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Study on the in-process measurements of the surface roughness of Douglas fir green veneers with the use of laser profilometer

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Abstract

The presented research concerns the use of a laser profilometer to measure the surface roughness of green Douglas fir heartwood veneers during the peeling process. It investigates the effect of various process parameters on the surface quality. Three experiments were carried out with a single variable factor for each experiment: log centration, soaking temperature and cutting speed. Moreover, the origin of the surface roughness of Douglas fir green veneers was investigated. The study shows that laser profilometer seems to be a useful equipment in online measurement of surface roughness of green veneers. Based on the experiment results it was stated that surface roughness of Douglas fir veneers is characterized by large differentiation depending on the location on the veneer. The performed analysis shows that the surface roughness of Douglas fir green veneer could be improved when using relatively high cutting speed, not too high steaming temperature and logs with a centered core. The presented study shows that the laser profilometer can be effectively applied to the measurement and evaluation of green veneers during the peeling process and that there is still an area to develop this methodology.

1 Introduction

Roughness is one of the most frequently used parameters in the analysis of the quality of wood surface. In veneer production, the surface roughness, beside lathe check occurrence and thickness variation, can be a proper indicator of veneer quality. Roughness of the veneers is important mainly in case of their further processing, especially in production of plywood and LVL. It has been previously stated that surface roughness has a significant effect on the gluing ability of veneers, glue consumption, penetration of adhesive into the veneer, and bonding strength of veneer products. Sogutlu (2017) found that the lower the roughness of wood, the lower is the glue consumption. Faust and Rice (1986) reported that adhesive strength is up to 30% higher for veneers with a smooth surface than with a rough surface. DeVallance et al. (2007) tested gluebond quality of Douglas fir plywood showing that the percent wood failure can be increased by reducing veneer roughness. Neese et al. (2004) conducted similar experiments and noticed the same dependence. Improving the quality of veneer surface can be done by conducting additional technological processes such as sanding or veneer densification (Candan et al. 2010; Bekhta et al. 2017), which allow obtaining better veneer properties, among others lower surface roughness (Diouf et al. 2011; Bekhta et al. 2014). However, in industrial process monitoring of the surface roughness during the peeling process and decreasing the roughness to the optimal level by appropriate selection of technological parameters can be necessary to obtain an acceptable surface quality.

The effects of pre-treatment and peeling parameters, such as cutting speed, soaking temperature, soaking time, clearance angle, etc. on the surface quality of veneers are considerable, but still not precisely understood, especially in terms of differentiation in structure and properties of different wood species. Tanritanir et al. (2006) stated that the steaming time has a significant effect on the surface roughness of beech veneers. Dundar et al. (2008b) completed similar experiments and demonstrated that the soaking time increased the surface roughness of beech veneers peeled from heartwood. Rohumaa et al. (2016) investigated the effect of the soaking temperature on the surface quality of birch veneers showing that too low soaking temperature

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(20 °C) causes high surface roughness of the loose side of veneers. Aydin et al. (2006) carried out research on a similar subject showing that surface roughness of spruce veneers obtained from the log with a temperature of 52 °C was lower than when the log temperature was 32 °C.

In case of Douglas fir, which is a highly heterogenous species (Echols 1973; Vonnet et al. 1985), property selection of soaking and peeling parameters may have a crucial influence on the product quality. Corder and Atherton (1963) used air-flow arrangement to measure surface roughness of veneers. The authors stated that an increase in the temperature of logs during the peeling process increased the surface roughness of Douglas fir veneers peeled from sapwood, and they reported that the optimal temperature of wood is 60 °C. Dupleix et al. (2013) also noted that soaking temperature has an effect on the lathe check distribution and depth. On the other hand, Hecker (1995a) found that the boiling time and the log temperature do not have a significant effect on the surface roughness, but it depends significantly on moisture content of wood during the peeling process. The author also showed that the surface roughness is higher for heartwood than for sapwood, what is directly connected to moisture content. The author used the contact stylus method to measure the surface roughness. However, most of the articles described above concern dry veneers. According to the authors` knowledge, there is no research on the surface roughness of green veneers, mainly because the stylus method of roughness measurement, which is most commonly used, is useless in green veneer evaluation, in particular in the case of continuous measurements.

