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THE INFLUENCE OF EARLYWOOD AND LATEWOOD UPON THE PROCESSING ROUGHNESS PARAMETERS AT SANDING

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Abstract:
Sanded wood surfaces contain irregularities caused by both the sanding process and the anatomy, so the anatomical roughness, which is independent of any machining operation, must be excluded from measurements of surface irregularities if the processing roughness is to be properly evaluated. This paper investigates the effect of earlywood and latewood on the roughness parameters of oak sanded with P180 and spruce and beech sanded with P120 grit size. The wood anatomy was excluded from the roughness profiles using a method based on the Abbot-curve. Latewood was smoother than earlywood with the greatest ratio in oak, followed by spruce and beech. The ratio of latewood to earlywood processing roughness.described by several roughness parameters was in an inverse relationship with the density ratio of these growth areas reported in literature. The roughness parameters in mix areas of latewood and earlywood seemed to be related to species density. A mean of the roughness parameters measured locally in both areas of earlywood and latewood was a good approximation of the surface roughness.

***Key words**: processing roughness; sanding; earlywood; latewood.*

INTRODUCTION

A sanded surface contains irregularities caused by the abrasive grit particles, which plough the material, creating scratches in the surface. Such irregularities of the surface are inherent in a machining process like sanding and are known as the **processing roughness**. However, measured data from any nominally flat surface contains not only roughness, but also form errors and waviness, which do not characterise the processing. Both form errors and waviness should be excluded from any assessment of the surface roughness by using filtering procedures suitable for wood surfaces since it was acknowledged that standard filters introduce distortions when applied to wood (Krish and Csiha 1999, Gurau *et al*. 2005). Such procedures for wood surfaces were developed and described in detail by Gurau *et al*. (2006 and 2009).

Compared to processed homogeneous materials, wood surface roughness data contains not only processing irregularities, but also a specific anatomical structure. This is specially the case of earlywood areas which may locally cause large surface irregularities which have nothing to do with the machining process (Magoss 2008). It was acknowledged that surface roughness of wood can be affected by the latewood/earlywood ratio (Goli *et al*. 2001, Kilic *et al*. 2006; Dundar *et al.* 2008; Wilkowski *et al.* 2010).

Earlywood is comprised of cells with thin walls and large lumen, which have a low resistance to processing, while latewood has cells that are more mechanical resistant to stresses, with thicker walls and narrow lumens (Pescarus 1982). The ratio of the latewood to the earlywood density is ρ_0 (LW)/ ρ_0 (EW) = 1.96-3.1 for softwoods, ρ_0 (LW)/ ρ_0 (EW) = 1.55-2.8 for ring porous hardwoods and ρ_0 (LW)/ ρ_0 (EW) = 1.21-1.76 for diffuse porous hardwoods (Kollmann and Côté 1968). Large differences between earlywood and latewood in softwoods and ring porous species can be explained by the high difference in cell lumen volume, while diffused pores species are more homogenous.

Differences between earlywood and latewood affect the smoothness of softwood surfaces more than of hardwoods (Lutz 1956, Wilkowski *et al.* 2010). Spruce is known as a species that is difficult to sand smoothly (Cotta *et al.* 1982). The particles may compress the earlywood elastically, but the latewood prevents proper cutting. After sanding the earlywood may recover and form ridges on the surface. Follrich *et al.* (2010) found that wood machining particularly affects earlywood tracheids of softwoods. Abrasively planed surfaces and saw-cut surfaces suffer from crushed and fractured surface cells and this is occuring to the earlywood cells, which have thin walls that are easily split. Vitosite *et al.* (2012) stated that surface sanding causes damage to the walls of wood cells, which are particularly weak in the earlywood area.

Sieminski and Skarzynska (1987) found that the roughness of earlywood surfaces was much higher than of the latewood surfaces. Similar result was found by Laiveniece and Morozovs (2014). However, it appears that all previous studies, although just a few on sanded surfaces, have made observations on the quality of processed earlywood and latewood areas without excluding the wood anatomy from the evaluation of the processing roughness.

A proper evaluation of the quality of the sanding operation implies not only that the roughness data has to be free of distortions, but also that irregularities due to wood anatomy are excluded from the numerical characterization of the processing roughness (Westkämper and Riegel 1993, Schadoffsky 2000, Gurau *et al*. 2007).

