Surface Characteristics of Scots Pine Veneers Produced with a Peeling Process in Industrial Conditions

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A test method was developed to evaluate the surface characteristics of veneers produced using the peeling process. Rotary cut Scots pine (*Pinus sylvestris* L.) veneers, which were produced from logs soaked at 65 °C for 42 h prior to peeling and dried at 125 °C, were used as the test specimens. The pine veneers were produced under industrial conditions. The density variation of the round wood was determined using X-ray computed tomography, the thickness variation of the pine veneers was measured using an optical microscope, and the structure of the veneers was examined using a scanning electron microscope. The pine wood was characterised by the density variation in the transverse section. At the same moisture level, broad-ring pith-adjacent juvenile sapwood had a lower density compared with that of perimeter-adjacent mature wood. The clear lack of density homogeneity was seen in the width of the subsequent annual growths. The roughness of the pine veneers demonstrated significant variation, depending on the tool angle (17° and 21°), wood area (sapwood and heartwood), and veneer side (tight and loose). The veneer thickness had a significant impact on the roughness values measured perpendicular to the grain.

Keywords: Computed tomography; Peeling; Pine wood; Scanning electron microscopy; Surface characteristics; Veneer

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INTRODUCTION

The circumferential peeling of wood is one of the basic methods for obtaining veneers (Denaud *et al.* 2012). This method is also a type of chipless woodworking. Veneers obtained as a result of circumferential peeling are commonly used to manufacture plywood and laminated veneer lumber (LVL). These veneers may also be used as a surface-enhancing material in applications such as wood-based panels, *i.e.*, particleboards and medium density fibreboards. Mainly softwood species (*i.e.*, Scots pine) and, to a lesser degree, diffuse-porous hardwood species (*i.e.*, beech, birch, and alder) are subjected to circumferential peeling in Central and Eastern Europe. The most serious difficulties arise when applying the peeling process to softwood. Softwood species are characterised by the greatest density variation in the width of single annual growths (Kollmann and Côté 1984). In Scots pine wood, the density range of earlywood in the absolutely-dry state ranges from 340 kg/m^3 to 360 kg/m^3, and the density of latewood ranges from 810 kg/m^3 to 900 kg/m^3; therefore, latewood is approximately three times as dense as earlywood. Unfortunately, the lack of radial homogeneity in pine wood has an adverse impact on circumferential peeling processes. The current resolution and speed of X-ray computed tomography (CT) scanners enable the complex internal structure of wood to be analysed in a non-destructive manner, with a full representation of the annual growth system and variation (lack of homogeneity) in the density (Wei *et al.* 2009). On a laboratory scale, it is necessary to convert the obtained CT images from the Hounsfield unit scale to the actual density (kg/m^3).

The quality of the veneer is determined by many parameters, both material- and technology-related (Baldwin 1995; Bekhta *et al.* 2014; Li *et al.* 2018). Among the material-related factors, the species and area of the block from which the veneer is obtained (sapwood and heartwood) has a remarkable impact on the quality of the veneer. The veneer thickness is also important (Dundar *et al*. 2008a). It is generally accepted that better quality veneers are obtained from the perimeter-adjacent area, called sapwood. This is because sapwood has a lower density than heartwood. Additionally, sapwood demonstrates a greater susceptibility to softening when subjected to a hydrothermal treatment because of its structure and location next to the perimeter. This area has less knots, which determine the quality class of the veneer. The methods for the hydrothermal treatment (in water or vapour) of wood designated for circumferential peeling is well known, but the aspect that changes is the equipment. The treatment processes are optimised based on the wood species, moisture content, wood density, and dimensions of the products (Baldwin 1995; Aydin *et al.* 2006; Dundar *et al*. 2008a,b; Yamamoto *et al*. 2015). It has been demonstrated that drying also has an impact on the properties of the material subjected to circumferential peeling (Aydin and Çolakoğlu 2002).

The properties of the veneer surface are important factors when determining the wood wettability, glue adhesion, and adhesive strength (Neese *et al*. 2004; Budakçi *et al.* 2007; Aslan *et al.* 2008; Coelho *et al.* 2008; Rohumaa *et al*. 2014). The roughness is commonly used to measure the quality of the wood surface (Hiziroglu 1996; Aydin and Çolakoğlu 2003; Söğütlü 2010; Söğütlü and Togay 2011; Söğütlü *et al*. 2016; Söğütlü 2017; Li *et al.* 2018). However, it should be noted that the determined roughness parameters do not allow one to directly specify the destruction degree of the anatomical structure of wood elements or the depth of cracks. These aspects must be specified with the use of scanning electron microscopy (SEM) (Rohumaa *et al.* 2016). The longitudinal cracks are more intense when the area from which the veneer is obtained is closer to the core log, and the orientation deflection of the growth rings from the tangential direction in the transverse section of the veneer is greater. Veneer cracks may have a positive impact during the gluing process because they improve the penetration of glue into the veneer structure, which strengthens the adhesive bonds (Baldwin 1995; Kamke and Lee 2007; Kurowska *et al*. 2011). Stehr and Johansson (2000) demonstrated that the sawn specimens of Scots pine (*Pinus sylvestris* L.) had a joint that was approximately twice as strong as that of microtomed specimens. In this case, the adhesive was reinforced by the damaged fibres at the surface. Nevertheless, the presence of cracks in thick veneers, which can be used as a structural layer in multi-layer flooring materials, is an undesired characteristic because each crack leads to a decrease in the strength properties of veneers, and consequently, incurs a decrease in the product strength.