Generally, methods of surface roughness measurement can be split into two categories: contact and non-contact. Methods from the first category are the most frequently used ones, and they are common in laboratory measurements, in particular for solid wood products (Kilic et al. 2006; Thoma et al. 2015), but also for wood veneers (Tanritanir et al. 2006; Dundar et al. 2008a; Candan et al. 2010; Bekhta et al. 2014). The main weakness of this approach is the contact between the fibers and the stylus, especially for fuzzy surfaces. The second category concerns mainly optical and laser scanning methods (Lundberg and Porankiewicz 1995; Sandak et al. 2004). Previous research, conducted in recent years, showed that these methods have larger potential for the use in wood processing than contact methods, in particular in on-line measurement of the surface roughness in manufacturing lines. A comparison of stylus and optical methods was done by Funck et al. (1993). Sandak and Tanaka (2003) showed that using a laser profilometer to measure roughness allows obtaining proper images of wood surfaces. Therefore, this solution can be applied to monitor and evaluate the surface roughness of veneers during the peeling process. Goli and Sandak (2016) used laser profilometer and optical camera to evaluate and image the surface of machined wood and proposed a method for automated assessment of the surface quality. It is assumed that only an optical measuring system can be relevant to measure online green veneer surface roughness, which is required to be able to adapt both steaming temperature and peeling process settings. This is especially true for wood species known to produce fuzzy surfaces due to the Horner effect as Douglas fir does (Mothe 1988). This phenomenon is perfectly described in Thibaut et al. (2016). According to the authors, a bundle of material is compacted ahead of the tool tip until separation can occur with small cracks above and beneath the cutting direction together with a quick swelling back of the bundle, as in the movement of an accordion. This was called the Horner effect. This phenomenon is occurring because of the low wood density of Douglas fir early wood especially when the logs were previously soaked or steamed.

The aim of this study was to use a laser profilometer to measure the surface roughness of thigh side of green Douglas fir (*Pseudotsuga menziesii*) heartwood veneers during the peeling process. The loose side of the veneer is highly influenced by the lathe check phenomenon and both surfaces are sensitive to cutting quality. It was assumed that the thigh side of the veneer was enough to measure the veneer surface quality. The effect of soaking temperature, log centration and cutting speed on green veneer surface roughness was investigated. Moreover, the origin of the surface roughness of Douglas fir veneers was analyzed.

This species represents a great potential to produce plywood or LVL panels in France. According to the authors` best knowledge, even if Douglas fir is one of the most peeled species in the world, there is no objective characterization of veneers by optical measurements.

2 Materials and methods

2.1 Peeling process

Green Douglas fir logs (*Pseudotsuga menziesii*) were sawn into six 800 mm length logs. Prior to peeling, all logs were soaked for 48 h in hot water to insure reaching 60 °C at the log’s core. Veneers were produced in LaBoMaP (ENSAM, Cluny, France) by a rotary peeling process using SEM S500 instrumented peeling machine.

Three experiments were carried out and analyzed separately, with one variable factor in each experiment: log centration with two logs from Matour (France), soaking temperature with two logs from St Germain la Montagne (France) and cutting speed with two logs from Matour (France). In total, 5 logs were peeled during the study. The peeling process parameters for each experiment are presented in Table 1. The edge angle of the cutting knife was 21° and the clearance angle was in the range of 0°–1°. All

Table 1 Parameters of the peeling processes carried out in this study

Variable factor	Process parameters		
	Soaking temperature (°C)	Cutting speed (m/s)	Log centration
Log centration	65	2	Centered/non-centered
Soaking temperature	55/80	2	Centered
Cutting speed	65	1 and 2	Centered

logs were peeled without the angular pressure bar. According to previous test, the Horner effect is highly penalizing the final veneer quality when using the angular pressure bar since bundles of fibers stay stacked to the tools creating local veneer thickness variation. Veneer thickness was 3 mm in all analyzed cases.

Non-centered log for the first experiment was prepared from a tree with the core located slightly non-centered. The procedure of preparing the log is presented in Fig. 1.

2.2 Surface roughness measurement

Surface roughness of the veneers was measured using LJ-V7080 laser profilometer (Keyence, Itasca, IL, USA). Repeatability in Z-axis was 0.5 µm. The profilometer was installed in the peeling line 85 mm above the moving veneer. Data obtained from the profilometer were filtered to eliminate waviness of the profile using the high-pass filter with the cut-off length of 8 mm. This value has been chosen based on ISO 4288 (1996), which says that if R_a is in the range of 10–80 µm, then the cut off length should be 8 mm. To filter and treat the data, Python with NumPy and Matplotlib packages in PyCharm software (JetBrains, Prague, Czech Republic) was used. An example of filtering results of veneer with a length of 1 m is shown in Fig. 2.

The surface roughness parameters were calculated in accordance with ISO 4287 (1997). The arithmetic mean surface roughness (R_a) and the maximum height of the profile (R_z) parameters were used. The reason for using these parameters is that R_a is the most commonly used indicator in the research on surface roughness of wood (Aydin et al. 2006; Tanritanir et al. 2006; Dundar et al. 2008b; Rohumaa et al. 2016), while R_z parameter allows to analyze the structure of wood, which contains deep cavities (Csanády and Magoss 2013). Roughness parameters were calculated using the following equations:

$$R_a = \frac{1}{l_m}\int_0^{lm} |z(x)| * dx \; [\mu\text{m}] \tag{1}$$

$$R_z = \frac{1}{5} * \left(Z_1 + Z_2 + Z_3 + Z_4 + Z_5\right) \; [\mu\text{m}] \tag{2}$$

The length of the measuring path l_m was 40 mm. Z_{1-5} is the distance between the highest peak and the deepest valley in the elementary section l_e of the measuring path, which amounted to 8 mm. Roughness parameters were calculated on 10 lines from the middle part of the measuring section. Then, for each measuring path l_m, mean values of R_a and R_z from 10 measuring lines were calculated, as presented in Fig. 3. Distance between each line was 0.1 mm, so 1 mm width area was analyzed.