OBJECTIVES

This paper examines the processing roughness of three sanded species, by considering the influence of earlywood and latewood areas when wood anatomical irregularities are removed.

METHOD, MATERIALS AND EQUIPMENT

The influence of earlywood and latewood areas was studied on single specimens of European oak (*Quercus robur*), beech (*Fagus Sylvatica*) and spruce (*Norway spruce*). Oak and spruce have different anatomies, and also significant differences in the size of the anatomical features between earlywood and latewood. Beech, as a diffuse porous species, has less difference between earlywood and latewood than the other two species. Oak had a density ρ_0 = 632kg/m^3, which was close to beech with ρ_0 = 697kg/m^3, while spruce had the lowest density ρ_0 = 396kg/m^3. Species were conditioned to a uniform moisture content of approximately 12% by storage in a climate-controlled environment.

The specimens were cut to surface dimensions of 100x90mm, suitable for sanding on a Makita 9402 portable belt sander. The machine was inverted and mounted on a solid base, and a stiff frame was constructed around the equipment. The specimen was held rigidly at all times on top of the belt. The sanding was performed with aluminium oxide closed-coated cloth belts measuring 600x100mm. The processing was conducted at a constant contact pressure of 3.2kN/m^2 and a belt speed of 5m/s, the fastest speed on this machine. Before the specimens were sanded, the new sanding belts were worn by continuous sanding for 30min to remove the initial sharpness of the abrasive grits. Fresh belts result in high roughness values, which are not representative of the process (Cotta *et al*. 1982, Carrano 2000).

The grit sizes were P120 for beech and spruce and P180 for oak, which represent abrasives commonly used in the furniture industry for the final sanding before coating.

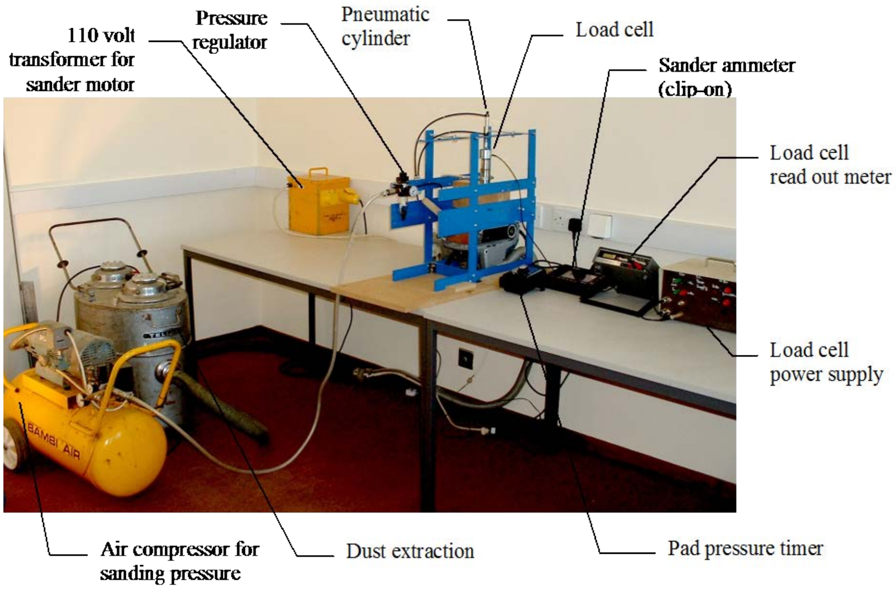

Fig. 1.
The sanding device and associated equipment.

The surface measurements were carried out by stylus method, which used a stylus with 2.5µm tip radius and 90° tip angle and measured the surface perpendicular to the sanding marks at a speed of 1mm/s. A stylus is preferred to a laser because it is better able to detect surface irregularities (Gurau *et al.* 2001).

One set of measurements was made by a visual examination of the surface to comprise both earlywood and latewood and to obtain information about a mix surface. Areas of 15mm x 10mm, one for each specimen, were scanned at a 5µm resolution on the x-axis and 500µm on the y-axis. Each of the 20 profiles had a length of 15mm and was measured across the grain. Separately, from these measured areas, five profiles were extracted so that they have included only latewood or earlywood data for comparison with mix areas.

Data for all three species were stored in ASCII format and processed with algorithms written in MathCad™. Form errors were removed according to the profile method of ISO 3274 (1996). For the set of specimens in this study form errors were removed with a second order polynomial regression, which proved to be the best fit for the initial data.