Veneers with a thickness ranging from 0.5 mm to 3.0 mm are usually obtained with circumferential peeling. Thicker veneers can be used, for example, as a balance material under the surface layer in multi-layer materials. There is currently no data available concerning the properties of this type of veneer. In view of the above discussion, the properties of 4-mm-, 6-mm-, and 8-mm-thick veneers were determined with the use of modern measurement systems and techniques. Because of the comprehensive nature of this study, the quality of the round wood used for manufacturing the veneers was also assessed.

EXPERIMENTAL

Materials

The Scots pine (*P. sylvestris* L.) wood was obtained from a forest in northwest Poland, which is located in Biała (52° 49′ 45″ N; 16° 18′ 35″ E) and managed by the State Forests National Forest Holding. The wood used had a circular cross-section, and knots with a diameter of 20 mm to 70 mm were visible on the side of the trunk. The study subject was pine wood that was 50 years old. The width of annual rings of wood was typical for planted Scots pine trees (narrower near the bark and wider near the core, from 0.6 mm to 4.5 mm). The density was changed cyclically in radial direction (lower in spring wood and higher in summer wood). The obtained raw material was subjected to preparatory procedures, cutting, and drying in a Polish plant. Round wood with a diameter of 200 mm to 360 mm and a length of 700 mm was treated hydrothermally at a temperature of 65 °C (low but applied temperature in energy-saving process for medium sized softwood logs). The treatment time was 42 h, while the pH of the water before the treatment was 8. After treatment, the wood was debarked. The moisture content of the wood prior to peeling was determined using a resistive hygrometer (WRD-100, TANEL Electronics & IT General Partnership, Gliwice, Poland). Measurements were performed at a depth of 6 mm. The time between the removal of the blocks from the hot water and peeling was 420 s. The average moisture content of the logs (taking into account the sapwood and heartwood) immediately before peeling was 76.8% (± 3.0%). The moisture content of the core log (heartwood) was only 44.4% (± 5.0%). The temperature of the wood before and after peeling was measured with a Voltcraft K101 digital thermometer (Wernberg-Köblitz, Germany). The temperature of wood after hydrothermal treatment (before peeling) was about 65 °C, but the average surface temperature of veneer (immediately after peeling - about 420 s) was only 27.6 °C (± 3.3 °C) and average temperature of the surface of core log was 31.6 °C (± 3.3 °C).

Wood-peeling Process

The wood-peeling process was done on a veneer lathe under industrial conditions. For peeling, flat knives with two tool angles (17° and 21°) were used. The pressure bar bevel was 55°. The blocks were peeled into 4-mm, 6-mm, and 8-mm veneers. The blocks for peeling were mechanically positioned. The ambient temperature of the machine hall was 16 °C and the air humidity was 60%. The veneers were dried in a tunnel kiln at 125 °C. The drying time was dependent upon the thickness of the veneers and was 14 min for the 4-mm-thick veneers, 21 min for the 6-mm-thick veneers, and 28 min for the 8-mm-thick veneers. The final moisture content of the veneers was measured using a capacitive method with a WIP-22D Hygrometer (TANEL Electronics & IT General Partnership) and was 6% ± 1%.

Methods

This study used an original methodology developed for the purposes of this work and was based on the most modern equipment. The pine wood was tested using X-ray CT, which was performed using a NeuViz 16 CT scanner (Neusoft Medical Systems Co., Ltd., Shenyang, China). This detected the density variability (diameter) and any defects.

The study was performed on round wood immediately after felling. Because of the technical constraints of the X-ray CT scanner, testing was done on 700-mm-long blocks.

The test veneer samples were delivered to the plant in the form of sheets with the dimensions 700 mm (longitudinal) × 1200 mm (tangential). For this study, the sheets were cut into veneers with the dimensions 100 mm × 100 mm and were separately made from the sapwood and heartwood of the pine wood.

An analysis of the surface of the pine veneers was done using a scanning electron microscope (QUANTA 200, FEI Company, Hillsboro, OR, USA). The thickness variability of the pine veneers was examined using an optical microscope (SMZ 1500, Nikon, Tokyo, Japan) with image analysing software. The setting parameters of the devices are given in Table 1.

Table 1. Measuring Devices for the Test Equipment

Device	Measurement Settings
X-ray CT scanner - CT NeuViz 16 with integrated DAS detector (Picus 16-row - activation 16 layers at one gantry rotation during 0.5 s - minimum resolution 0.75 mm)	HFP, 120 kV, 40 mA, $CTDI_{vol}$ = 3mGy, Helical mode without contrast, scanning depth = 5 mm, diameter up to 40 cm, mass up to 200 kg
Scanning electron microscope - FEI QUANTA 200 with EDS EDAX analyzer, zoom up to 150000x	Vacuum = 1.30 mbar, voltage = 25.0 kV, LFD detector, samples without sputtering

The roughness of the pine veneers was examined in accordance with the requirements of ISO 4287 (1997). As part of the study, the arithmetic mean deviation of the assessed profile (R_a) and maximum height of the assessed profile (R_z), as defined in ISO 4287 (1997), were measured. The surface roughness was determined using the Surftest SJ-210 Series 178-Portable Surface Roughness Tester (Mitutoyo Corporation, Kawasaki, Japan). The parameters were measured 20 times each in the parallel and perpendicular to the grain directions for each veneer variant. The roughness parameters were marked separately for the pine sapwood and heartwood. The analysis was on the tight ("right") and loose ("left") sides of the veneers. The test factors and their variability levels are summarised in Table 2.

Table 2. Levels of the Tested Factors in Relation to the Pine Veneer Roughness

Veneer Thickness (mm)	Tool Angle (º)	Wood Area	Veneer Side	Measurement Direction
4 6 8	17 21	sapwood heartwood	tight loose	parallel to the grain perpendicular to the grain

Statistical analysis was performed using STATISTICA software (version 12, StatSoft, Inc., Tulsa, OK, USA) and was performed at a significance level (p) of 0.05.