The calculation of the mean values from 10 middle sections of the measuring area helps getting representative information about the surface, which is mainly constituted of tracheids perpendicular to the measuring direction (see Fig. 5). Variability of the roughness is considerably higher in the measuring direction (veneer length in Fig. 3). However, the longitudinal variability may also affect the final results of the surface roughness. Figure 4 presents the roughness measurements of a 1 m veneer length. Each point on the graph represents R_a on the measuring path l_m (40 mm), obtained from the 10 middle sections of the profile in accordance with the method described above. The presented standard deviation represents the variability of R_a on each l_m from 100 measuring sections, so from 10 mm width part of the veneer.

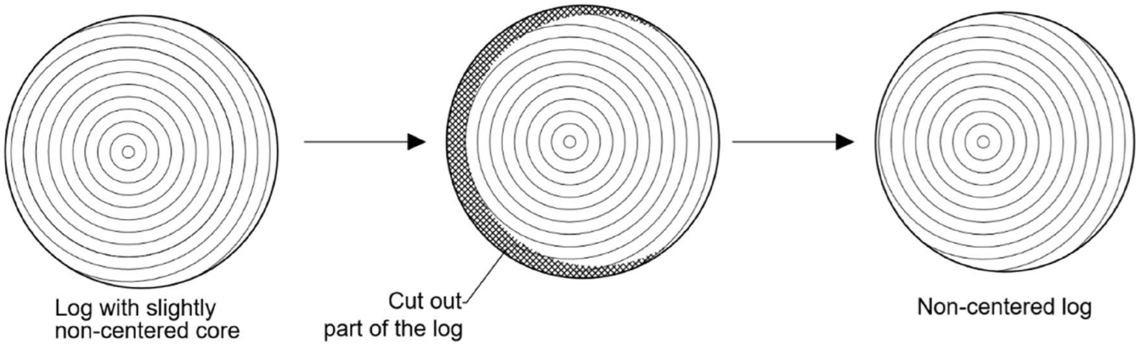

Fig. 1 Procedure of preparing non-centered log for the first experiment

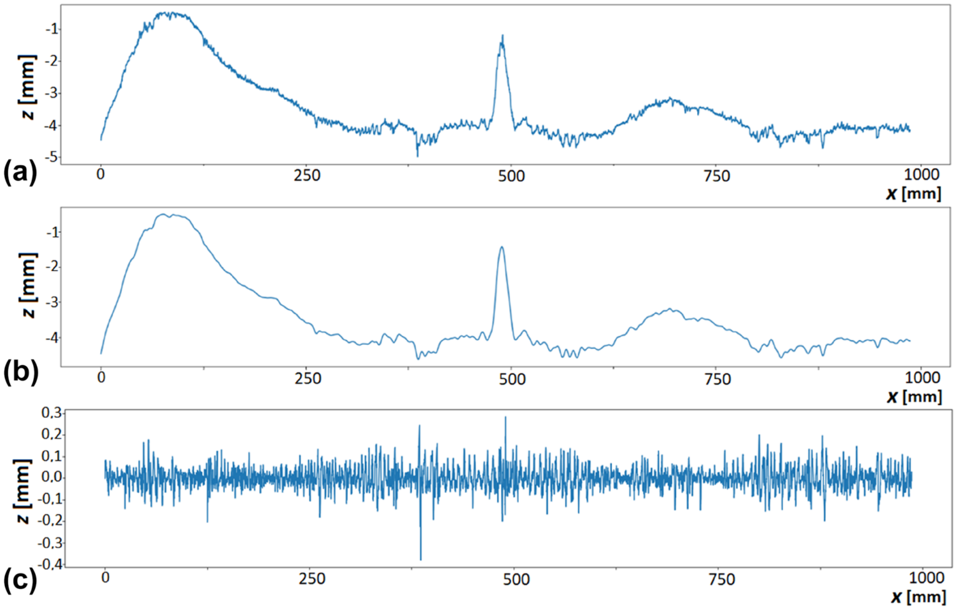

Fig. 2 An example of filtering results of the surface profile: **a** unfiltered surface profile (direct profile), **b** waviness profile of the surface, **c** roughness profile of the surface