The total roughness profiles, which contain both processing roughness and wood anatomy, were obtained by filtering the surface with the Robust Gaussian Regression Filter from ISO/TS 16610-31 (2010). A cut-off length of 2.5mm produced undistorted profiles (Gurau *et al.* 2006).

The anatomical irregularities were separated from processing irregularities with a method based on the Abbot-curve (Gurau 2004), in which outlying peaks and valleys were detected and replaced with zeros. The zero values were neglected when the roughness parameters were calculated.

The processing roughness was evaluated with the roughness parameters *Ra, Rq, Rt, Rsk, Rku* from ISO 4287 (1998) and a parameter *RSmw*, which was modified from *RSm.* The parameter *RSmw* is a measure of the irregularities width. It differs from the standard *RSm* in that the minimum height and spacing requirements for a profile element are disregarded. If they are not, then the width and depth of the anatomical features can obscure the processing features.

Mean parameters *Ra* and *Rq* are common roughness indicators, but alone, they do not provide sufficient information about wood surface topography. Height parameter *Rt* and shape parameters *Rsk* and *Rku* are instead very sensitive to isolated extreme irregularities.

Rsk is a parameter that can be strongly influenced by isolated peaks or isolated valleys. Surfaces with a positive skewness, *Rsk*>0 have fairly high peaks that protrude above a smoother plateau, while surfaces with a negative skewness, *Rsk*<0 have fairly deep valleys in a smoother plateau.

Rku is also a parameter that can be strongly influenced by isolated peaks or valleys, which lead to high kurtosis (*Rku*>3).

The parameters were adapted for wood in that they were calculated over the entire evaluation length rather than shorter sampling lengths. The evaluation length is restricted by the capacity of the measuring instrument, so its division into sampling lengths, as instructed by ISO 4287 (1998), leads to data sets that do not represent the variation of the wood surface.

Other calculated parameters were *Rk*, *Rpk* and *Rvk* from ISO 13565-2 (1996). *Rk* is a measure of the core roughness data. *Rpk* and *Rvk* are parameters that define isolated peaks or valleys in the profile. They are sensitive to any change in the thresholds that separate the processing roughness from wood anatomy and that can add or remove a few peaks or valleys.

Each roughness parameter was calculated as a mean of all values obtained from each individual profile for earlywood and latewood and mix areas and their corresponding mean coefficients of variation for oak P180, beech P120 and spruce P120 respectively. Data was included in tables. Supplementary, a column of each table calculates the mean roughness value for the earlywood and latewood combined as (EW + LW)/2. Roughness parameters from latewood and earlywood were compared by the ratio LW/EW. Roughness parameters measured individually from earlywood and latewood were further compared with roughness parameters from mix areas containing both earlywood and latewood.

RESULTS

Table 1, Table 2 and Table 3 contain mean values of the roughness parameters for earlywood and latewood and their corresponding mean coefficients of variation for oak P180, beech P120 and spruce P120 respectively.

In Table 1, Table 2, Table 3, Fig. 2 and Fig. 3 it can be seen that all the roughness parameters showed that latewood was smoother than earlywood, which is in agreement with Cotta et al. (1982), who made this observation from surface photographs and with Sieminski and Skarzynska (1987), although they did not separate processing and anatomical roughness. Latewood roughness, as defined by parameters which measure the height of the irregularities, was only approximately 46-50% of the earlywood roughness of oak P180 (Table 1), followed by spruce P120 with approximately 65-72% (Table 2) and beech with 76-84% (Table 3). These results can be explained by the anatomical differences between earlywood and latewood, which led to different densities and consequently to different depths of the sanding marks. Kollmann and Côté (1968) recorded the existence of different densities of earlywood and latewood (Table 4). The density ratios in Table 4.seem to agree well with the ratios of roughness parameters from earlywood and latewood for all three species. The ratio of LW/EW for Ra, which is a mean roughness parameter, aproximated the best the inverse ratio EW/LW of densities (upper range values), as they were reported by Kollmann and Côté (1968).

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Table 1

The influence of earlywood and latewood on roughness parameters of oak sanded with P180. Values represent mean roughness parameters (µm). The values in brackets are mean percentage coefficients of variation. EW – earlywood; LW – latewood; Mix - mix of both earlywood and latewood.