RESULTS AND DISCUSSION

Variation in the Round Wood Density

The results of the CT scanning test were recorded in the Hounsfield unit scale, and therefore the CT scanner that was used for this study was calibrated by examining wood samples with a known moisture content (ISO 13061-1 2014). The density was determined using the stereometric method (ISO 13061-2 2014). In this way, an equation with a linear correlation was obtained, which incorporated the relationship between the Hounsfield unit scale and actual density of the wood (Fig. 1). Therefore, the obtained CT images of the pine wood could then be used to take a direct density reading (kg/m^3) (Figs. 2 and 3).

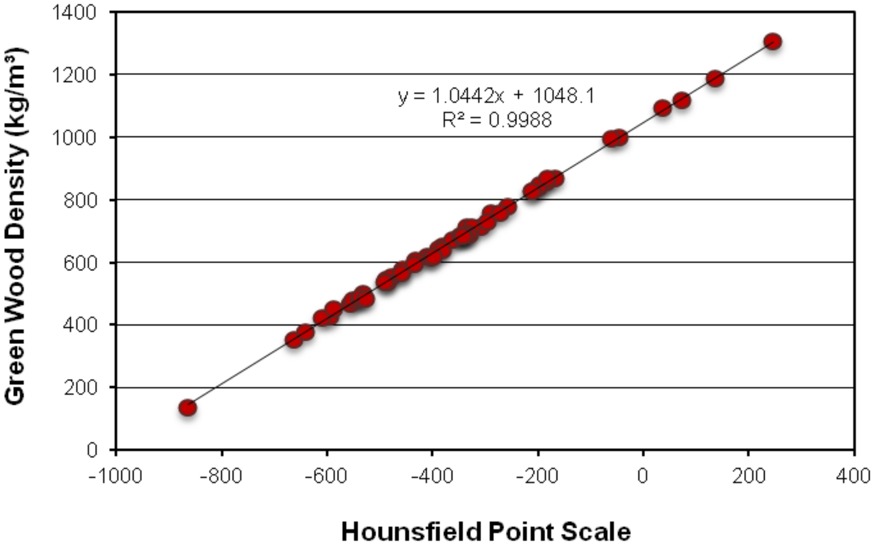

Fig. 1. Relationship between the Hounsfield density point scale and actual wood density used during CT scanning

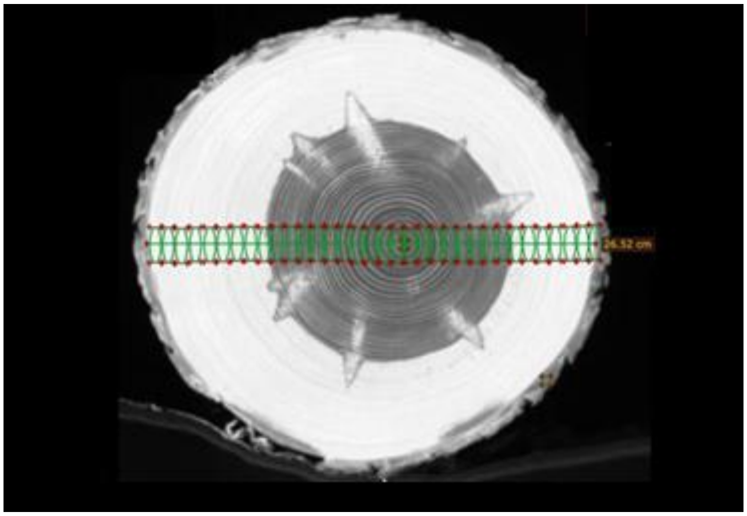

Fig. 2. Typical CT image of the transverse section of the pine wood presented using the Hounsfield unit scale

There was a clear difference in the densities of the freshly cut round wood, which to a large extent may have been caused by the differences in the moisture content of the sapwood and heartwood. The heartwood, with a density ranging from 450 kg/m^3 to 550 kg/m^3, had a moisture content of 35% to 40%, whereas the wide sapwood area, with a density of approximately 1100 kg/m^3, had a moisture content of 100% to 110%. When the entire log had a moisture content of 6%, as was recorded in the examined veneers

(Kollmann and Côté 1984; ISO 13061-2 2014), the density was approximately 410 kg/m^3 for the pine heartwood and reached up to 640 kg/m^3 for the sapwood. In the case of flooring layered materials, which are produced by pressing, the wood density is an important property (Kurowska *et al*. 2010; Gaff and Gašparík 2015). Density plays an important role during pressing and influences the compatibility of veneers with one another (Aydin and Çolakoğlu 2005; Gaff and Gašparík 2015; Gaff *et al*. 2016).