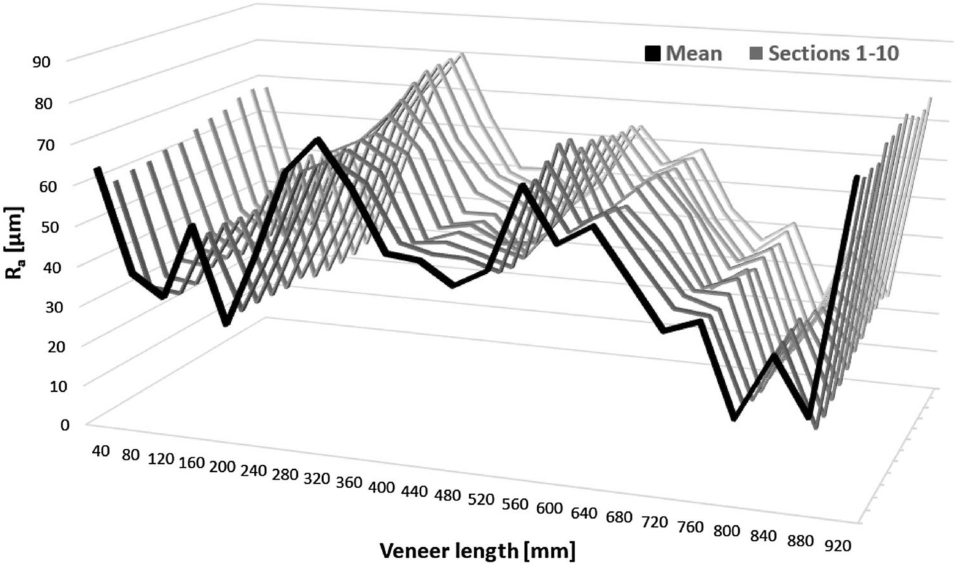

Fig. 3 Sections of the surface roughness measurement with calculated mean line in a band on 1 mm width

Veneer variability in the grain direction is not negligible. Standard deviation was higher especially when values of R_a were also high. More precisely, earlywood seems to present the roughest surfaces.

The attempt to evaluate surface roughness of veneers using three dimensional parameters (3D surface map), as proposed by Goli and Sandak (2016) for solid wood machining, seems to be an article-relevant approach.

For each analyzed log, 125 measurements of roughness parameters from the last part of the veneer were analyzed. This part of the veneer was produced with stabilized cutting conditions (neither at the beginning nor at the end of the ribbon). In total, 5 m of veneer from each log was analyzed. Analysis was conducted only on the last 5 m of the veneer in order to analyze only a heartwood and thus avoid the effect of a sapwood on the results, which could perturb interpretation of the experiment.

In order to establish significant dependences between the results, the unequal variance t-test was completed at the significance level of $\alpha = 0.05$. Statistical analysis and calculation of statistical indicators was done in Excel software (Microsoft, Redmond, WA, USA).

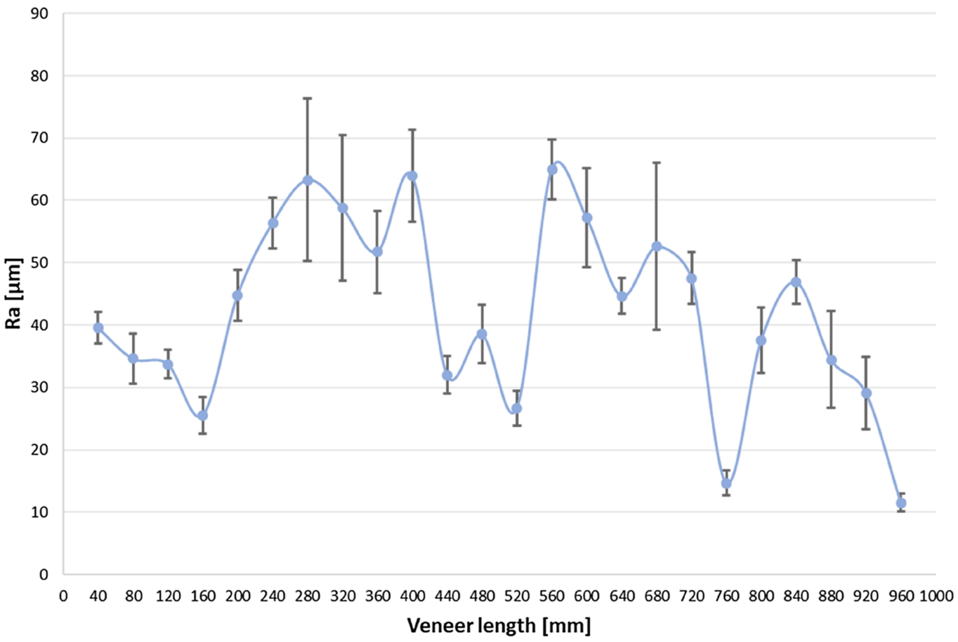

Fig. 4 Results of R_a measurement on one veneer. Each point represents mean from 10 measuring sections and standard deviation shows variability of 100 measuring sections

