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Understanding of surface roughness of wood based on analysis its structure and density

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Abstract: *Understanding of surface roughness of wood based on analysis its structure and density*. The main aim of presented paper was to investigate the influence the wood density and anatomical details on surface roughness. The scope of study included samples from ten different species of wood (mainly tropical) because of wide range of density and anatomical difference. The results allow to conclude that the roughness of tested wood species demonstrated variation, depending on the wood section and the measurement direction. In general, radial sections showed higher roughness than tangential sections due to interlocked fibres in tested wood species (fibres cut in various ways on the radial section of the wood). Roughness measured perpendicular to the wood fibres were twice as high as those measured parallel to the grain. Wood density was not an important indicator determining surface roughness for tested wood species. The determining element for the roughness measured across the fibres was the diameter of the vessels. Further research is advisable due to the enormous variability of the structure and properties of wood.

Keywords: wood roughness, tropical wood, wood structure

INTRODUCTION

The attractiveness of wood is a consequence of its complex structure. Wood is primarily composed of unfilled, elongated cells that are arranged parallel to each other along the trunk of a tree. Because of that, the porous structure of wood will never be perfectly smooth (Sandak and Negri 2005). Surface roughness impacts not only aesthetical characteristics of products, but also the adhesion, penetration and wettability of wood coatings (Jankowska et al. 2018).

The wood surface is the result of complex factors including the interaction of used raw material, types of processes and time. During cutting processes, various anatomical parts of wood are separated and the properties of the separated pieces are influenced by the grain pattern and, physical and mechanical properties of wood. Wood structure makes the micro-geometry of the created that material surfaces heterogeneous (Thoma et al. 2015).

So far, studies on relationships between anatomical structure, wood density and surface roughness of tropical hardwoods have not been done sufficiently. The experience so far concerns wood from the temperate climate of relatively similar density. The size, shape, and arrangement of pores vary considerably between species but are relatively constant within a species (Wiedenhoeft 2013). Unlike temperate hardwood, tropical hardwood has slightly different anatomical structure due to the influence of growing season. In general, tropical wood is characterized by large diameter vessels as the vessels provide an efficient water conduction system. While the vessels in dry wood from temperate zones are much smaller (Jankowska et al. 2012). Vessels appear as holes or pores on a cross-section. Moreover, each measurement technique is more or less affected by wood anatomy, resulting in measurement uncertainty.

The main aim of that paper was to investigate the influence the wood density on its surface roughness. The scope of study included samples from ten different species of wood because of its density, anatomical difference together with the influence of the plane of section.

MATERIAL AND METHODS

Wood species used in presented study are listed in tab. 1. These species were selected to have a representative sample of hardwood with a wide range of densities, types and amounts of extraneous substances, and different anatomical structures (Richter and Dallwitz 2000). All test materials were heartwood, as it is more commercially usable than sapwood, except for European birch and European beech that do not produce heartwood. Wood from each of tropical wood species was acquired form DLH Global, Warsaw, Poland. European wood species were derived from Polish forest managed by The State Forests National Forest Holding. Identification was made in the laboratory based on macroscopic features. As a part of identification, wood density was identified based on PN-D-04101:1977. Selected for the tests wood species are widely used in the European wood industry for the production of floors, both from solid wood and glue laminated wood.

Table 1. Wood species used in tests

Wood name*	Scientific name	Special features	Vessels diameter** [μm]
Garapa	*Apuleia leiocarpa* (Vogel) J.F.Macbr.	Irregular fibres arrangement	70-100-120
Tatajuba	*Bagassa guianensis* Aubl.	Irregular fibres arrangement	155-225-290
European birch	*Betula pendula* Roth.	Simple fibres arrangement	30-90-130
European beech	*Fagus sylvatica* L.	Simple fibres arrangement	45-60-80
Courbaril	*Hymenea courbaril* L.	Irregular fibres arrangement, paratracheal parenchyma and in narrow bands	75-175-260
Massaranduba	*Manilkara bidendata* (A. DC.) A. Chev.	Irregular fibres arrangement, parenchyma in narrow bands	82-112-150
Opepe	*Nauclea diderrichii* Merrill	Irregular fibres arrangement	140-190-240
Wenge	*Millettia laurentii* De Wild.	Irregular fibres arrangement, paratracheal parenchyma and in wide bands	155-265-320
Sapeli	*Entandophragma cylindricum* Sprague	Irregular fibres arrangement, paratracheal parenchyma and in narrow bands	90-140-200
Merbau	*Intsia* sp.	Irregular fibres arrangement	120-200-280

*Names according to PN-EN 13556:2005, ** minimum-average-maximum according to Richter and Dallwitz [2000].