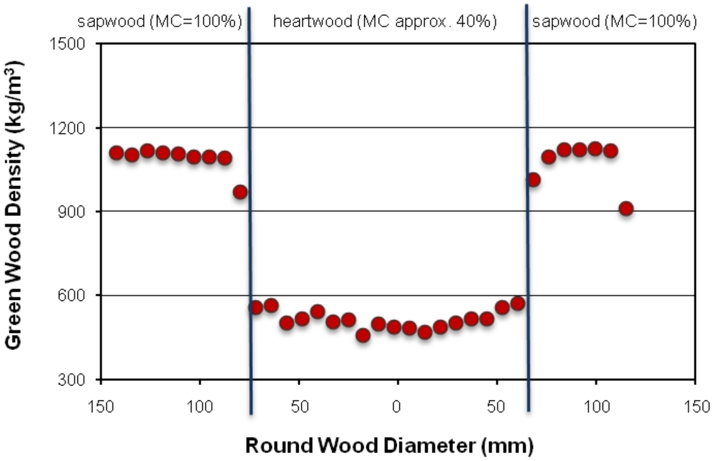

Fig. 3. Typical variability of the density in round pine wood

Typical pine raw materials (round wood) are characterised by a clearly lower density in the rings adjacent to the pith, whose fibres tend to pill and tear during chip woodworking. The pith-adjacent area also includes juvenile wood with shorter structural elements and a different layout of fibrils in the cell walls (Fabisiak 2005), which contributes to increased shrinkage and cracking. Chipless woodworking, done by circumferential peeling, enables the separation of undesirable pith-adjacent wood (by encasing it in a core log) from full quality mature wood, which generally corresponds to the sapwood in pine wood with a diameter ranging from 200 mm to 360 mm. This ensures that only full quality raw material makes it to the final products. It should also be noted that the presence of low-density juvenile pine wood multi-layer flooring materials in a structural layer leads to a decreased resistance to dents. Chipless woodworking enables the elimination of undesirable wood areas from further processing.

Variation in the Pine Veneer Thickness

The veneers obtained from the heartwood were characterised by a greater variation in the thickness compared with those obtained from the sapwood (Fig. 4). The relative standard deviation (RSD) is defined as the ratio of the standard to the mean and was 2% and 5% for the 4-mm-thick veneers obtained from the sapwood and heartwood, respectively. The RSD for the 6-mm-thick veneers obtained from the sapwood and heartwood was 2% and 4%, respectively. Meanwhile, the RSD for the 8-mm-thick veneers obtained from the sapwood and heartwood was 1% and 2%, respectively.

The smaller variation in the thickness of the veneers obtained from sapwood was related to the better softening of the material and, maybe consequently led to more favourable temperature and moisture content conditions while peeling. The moisture content of the surface of the block after the hydrothermal treatment was higher than the moisture content of the surface of the core log. Furthermore, the heartwood had wider growth rings than the sapwood. Dupleix *et al*. (2013) showed that the thickness variation in spruce veneers decreased as the heating temperature increased (by soaking the wood), which demonstrated the positive effects of heating on the veneer thickness consistency. At a temperature of 50 °C, the positive effects of heating ensure an efficient peeling process.

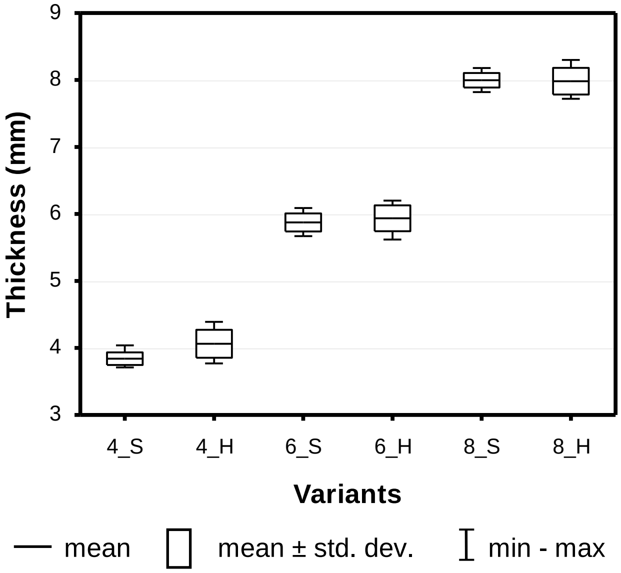

Fig. 4. Variation in the pine veneer with a nominal thickness of 4 mm, 6 mm, and 8 mm obtained from the sapwood (S) and heartwood (H)

Roughness of the Pine Veneers

Table 3 shows the statistical evaluation of the specific influence of the factors on the roughness parameters of the pine veneers. The roughness of the pine wood demonstrated significant variation, depending on the tool angle (17° and 21°), wood area (sapwood and heartwood), and veneer side (tight and loose). The wood area had the greatest impact on the R_a and R_z parameters parallel to the grain (26% and 24%, respectively). In contrast, the veneer side had the greatest impact on the R_a and R_z determined perpendicular to the grain (20% and 19%, respectively). The wood area had a slightly lesser impact. The thickness of the veneers had a significant impact only in the case of the R_a and R_z measured perpendicular to the grain ($p < 0.05$). Among the interactions examined in this study, only the interaction between the veneer thickness and tool angle had a significant impact on the R_a and R_z measured parallel to the grain (14% and 16%, respectively).

The roughness (R_a and R_z) of the pine veneers varied significantly depending on the measurement direction (parallel and perpendicular to the grain). In general, it was concluded that the R_a values measured perpendicular to the grain of the pine veneers were twice as high as those measured parallel to the grain. A similar correlation was observed in the case of the R_z. Wood is a non-homogeneous material and its properties are different in different directions (Li *et al*. 2018). This is because of the anatomical structure of wood. The measurement perpendicular to the grain contains irregularities that are mainly caused by the size of the structural wood elements. In the case of softwood species, these elements are primarily tracheids. The diameter of tracheids in earlywood is approximately 38 μm, whereas in latewood it is approximately 18 μm (Wagenführ 2007).