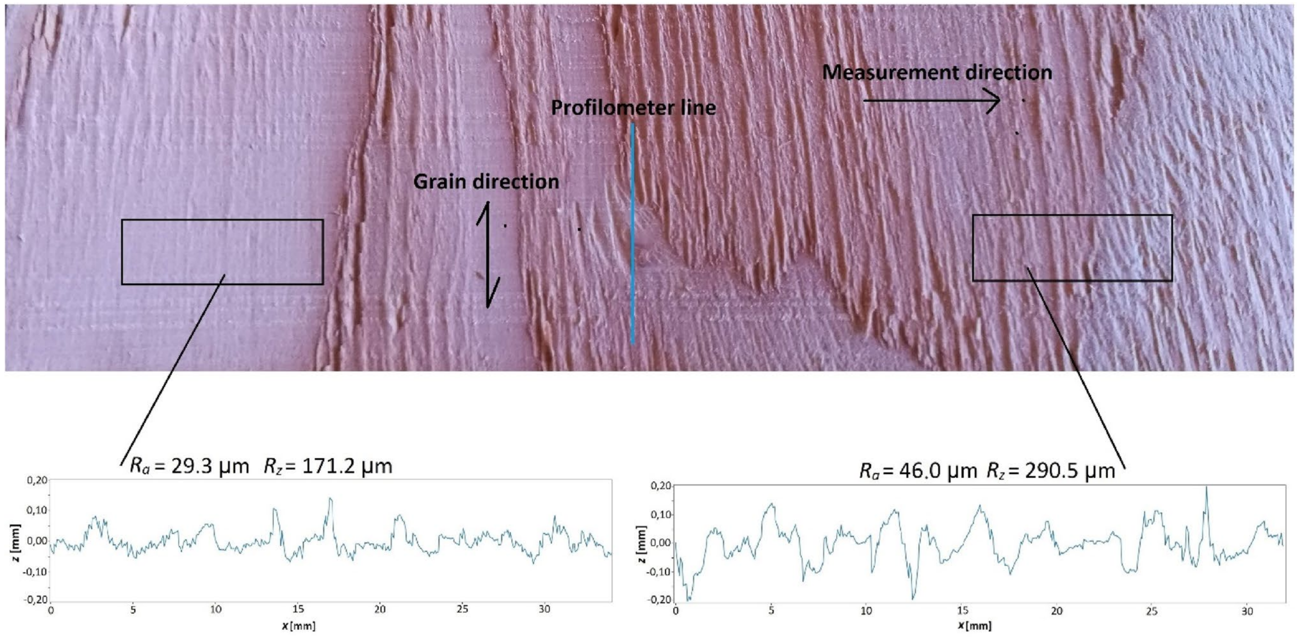

Fig. 5 An example of latewood (left) and earlywood (right) surface, roughness profiles and values of roughness parameters of the veneer

3 Results and discussion

3.1 The origin of the surface roughness of Douglas fir green veneers

The surface roughness of Douglas fir green veneers peeled from heartwood is characterized by high variability. In some parts of the veneer, the surface is very wavy and consisted of regular high peaks and deep cavities, which occurred most often in earlywood. This phenomenon can be seen on the image of the surface in Fig. 5. In the earlywood part, the surface is rough and big differences between the highest and the deepest points exist. The opposite dependence occurs in latewood, where the surface is smooth and roughness parameters are lower by over 50%.

The presented image shows that the structure of the surface and values of roughness parameters may be considerably different for different areas of the veneer. The explanation of this feature is a different structure and properties of early- and latewood, such as density and structure of cells.

Another element of wood characteristics affecting the surface roughness of veneers are knots. Generally, knots decrease the quality of veneers, because they cause deterioration in mechanical properties of veneer-based boards, such as LVL and plywood. They also have a negative effect on the product aesthetics. Therefore, they are not desirable in veneer manufacturing. In case of the surface roughness, knots may have various effects, depending on their type. The intergrown knots may decrease the surface roughness, because of their higher density. An example of such case is shown in Fig. 6. However, except for intergrown knots, there are other types, for example, encased or decayed knots, which may negatively affect the surface roughness and decrease the quality.

3.2 The effect of process parameters on the surface roughness of green veneers

Table 2 Results of roughness parameters of centered and non-centered logs

	Centered log		Non-centered log	
	R_a	R_z	R_a	R_z
Average (µm)	29.8	154.8	46.8	246.1
Standard deviation (µm)	12.5	55.7	19.8	102.7
Variance	156.3	3102.3	393.8	6398.8
Coefficient of variation (%)	42.0	36.0	42.4	41.7
Normalized kurtosis	1.59	0.76	− 0.90	− 0.58
Skewness	0.95	0.58	0.35	0.51

Table 2 contains statistical indicators of R_a and R_z parameters for centered and non-centered logs. Significant variation of indicators can be observed for each parameter (from 36 to 43%), which could be attributed to the heterogeneous structure of Douglas fir. It has been previously reported that factors such as ring widths, density of earlywood and latewood and specific cell structure have an effect on the surface roughness (Mothe et al. 1992; Sachsse and Roffael 1993; Hecker 1995b). The surface roughness and variation of the results are higher for non-centered logs than for centered logs, which can be explained by a different ring arrangement in the non-centered log and thus different distribution of late- and earlywood. Both calculated roughness parameters for the non-centered log are higher by approximately 55% than the ones of centered logs. It was decided to present the results using histograms, which give a more precise information in case of a high number of results. The distribution of the results for centered and non-centered logs is shown in Fig. 7.