Parameter	Oak P180				
	EW	LW	LW/EW	(EW + LW)/2	Mix
Ra	2.29 (13.79)	1.13 (12.65)	0.50	1.71	1.86 (9.56)
Rq	2.70 (12.56)	1.32 (11.27)	0.49	2.01	2.19 (8.45)
Rsk	-0.13	-0.12		-0.13	-0.07
Rku	2.22 (4.78)	2.13 (6.36)		2.18	2.17 (4.10)
Rt	11.08 (13.35)	5.22 (13.34)	0.47	8.15	8.85 (9.32)
Rk	7.25 (9.03)	3.55 (5.92)	0.49	5.40	5.96 (4.92)
Rpk	1.26 (32.66)	0.60 (35.97)	0.48	0.93	1.01 (16.12)
Rvk	2.20 (25.75)	1.01 (24.05)	0.46	1.61	1.62 (21.89)
RSmw	67.7 (7.51)	47.4 (6.70)	0.70	57.5	65.2 (5.08)

Table 2

The influence of earlywood and latewood on roughness parameters of beech sanded with P120. Values represent mean roughness parameters (µm). The values in brackets are mean percentage coefficients of variation. EW – earlywood; LW – latewood; Mix - mix of both earlywood and latewood.

Parameter	Beech P120				
	EW	LW	LW/EW	(EW + LW)/2	Mix
Ra	2.42 (11.2)	1.84 (10.9)	0.76	2.13	2.24 (8.04)
Rq	2.79 (9.78)	2.16 (10.1)	0.78	2.48	2.66 (7.36)
Rsk	-0.09	-0.15		-0.12	-0.12
Rku	2.10 (4.14)	2.18 (7.18)		2.14	2.20 (3.90)
Rt	11.1 (10.6)	8.67 (13.2)	0.78	9.90	10.9 (8.57)
Rk	7.56 (7.06)	6.02 (5.89)	0.80	6.79	7.35 (4.51)
Rpk	1.37 (31.2)	1.15 (25.2)	0.84	1.26	1.29 (22.5)
Rvk	1.90 (25.9)	1.46 (22.9)	0.77	1.68	1.93 (19.5)
RSmw	75.5 (7.47)	65.5 (6.11)	0.87	70.5	80.6 (3.77)

Table 3

The influence of earlywood and latewood on roughness parameters of spruce sanded with P120. Values represent mean roughness parameters (μm). The values in brackets are mean percentage coefficients of variation. EW – earlywood; LW – latewood; Mix - mix of both earlywood and latewood.

Parameter	Spruce P120				
	EW	LW	LW/EW	(EW + LW)/2	Mix
Ra	3.63 (13.6)	2.35 (12.6)	0.65	2.99	2.85 (9.70)
Rq	4.07 (11.6)	2.74 (11.0)	0.67	3.41	3.36 (8.34)
Rsk	-0.10	-0.05		-0.08	-0.06
Rku	1.94 (5.66)	2.12 (5.15)		2.03	2.13 (3.48)
Rt	15.5 (12.0)	11.1 (11.4)	0.71	13.3	13.5 (9.04)
Rk	10.7 (8.46)	7.44 (8.59)	0.70	9.06	9.56 (5.26)
Rpk	1.97 (28.4)	1.37 (30.3)	0.69	1.67	1.60 (20.5)
Rvk	2.61 (23.8)	1.89 (23.6)	0.72	2.25	2.06 (15.7)
RSmw	75.8 (7.55)	63.6 (5.56)	0.84	69.7	71.8 (4.54)

Table 4

Absolute density values ρ_0 of latewood and earlywood for spruce, oak and beech (from Kollmann and Côté, 1968)

Species	ρ_0 earlywood (kg/m^3)	ρ_0 latewood (kg/m^3)	Density ratio $\frac{\rho_0(LW)}{\rho_0(EW)}$	Density ratio $\frac{\rho_0(EW)}{\rho_0(LW)}$
Spruce	307	601	1.96	0.51
Oak	317 – 454	888 – 930	1.96 – 2.80	0.36 – 0.51
Beech	502 – 536	748 – 883	1.34 – 1.76	0.57 – 0.75

Roughness parameters in latewood and earlywood in Fig. 2, but also on mix areas in Table 1, Table 2 and Table 3 seemed to be related to species density, as expected spruce was rougher than the other two. The influence of grit size can also be noted; although the oak had a lower density than the beech, all the roughness parameters were lower than those from beech, because the oak was processed with a finer grit size.