Table 3. Statistical Evaluation of the Factors Influencing the Roughness Parameters of the Pine Veneers

Property	Factor	Sum of Squares	Degrees of Freedom	Variance	Fisher's F-test	Significance Level	Factor Influence (%)
		SS	Df	MS	F	p	
Ra II	Intercept	3881.045	1	3881.045	4994.332	0.000000	-
	Thickness (1)	3.750	2	1.875	2.413	0.093676	2
	Tool angle (2)	14.226	1	14.226	18.306	0.000037	6
	Wood area (3)	63.938	1	63.938	82.279	0.000000	26
	Veneer side (4)	17.456	1	17.456	22.463	0.000006	7
	1 × 2	33.761	2	16.880	21.722	0.000000	14
	1 × 3	3.421	2	1.710	2.201	0.114903	1
	1 × 4	1.692	2	0.846	1.089	0.339699	1
	2 × 3	4.057	1	4.057	5.221	0.023972	2
	2 × 4	1.266	1	1.266	1.629	0.204182	1
	3 × 4	2.340	1	2.340	3.011	0.085115	1
	1 × 2 × 3 × 4	1.230	2	0.615	0.792	0.455362	1
	Error	98.690	127	0.777	-	-	38
Ra ⊥	Intercept	20346.26	1	20346.26	4804.479	0.000000	-
	1	156.98	2	78.49	18.534	0.000000	11
	2	34.79	1	34.79	8.215	0.004863	2
	3	287.00	1	287.00	67.771	0.000000	19
	4	296.97	1	296.97	70.125	0.000000	20
	1 × 2	31.33	2	15.67	3.699	0.027445	2
	1 × 3	13.58	2	6.79	1.603	0.205270	1
	1 × 4	25.74	2	12.87	3.039	0.051393	2
	2 × 3	56.43	1	56.43	13.325	0.000381	4
	2 × 4	1.67	1	1.67	0.393	0.531742	0
	3 × 4	14.21	1	14.21	3.356	0.069315	1
	1 × 2 × 3 × 4	22.89	2	11.45	2.703	0.070849	2
	Error	537.83	127	4.23	-	-	36
Rz II	Intercept	133170.7	1	133170.7	5714.875	0.000000	-
	1	74.7	2	37.3	1.602	0.205558	1
	2	354.1	1	354.1	15.194	0.000156	5
	3	1716.0	1	1716.0	73.642	0.000000	24
	4	430.9	1	430.9	18.490	0.000034	6
	1 × 2	1153.6	2	576.8	24.754	0.000000	16
	1 × 3	110.5	2	55.3	2.371	0.097503	2
	1 × 4	11.0	2	5.5	0.235	0.790852	0
	2 × 3	224.7	1	224.7	9.644	0.002343	3
	2 × 4	26.8	1	26.8	1.152	0.285252	0
	3 × 4	3.4	1	3.4	0.147	0.702292	0
	1 × 2 × 3 × 4	3.7	2	1.8	0.079	0.924123	0
	Error	2959.4	127	23.3	-	-	43
Rz ⊥	Intercept	685355.5	1	685355.5	5468.633	0.000000	-
	1	2367.6	2	1183.8	9.446	0.000150	6
	2	587.0	1	587.0	4.684	0.032321	1
	3	5921.2	1	5921.2	47.247	0.000000	15
	4	7347.7	1	7347.7	58.629	0.000000	19
	1 × 2	830.8	2	415.4	3.315	0.039512	2
	1 × 3	285.2	2	142.6	1.138	0.323758	1
	1 × 4	164.0	2	82.0	0.654	0.521613	0
	2 × 3	2920.2	1	2920.2	23.301	0.000004	7
	2 × 4	205.0	1	205.0	1.636	0.203223	1
	3 × 4	965.0	1	965.0	7.700	0.006356	2
	1 × 2 × 3 × 4	1626.7	2	813.3	6.490	0.002072	4
	Error	15916.3	127	125.3	-	-	42

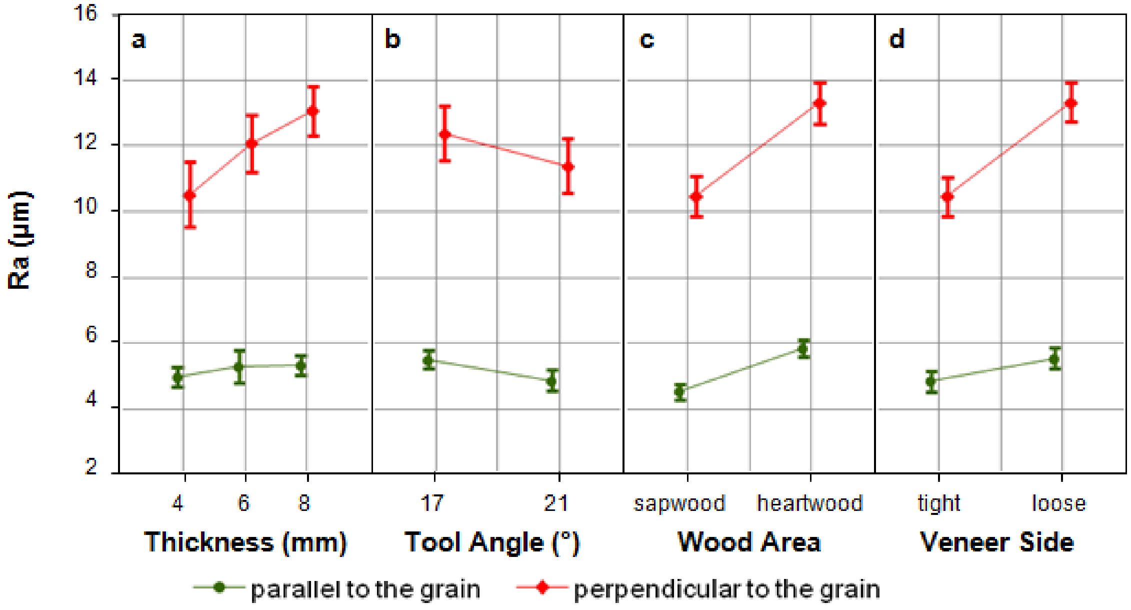

Fig. 5. Influence of the tested factors on the R_a of the pine wood veneers: (a) thickness; (b) tool angle; (c) wood area; and (d) veneer side

The roughness of the pine veneers varied significantly depending on the examined factor (thickness, tool angle, wood area, and veneer side) and degree of variation (Figs. 5 and 6).