As can be seen on the histograms, distributions of the results for both kinds of logs are considerably different. Generally, the results of both analyzed logs are characterized by positive skewness, thus they are right-tailed distributed. However, a non-centered log is characterized by a larger number of high value results, which results in significantly higher mean values of R_a and R_z for this log.

Table 3 presents results of roughness parameters for logs soaked in different temperatures. As before, results

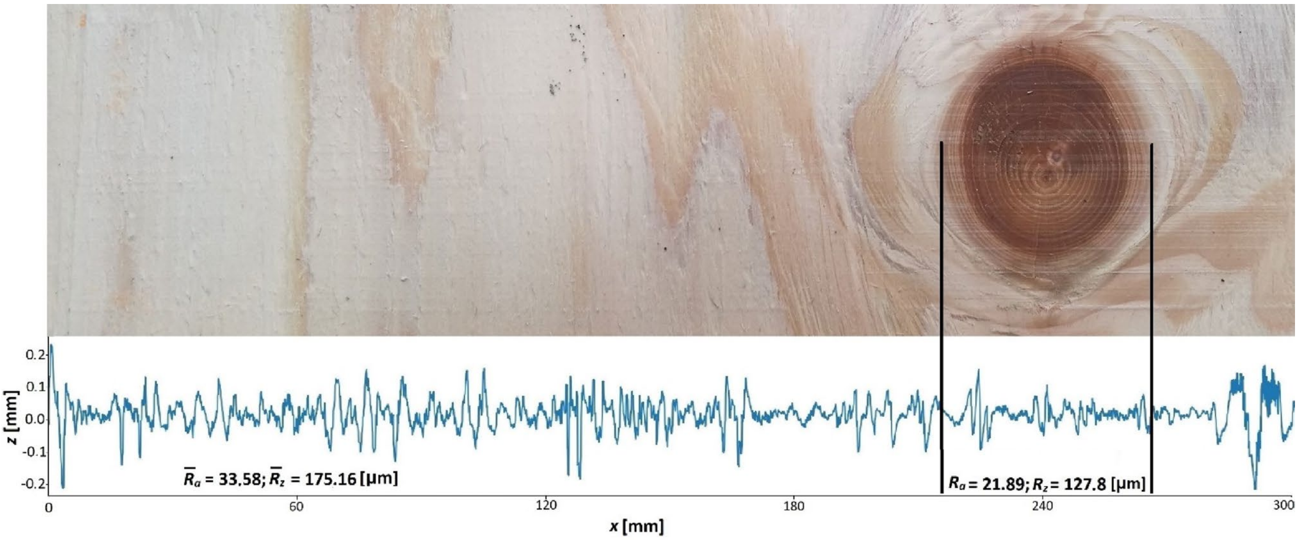

Fig. 6 Roughness profile of intergrown knot compared to regular wood, with calculated roughness parameters of sections before and within the knot

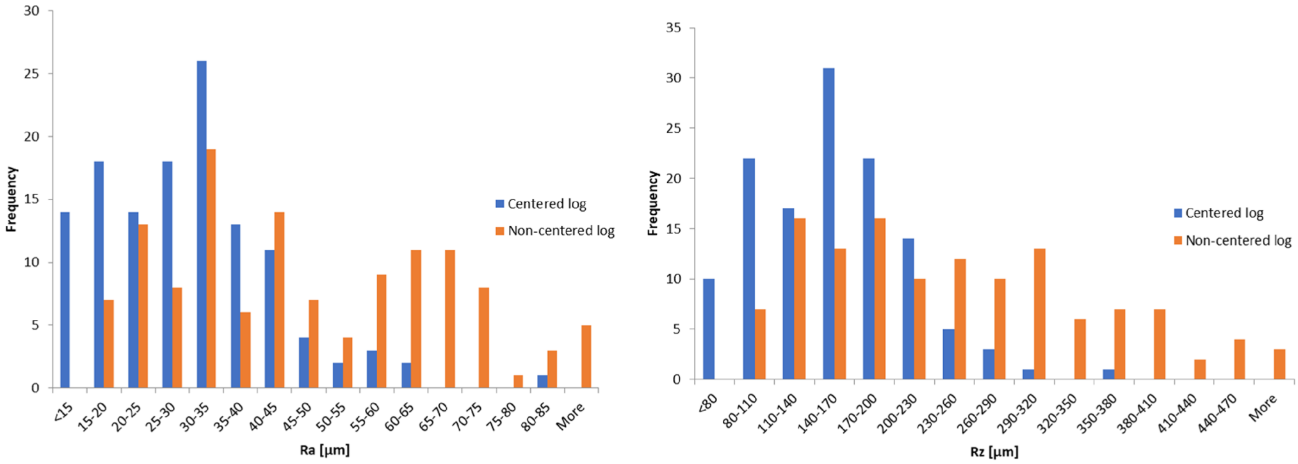

Fig. 7 Distribution of the results of roughness parameters for centered and non-centered logs