From Fig. 3, *RSmw* depended on the grit size; values for earlywood of beech and spruce sanded with P120 were very similar as were the latewood values, while for oak sanded with P180 the values were lower. This parameter appears less sensitive to density.

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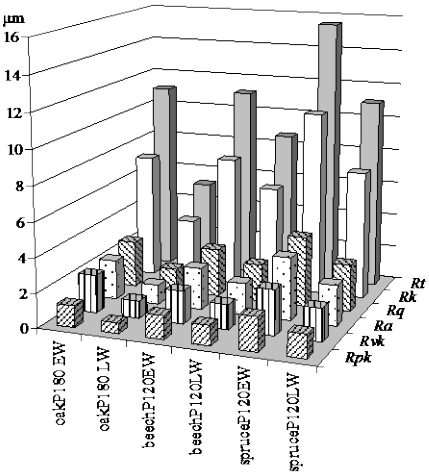

Fig. 1.
The influence of early-wood and late-wood areas on roughness parameters Rpk, Rvk, Ra, Rq, Rk and Rt for oak sanded with P180 and beech and spruce sanded with P120 (EW – earlywood; LW – latewood).

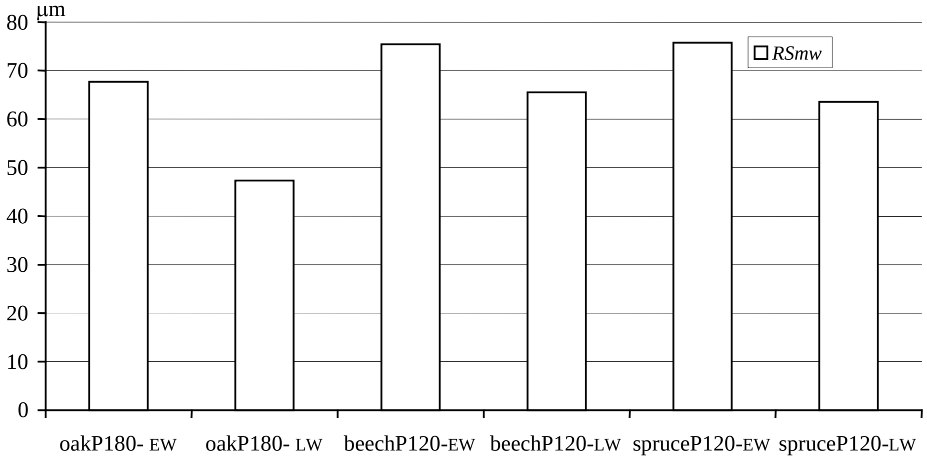

Fig. 2.
The influence of earlywood and latewood areas on roughness parameter RSmw for oak sanded with P180 and beech and spruce sanded with P120.

Given the differences in roughness between earlywood and latewood, it appears that the percentage of these areas on the surface under evaluation is important. However, mean values of roughness parameters measured separately on earlywood and latewood, (EW + LW)/2, had similar results to the processing roughness parameters measured from mixed areas (Table 1 to Table 3). Although is was not studied the exact correlation between different percentage of earlywood and latewood areas and their influence on surface roughness, it appears that measured surfaces should contain both, to be relevant for assessing surface quality of wood.

CONCLUSIONS

A rigurous quantification of the effect of species, expressed by its latewood and earlywood growth areas, on the processing roughness at sanding implies that anatomical irregularities are removed from the evaluation of roughness parameters. The effect of the processing roughness on oak sanded with P180 and on beech and spruce sanded with P120 was examined considering the two types of annual growth, earlywood and latewood. The biasing effect of the anatomical irregularities was removed by separating the roughness data with a method based on the Abbot curve.

Latewood was smoother than earlywood with the greatest ratio in oak, followed by spruce and beech. The ratio of latewood to earlywood processing roughness described by several roughness parameters was in an inverse relationship with the local density ratio of latewood to earlywood provided in literature. Furthermore, the roughness parameters in mix areas of latewood and earlywood seemed to be related to species density. Although it was not studied the exact correlation between the percentage of areas with earlywood and latewood and surface roughness, it appears that measured surfaces should contain both earlywood and latewood, to be relevant for assessing surface quality of wood. A mean of those extremes was a good approximation of surface roughness.

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