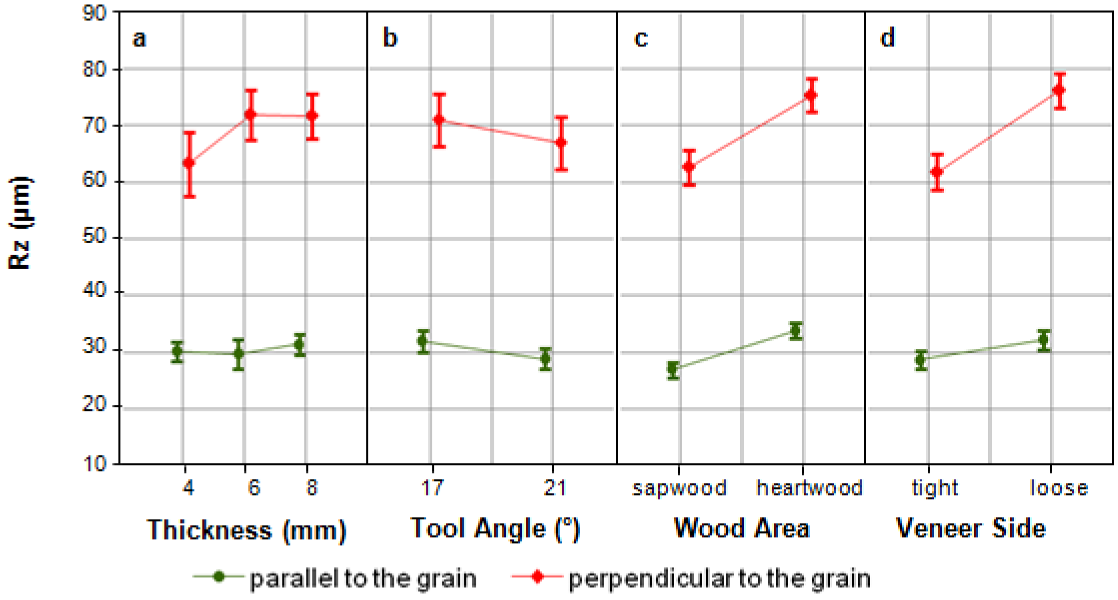

Fig. 6. Influence of the tested factors on the R_z of the pine wood veneers: (a) thickness; (b) tool angle; (c) wood area; and (d) veneer side

The 4-mm-thick veneers had the smallest roughness values. In general, it can be stated that the roughness values of the 6-mm-thick veneers were close to those of the 8-mm-thick veneers. Dundar *et al*. (2008a) showed that the surface roughness of a veneer increases with an increasing veneer thickness. Aydin and Çolakoğlu (2005) stated that a rough veneer is difficult to glue because of a lack of close contact between the veneer surfaces. Furthermore, a high roughness promotes conditions that can result in dryout and over-penetration. Higher soaking or peeling temperatures decrease the surface roughness (Aydin *et al.* 2006). Rohumaa *et al.* (2016) showed that soaking logs at 70 °C, rather than 20 °C, before peeling produced birch (*Betula pendula* Roth) veneers with a decreased surface roughness.

The roughness of the pine veneers was smaller after peeling with a knife with a tool angle of 21°. The R_a values (both parallel and perpendicular to the grain) for the veneers obtained using a knife with a tool angle of 21° were approximately 10% lower than those of the veneers obtained with a tool angle of 17°. Similar correlations were found for the R_z.

Lower roughness values were recorded for sapwood and the tight side of the veneer. The R_a values (both parallel and perpendicular to the grain) for veneers obtained from sapwood were approximately 20% lower than for the veneers obtained from heartwood. Similar correlations were found for the R_z. The sapwood being softened to a greater extent under the influence of hot water than the heartwood. As a result, the irregularities in the surface of the sapwood were smaller. Tanritanir *et al*. (2006) showed that the surface roughness of samples cut from the inner portion of beech logs (*Fagus orientalis* L.) had a significant dependence on the steaming time.

The tight side of the veneer shows lower roughness values than the loose side. The R_a and R_z values parallel to the grain for the tight side of the veneers were approximately 10% lower than those for the loose side of the veneers. The R_a and R_z values perpendicular to the grain for the tight side of the veneers were approximately 20% lower than those for the loose side of the veneers. The loose side was characterised by a greater roughness because more irregularities and cracks appeared on that side as a result of tensile stresses. Such stresses are an effect of veneer bending during the peeling process. This links to wood anatomy and parameters of machining processes (Mothe 1988; Thibaut *et al*. 2016). These factors also determine other types of wood machining, *i.e.* cutting (Söğütlü *et al*. 2016) or planing (Söğütlü 2010; Söğütlü and Togay 2011; Öhman *et al*. 2016). Rohumaa *et al.* (2016) demonstrated that the soaking temperature influenced the roughness of the loose side of birch veneers, but did not have a significant effect on the roughness of the tight side when measured by the stylus method.

Structure and Surface Conditions of the Pine Veneers

Figures 7 and 8 show selected images of the structure and quality of the pine veneer surfaces after the drying process. Typically, after the peeling processes and irrespective of the individual settings, the obtained veneers had a distinguishable tight side (smoother) and loose side (characterised by a greater roughness). The output quality of the raw material (presence of knots) did not have a significant impact on the quality of the circumferential peeling. Generally, it was concluded that, in the case of the studied veneers and irrespective of their thickness, the most visible longitudinal cracks were recorded from veneer sheets obtained from heartwood. When the tool angle was greater, *i.e.*, 21°, the veneers were characterised with smaller roughness values, but the number of lathe checks increased.