Table 3 Results of roughness parameters depending on the soaking temperature

	Soaking temp. 55 °C		Soaking temp. 80 °C	
	R_a	R_z	R_a	R_z
Average (µm)	38.0	216.9	45.8	250.5
Standard deviation (µm)	14.2	105.2	14.8	80.5
Variance	201.3	11,059.3	220.1	6482.5
Coefficient of variation (%)	37.4	48.5	32.4	32.1
Normalized kurtosis	0.68	4.62	1.60	0.5
Skewness	0.78	1.75	0.83	0.69

variability is high and amounts up to 49%. Higher roughness values were obtained for logs soaked at 80 °C, which is in an agreement with Corder and Atherton (1963). It may be caused by "softification" of early wood at high temperature, which can produce the Horner effect (Mothe 1988; Marchal et al. 2009; Thibaut et al. 2016).

Based on Fig. 8, it can be seen that the most frequent values of roughness parameters for analyzed logs are considerably different. All distribution parameters are characterized by positive skewness and kurtosis. The distribution of R_a parameter is close to a normal distribution. It can be noticed that kurtosis for R_z parameter for 55 °C is clearly higher

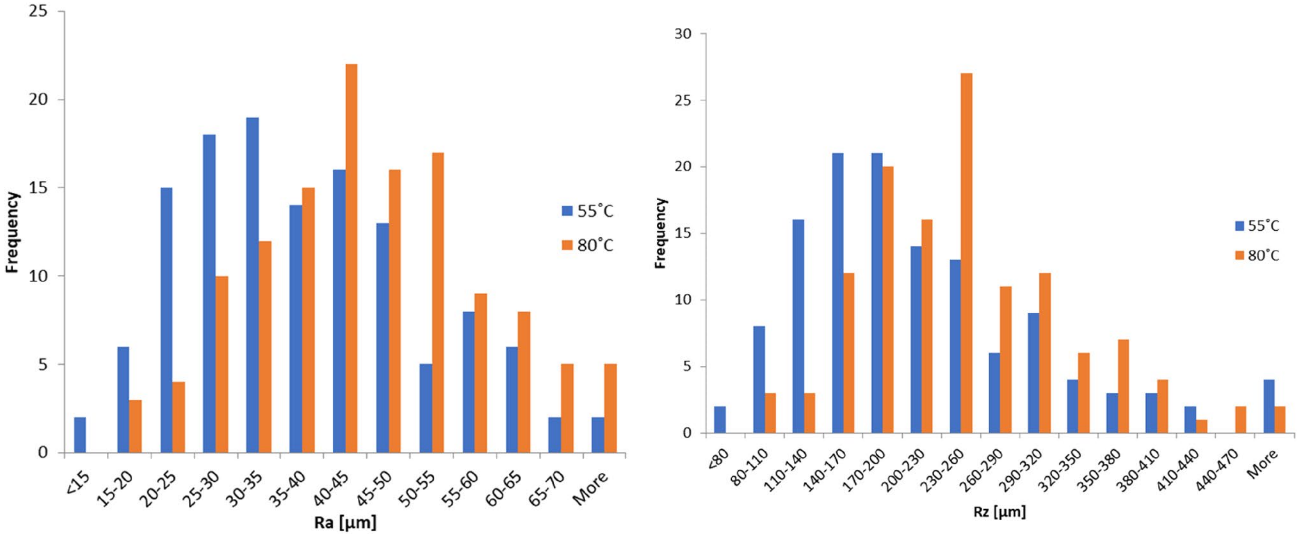

Fig. 8 Distribution of the results of roughness parameters depending on the soaking temperature

compared to other cases, showing that this distribution is leptokurtic. The surface of the veneer peeled from this log was characterized by similar number of high and low values of R_z (distribution is more uniform).

Table 4 presents surface roughness parameters depending on the cutting speed. All the roughness parameters are higher for the cutting speed of 1 m/s. The reason of this feature is that when the cutting speed is too low, cell wall cannot be cut correctly especially on earlywood, and produces the Horner effect (Mothe 1988; Marchal et al 2009; Thibaut et al. 2016). This phenomenon also concerns different techniques of wood machining, among others veneer production by slicing (Dundar et al. 2008a). It can be seen on the diagrams in Fig. 9 that results of the cutting speed of 1 m/s are more evenly distributed (especially distribution of R_z results) and characterized by negative kurtosis (− 0.35 for R_a and R_z).

According to the authors conclusions, future research on this subject could be limited to analyze only R_z parameter. This approach allows to limit the number of results and analyze the surface structure more precisely by focusing just on one parameter.