Samples of each wood species were taken from planks approx. 4 cm thick. The planks were air-dried in a room with relative humidity up to 50% and temperature of 21 °C for 6 months prior to testing. The defect-free planks were sawn and sized into samples for the measurements. The radial-oriented or tangential-oriented surface of the planks were planned following Gardner (1996) and Liptáková and Kúdela (1994) to make wood showing the roughness caused by the cellular structure of wood and only a negligibly small roughness caused by cutting. Immediately after planing, samples were cut. Thirty samples of each wood species were prepared, each with a radial and tangential cross-section of 10 mm × 10 mm and a length of 70 mm.

The roughness was evaluated in accordance with the requirements of ISO 4287. As part of the conducted research, the arithmetic mean deviation of the assessed profile (R_a) was measured. The surface roughness was tested using the Surftest SJ-210 Series 178-Portable Surface Roughness Tester (Mitutoyo Corporation, Takatsu-ku, Japan).

Statistical analysis of the test results was carried out using Statistica v. 10 software (TIBCO Software Inc., CA, USA). Data was analysed and provided as the mean ± standard deviation. Analysis of variance (ANOVA) was used to determine the influence of wood species (wood density) and anatomical properties such as direction of measurements and cross-section (tangential or radial). Simple regression was used as well. In analysis, data on the dimensions of the structural elements of wood given by Richter and Dallwitz [2000] were used. In presented paper, average vessels diameter was included in the statistical analysis.

RESULTS

Results of the surface roughness (R_a) of tested wood species are shown in tab. 2. The surface roughness demonstrated variation, depending on the tested wood section and the measurement direction (parallel or perpendicular to the grain). As can be seen from tab. 2, mostly radial sections showed higher roughness than tangential sections. The wood roughness is a complex phenomenon due to the fact that wood is a anisotropic and heterogeneous material. Several factors such as anatomical differences, the machining properties should be considered in evaluating the surface roughness of wood (Aydin and Colakoglu 20050). All tested tropical wood species are characterized with interlocked fibres which causes variable fibres orientation. As a result, they are cut in various ways on the radial section of the wood. In general, R_a values (measured perpendicular to the wood fibres) were twice as high as those measured parallel to the fibres. Wood as a non-homogeneous material shows differences in its properties depending on direction. The roughness perpendicular to the fibres is mostly caused by irregularities of the structural element sizes, such as vessels diameter.

According to the ANOVA results (at the 0.05 confidence level), the surface roughness varied significantly depending on the examined factors (Tab. 3).

Tabela 2. Roughness of tested wood species (means and standard deviations in parentheses)

Wood name	Roughness [μm]				Wood density [kg/m^3]
	perpendicular to the grain		along to the grain		
	on tangential section	on radial section	on tangential section	on radial section	
Courbaril	3.96 (0.82)	3.97 (0.82)	1.16 (0.38)	3.26 (0.75)	1042 (6)
European beech	4.34 (0.65)	5.77 (1.10)	2.15 (0.28)	3.28 (0.41)	585 (21)
Garapa	3.73 (0.68)	6.87 (0.99)	1.36 (0.44)	3.32 (0.62)	739 (8)
Massaranduba	4.01 (0.50)	5.75 (0.72)	1.21 (0.37)	1.75 (0.66)	1132 (18)
Merbau	7.43 (0.71)	8.09 (1.53)	3.42 (1.24)	2.86 (0.98)	560 (23)
Opepe	5.40 (0.66)	6.87 (1.21)	4.02 (1.62)	4.71 (1.75)	820 (16)
Sapeli	3.81 (0.60)	4.94 (1.10)	2.59 (1.30)	2.24 (0.32)	658 (7)
Silver birch	4.39 (0.47)	4.71 (0.59)	1.64 (0.74)	1.54 (0.32)	543 (12)
Tatajuba	4.06 (0.78)	7.21 (1.31)	1.54 (0.49)	2.98 (0.84)	884 (35)
Wenge	5.76 (2.07)	11.04 (2.11)	5.13 (2.13)	9.10 (2.10)	896 (10)