The best quality, in terms of the coherence of the structure (the absence of cracks on the transverse section of the veneers) and irrespective of the applied tool angle, was found in the 4-mm-thick veneers obtained from sapwood (Figs. 7a, 7c, and 7e).

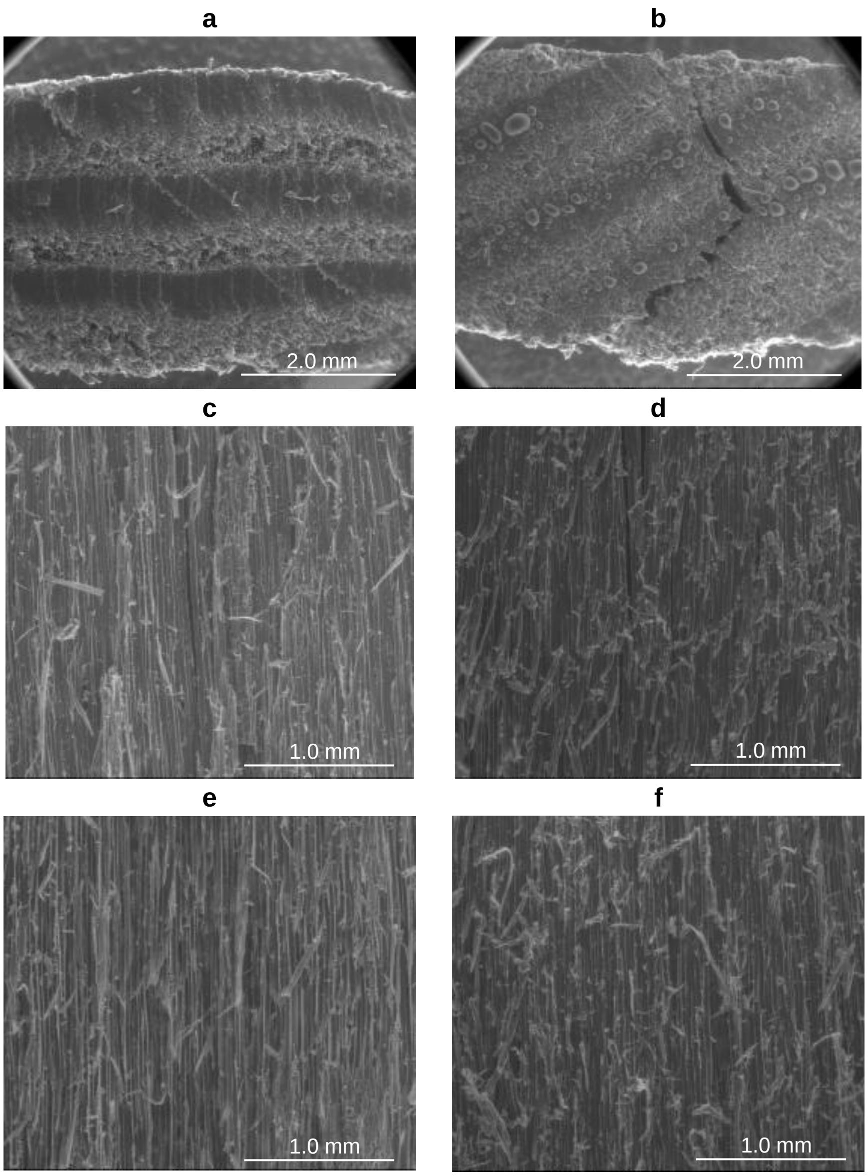

Fig. 7. SEM images of the structure of 4-mm-thick pine veneers circumferentially peeled from the: transverse section of the (a) sapwood (b) heartwood; tangential section from the loose side of the (c) sapwood and (d) heartwood; and tangential section from the tight side of the (e) sapwood and (f) heartwood

Peeling at the final stage (the heartwood with a decreasing core log diameter) resulted in strong stresses, and once the drying process was complete the non-through cracks became apparent and were perpendicular to the surface of the veneer sheets (Figs. 7b, 7d, and 7f). The surface of those veneers demonstrated an increased roughness from 50% (tight sides) to 70% (loose sides) and had small spots where fibres were torn.

The worst quality, in terms of the structure coherence and surface condition, was found in the thickest veneers, *i.e.*, 8 mm (Fig. 8). In these veneers, noticeable surface irregularities and small spots where fibres were torn were found on the entire surface, on both the tight and loose sides, which increased the roughness. Numerous lathe checks could be found every 10 mm on the loose side.