Table 5 contains statistical analysis of results of the surface roughness of green heartwood veneers. For both analyzed roughness parameters of all tested samples, average values are significantly different at assumed significance level of $\alpha = 0.05$.

4 Conclusion

This research shows that in-process optical measurement of the surface roughness carried out with the use of a laser profilometer can be effectively useful in the veneer production. Laser measurement has the potential to quantify and evaluate surface roughness, which may be a proper indicator

Table 4 Surface roughness parameters depending on the cutting speed

	Cutting speed 2 m/s		Cutting speed 1 m/s	
	R_a	R_z	R_a	R_z
Average (µm)	29.8	154.8	34.4	217.2
Standard deviation (µm)	12.5	55.7	15.9	80.0
Variance	156.3	3102.3	253.8	6398.8
Coefficient of variation (%)	42.0	36.0	46.3	36.8
Normalized kurtosis	1.59	0.76	− 0.35	− 0.35
Skewness	0.95	0.58	0.54	0.50

Table 5 Statistical analysis of the results of the surface roughness obtained during the study

	R_a	R_z
Centered log mean (µm)	29.8	154.8
Non-centered log mean (µm)	46.8	246.1
t value	6.25	6.99
P value	< 0.001	< 0.001
Soaking temp. 55 °C mean (µm)	38.0	216.9
Soaking temp. 80 °C mean (µm)	45.8	250.5
t value	8.04	6.36
P value	< 0.001	< 0.001
1 m/s mean (µm)	34.4	217.2
2 m/s mean (µm)	29.8	154.8
t value	8.71	13.49
P value	< 0.001	< 0.001

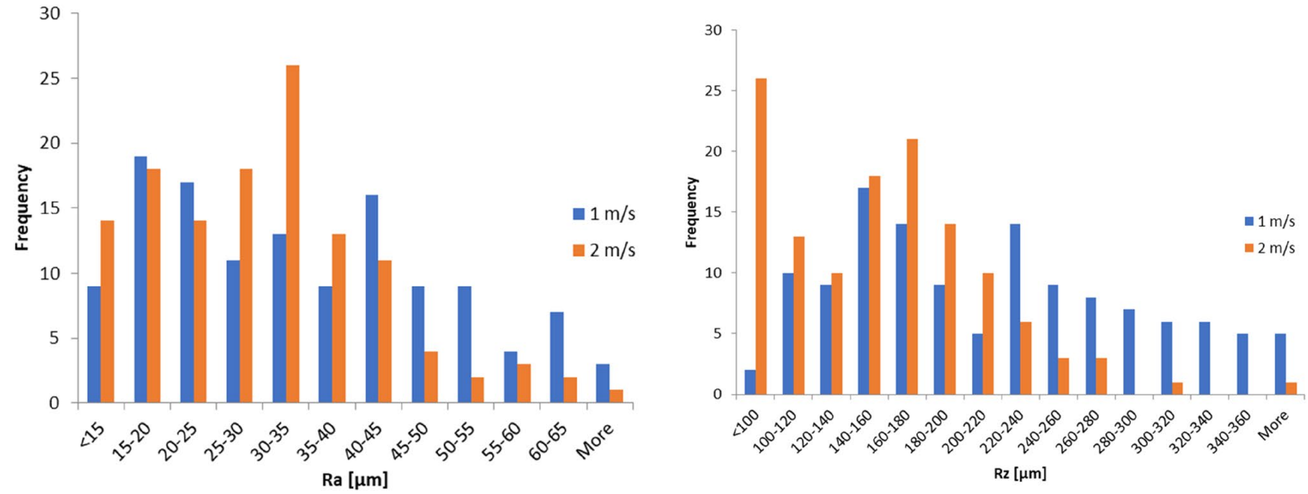

Fig. 9 Distribution of the results of roughness parameters depending on the cutting speed

of green veneer quality. The investigation shows that using a laser profilometer allows finding differences in the surface roughness of green veneers peeled in various conditions. The surface quality of the heartwood veneers is significantly different depending on the parameters of both pre-treatment and peeling processes. It has been found that veneer surface roughness is sensitive to soaking temperature. Values of roughness parameter were the lowest when the soaking temperature was 65 °C and the highest when the soaking temperature was 80 °C. More experiments are required in this regard. Peeling of well-centered core log is also favorable because irregular distribution of early- and latewood has a negative effect on the surface quality. This configuration (2 m/s, centered, 65 °C) allows obtaining the lowest surface roughness in the range of the conducted experiments.

Moreover, the origin of the surface roughness of Douglas fir veneers was analyzed, including the effect of the structure and properties of wood on the surface roughness. Structure of the surface is very diverse depending on location in the veneer. The surface roughness is considerably higher for earlywood than for latewood for Douglas fir, what is connected to higher density and different structure of cells in latewood. For this reason, the results are characterized by high variation, which in some cases amounts up to 50%. Statistical analysis showed that in the range of the conducted experiments, the log centration, the soaking temperature and the cutting speed have a significant effect on the surface roughness of green Douglas fir veneers peeled from heartwood.

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Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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