kamperidou, V., 2019: Biological durability of thermally and chemically modified black pine and poplar wood against basidiomycetes and mold action. Forests, 10 (12):1-18. https://doi.org/10.3390/f10121111
20. Kamperidou, V.; Barboutis, I.; Vasileiou, V., 2012: Effect of thermal treatment on colour and hygroscopic properties of poplar wood. In: Proceedings of 23rd International Scientific Conference: Wood is Good – With Knowledge and Technology to a Competitive Forestry and Wood Technology Sector, Proceedings, Zagreb, Croatia, pp. 59-67.
21. Kamperidou, V.; Barboutis, I., 2017: Mechanical strength and surface roughness of thermally modified poplar wood. PRO Ligno, 13: 107-114. (online). http://www.proligno.ro/en/articles/2017/201704.htm (Accessed Dec. 30, 2017)
22. Korkut, D. S.; Korkut, S.; Bekar, I.; Budakçı, M.; Dilik, T.; Çakıcıer, N., 2008: The effects of heat treatment on the physical properties and surface roughness of turkish hazel (*Corylus colurna* L.) wood. International Journal of Molecular Sciences, 9 (9): 1772-1783. ttps://doi.org/10.3390/ijms9091772
23. Korkut, S.; Budakci, M., 2010: The effects of high-temperature heat-treatment on physical properties and surface roughness of Rowan (*Sorbus aucuparia* L.) wood. Wood Research, 55: 67-78. (online9. http://www.woodresearch.sk/wr/201001/08.pdf (Accessed Oct. 30, 2010)
24. Leal, S.; Sousa, V. B.; Pereira, H., 2007: Radial variation of vessel size and distribution in cork oak wood (*Quercus suber* L.). Wood Science and Technology, 41 (4): 339. https://doi.org/10.1007/s00226-006-0112-7
25. Levene, H., 1960: Robust tests for equality of variances. In: Ingram Olkin; Harold Hotelling *et al*. (eds.). Contributions to Probability and Statistics: Essays in Honor of Harold Hotelling. Stanford University Press. pp. 278-292.
26. Li, G.; Lv, Z.; Liu, Z., 2015: A preliminary study on the main mechanical properties of the high moisture content wood after finger-jointed. Journal of Northwest University, 30: 224-227.
27. Li, G.; Wu, Q.; He, Y.; Liu, Z., 2018: Surface roughness of thin wood veneers sliced from laminated green wood lumber. Maderas. Ciencia y tecnología, 20 (1): 3-10. http://dx.doi.org/10.4067/S0718-221X2018005001101
28. Li, X.; Liu, Y.; Yu, H.; Li, J., 2010: Evaluation of the surface roughness of wood-based environmental materials and its impact on human psychology and physiology. Advanced Materials Research, 113-116. https://doi.org/10.4028/www.scientific.net/AMR.113-116.932
29. Mummery, L., 1993: Surface texture analysis; Hommelwerke: Muhlhausen, Germany, pp. 106.
30. Peng, X.; Zhang, Z., 2019: Surface properties of different natural precious decorative veneers by plasma modification. European Journal of Wood and Wood Products, 77: 125-137. https://doi.org/10.1007/s00107-018-1355-3
31. Pinkowski, G.; Krauss, A.; Piernik, M.; Szymański, W., 2016: Effect of thermal treatment on the surface roughness of scots pine (*Pinus sylvestris* L.) wood after plane milling. BioResources, 11 (2): 5181-5189. https://doi.org/10.15376/biores.11.2.5181-5189
32. Sandak, J.; Orlowski, K.; Sandak, A.; Chuchala, D.; Taube, P., 2020: On-Line measurement of wood surface smoothness. Drvna industrija, 71 (2): 193-200. https://doi.org/10.5552/drvind.2020.1970
33. Tanritanir, E.; Hiziroglu, S.; As, N., 2006: Effect of steaming time on surface roughness of beech veneer. Building and Environment, 41 (1): 1494-1497. https://doi.org/10.1016/j.buildenv.2005.05.038
34. Tsoumis, G., 2002: Wood Science and Technology, Wood Structure and Properties. Aristotle University of Thessaloniki. AUTh, Thessaloniki, pp.346.
35. Vassiliou, V.; Barboutis, I.; Kamperidou, V., 2016: Strength of corner and middle joints of upholstered furniture frames constructed with black locust and beech wood. Wood Research, 61 (3): 495-504.
36. Wang, B.; Chunping, D.; Ellis, S., 2006: Veneer surface roughness and compressibility pertaining to plywood/LVL manufacturing. Part I: Experimentation and implication. Wood and Fiber Science, 38 (3): 535-545.
37. Yu, X.; Xu, D.; Sun, Y.; Geng, Y.; Fan, J.; Dai, X.; He, Z.; Dong, Y.; Li, Y., 2020: Preparation of wood-based panel composites with poplar veneer as the surface layer modified by In-Situ polymerization of active monomers. Forests, 11 (8): 893. https://doi.org/10.3390/f11080893
38. Zhao, X.; Guo, P.; Zhang, Z.; Yang, Y.; Zhao, P., 2020: Wood density, anatomical characteristics, and chemical components of alnus sibirica used for industrial applications. Forest Products Journal, 70 (3): 356-363. https://doi.org/10.13073/FPJ-D-20-00006
39. ***ISO 13061-1, 2014: Physical and Mechanical Properties of Wood – Test Methods for Small ClearWood Specimens. Part 1: Determination of Moisture Content for Physical and Mechanical Tests; ISO: Geneva, Switzerland.
40. ***ISO 13061-2, 2014: Physical and Mechanical Properties of Wood – Test Methods for small clear wood specimens — Part 2: Determination of Density for Physical and Mechanical Tests; ISO: Geneva, Switzerland.

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