Tabela 3. Results of ANOVA

Factor	Sum of squares	Mean sum of squares	Fisher's F-test	Significance level
	SS	MS	F	p
Species	69.94	69.94	64.11	0.000000*
Section	21.22	21.22	19.45	0.000028*
Direction	78.95	8.77	8.04	0.033570*
Error	30.55	1.09	-	-

* - Significant at the 0.05 level.

Tabela 4. Correlation coefficients between surface roughness, wood density and vessels diameter

Factor	Roughness			
	along the grain		perpendicular to the grain	
	on tangential section	on radial section	on tangential section	on radial section
Density	-0.17^{NS}	0.19^{NS}	-0.30^{NS}	0.02^{NS}
Vessels diameter	0.62^{NS}	0.66*	0.51^{NS}	0.67*

^{NS} – Not significant, * - significant at the 0.05 level.

The standardized regression coefficients (tab. 4) were applied to verify wood density and anatomical factor (vessels diameter) determining the tested surface roughness. The larger the absolute values of the standardized regression coefficient, the greater its influence was on the dependent variables.

As density is widely acknowledged to reflect many wood properties, it was expected to influence the surface roughness of the tested wood species. However, it appeared that wood density was not an important indicator determining surface wood properties. As demonstrated in tab. 4, the calculated correlation coefficients were relatively low (below 30%). Significant correlations were determined for average vessels diameter that indicated a high role in wood roughness measured perpendicular to the fibres.

Based on the above, it can be assumed that the wood density and wood porosity (the amount of wood in the wood) are not important for the surface roughness. The size of the pores formed by the vessels determines the deviation from flatness. It should also be assumed that tests performed on a different set of wood may produce different results. Therefore, knowledge in this area should be expanded.

CONCLUSIONS

The results of presented experiment allow to conclude that:

1. The roughness of tested wood species demonstrated variation, depending on the wood section and the measurement direction. In general, radial sections showed higher roughness than tangential sections due to interlocked fibres in tested wood species (fibres cut in various ways on the radial section of the wood). Roughness measured perpendicular to the wood fibres were twice as high as those measured parallel to the grain. Thus, the roughness of the wood surface is influenced by the arrangement of anatomical elements.
2. Wood density was not an important indicator determining surface roughness for tested wood species. The determining element for the roughness measured across the fibres was the diameter of the vessels.
3. Further research is advisable due to the enormous variability of the structure and properties of wood.

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Streszczenie: *Analiza chropowatości powierzchni drewna w oparciu o analizę jego struktury i gęstości.* Celem prezentowanych badań było określenie wpływu gęstości drewna oraz szczegółów budowy strukturalnej na chropowatość powierzchni materiału. Zakresem badań objęto dziesięć różnych gatunków drewna (głównie tropikalnego) ze względu na szeroki zakres gęstości i różnice anatomiczne. Wyniki przeprowadzonych badań pozwalają na stwierdzenie, że chropowatość drewna badanych gatunków wykazywała zmienność w zależności od przekroju drewna i kierunku pomiaru. Przekroje promieniowe wykazywały większą chropowatość, co jest spowodowane zawiłościami w układzie włókien. Chropowatość mierzona prostopadle do włókien drzewnych była dwukrotnie większa niż mierzona równolegle do kierunku przebiegu włókien. Gęstość drewna nie była istotnym wskaźnikiem określającym chropowatość powierzchni badanych gatunków drewna. Elementem determinującym chropowatość mierzoną w poprzek włókien była średnica naczyń. Wskazane są dalsze badania ze względu na ogromną zmienność struktury i właściwości drewna.

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