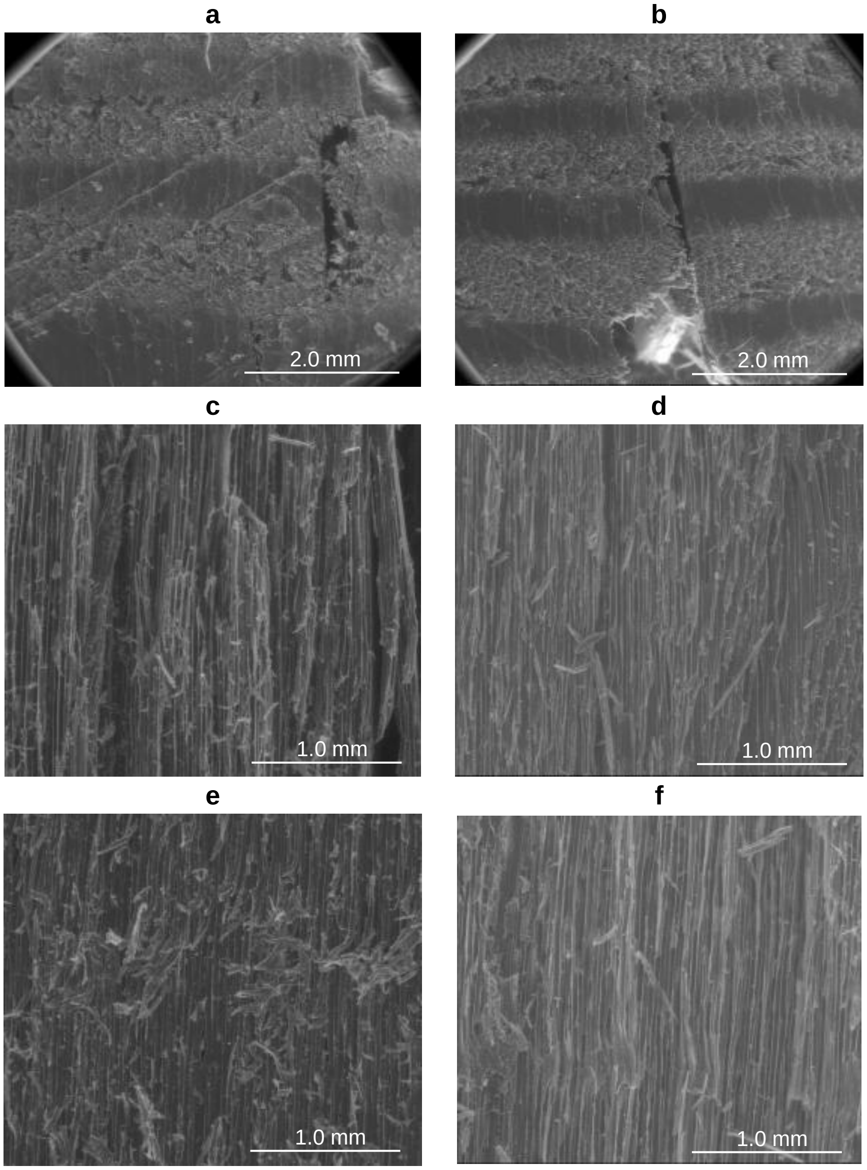

Fig. 8. SEM images of the structure of 8-mm-thick pine veneers circumferentially peeled from the: transverse section of the (a) sapwood and (b) heartwood; tangential section from the loose side of the (c) sapwood and (d) heartwood; and tangential section from the tight side of the (e) sapwood and (f) heartwood

Regrettably, some of them were cracks that went through to the tight side of the sheet, which disrupted its coherence. During the rotary peeling of birch (*B. pendula* Roth) veneer for plywood or manufacturing LVL, lathe checks went as deep as 70% to 80% of the veneer thickness (Rohumaa *et al*. 2013). Dupleix *et al.* (2013) investigated the influence of heating temperatures during soaking (20 °C to 80 °C) of beech, birch, and spruce on veneer lathe checking. The authors found that low temperatures produced veneers with deeper and more spaced checks than high temperatures. The most efficient peeling process was observed at 50 °C.

Local tears (hollows) were found mainly on the 6-mm- and 8-mm-thick veneers, in the earlywood area. These tears were an effect of the irregularities during the hydrothermal treatment and peeling processes (Thibaut *et al*. 2016). The size of hollows depended on the area from which the veneer was obtained and the arrangement of growth rings in the transverse section in relation to the veneer surface. Smaller hollows (up to 200 µm) were recorded for the veneers obtained from sapwood. In the veneers obtained from heartwood, the depth of the hollows reached approximately 1200 µm.

The quality of the 6-mm-thick veneers (determined based on the presence of defects, *i.e.*, roughness, tears, scratches, lathe check, and cracks) was intermediate between the quality of the 4-mm- and 8-mm-thick veneers. The usefulness of the 6-mm-thick veneers as a structural layer of multi-layer flooring materials should be verified with stress tests. The tests conducted showed that a complex analysis of the surface quality, especially in the case of thick veneers, required the examination of multiple characteristics, with the use of various specialised equipment. Veneer roughness studies should be completed along with veneer studies conducted by SEM, which would enable the thorough observation of cracks, among other things. Veneer surface irregularities may have an adverse impact on the quality of adhesive bonds in multi-layer materials (Faust and Rice 1986; Pocius 2002; Rohumaa *et al*. 2013; Pot *et al*. 2015).

CONCLUSIONS

1. Typical pine raw materials (round wood) show a significant variation in the density between juvenile wood and mature wood. In pine wood with a diameter of 200 mm to 360 mm, these areas correspond to the visible area of the heartwood and sapwood.
2. The roughness of the pine veneers demonstrated a significant variation, depending on the tool angle (17° and 21°), wood area (sapwood and heartwood), and veneer side (tight and loose). The thickness of the veneers had a significant impact only in the case of the R_a and R_z measured perpendicular to the grain. The veneers obtained from the heartwood were characterised by a greater variation in the thickness, greater number of perpendicular cracks, and a higher roughness compared with those of the pine sapwood veneer.
3. An analysis of the veneer images obtained by SEM significantly broadens the roughness study. The worst quality, in terms of the structure coherence and surface condition, was seen in the thickest veneers, *i.e.*, 8 mm. Regardless of the veneer thickness, the intensity of perpendicular cracks and tears (hollows in the surface) depended on the arrangement of growth rings and the non-homogenous density of the wood.

ACKNOWLEDGEMENTS

The authors are grateful for the support of the National Centre for Research and Development in Poland, under the "Environment, agriculture and forestry" – BIOSTRATEG Strategic R&D Programme (Agreement No. BIOSTRATEG2/298950/1/NCBR/2016).

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Article submitted: May 26, 2018; Peer review completed: July 21, 2018; Revised version received and accepted: August 20, 2018; Published: September 21, 2018.
DOI: 10.15376/biores.13.4.8342-8357