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ANALYSIS OF ROUGHNESS OF SANDED OAK AND BEECH SURFACES

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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 comparative surface roughness and the effect of wood anatomy on roughness parameters of oak and beech sanded with various grit sizes. The wood anatomy was excluded from the roughness profiles using a method based on the Abbot-curve. Total roughness parameters, which contain both the processing irregularities and the wood anatomy, were compared with processing roughness parameters for both species. The processing roughness of sanded oak and beech surfaces increased with the abrasive grit size and was higher for beech compared to oak. The effect of anatomy was to increase measures of roughness with greatest amount for oak compared to beech.

Key words: *total roughness; processing roughness; sanding.*

INTRODUCTION

A quantitative reproducible evaluation of surface quality implies the use of measuring instruments to collect data from the surface, followed by a numerical evaluation of the data. The numerical evaluation can calculate standard roughness parameters so that comparisons can be made between different surface textures.

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 that is independent of any machining. 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).

In studies reported in the literature the anatomy is generally not removed. In some studies the measurements are deliberately made in areas less affected by wood anatomy, such as latewood areas (Cotta *et al.* 1982, Costes and Larricq 2001). Other approaches involve mechanically separating the anatomy by using a variety of sizes and shapes of styli (Ehlers 1958, Peters and Mergen 1971, Heisel and Krondorfer 1995). A number of numerical methods have been reported to identify wood anatomical irregularities. These include the use of a material ratio curve called the Abbot curve, defined in ISO 13565-1 (1996), (Westkämper and Riegel 1993), image analysis (Schadoffsky 2000) or setting subjective levels of threshold, through a visual examination of the data, to exclude the anatomy (Fujiwara *et al.* 2003).

These different approaches in wood surface metrology make a comparison between various results difficult. However, in a doctoral study, Gurau (2004) found that once a roughness profile is free of any distortions, the Abbot-curve was a straightforward tool for separating the processing roughness from anatomical irregularities (Gurau *et al*. 2007).

OBJECTIVES

This paper employs the principle of the method of separation based on the Abbot-curve to comparatively evaluate the processing roughness of sanded oak and beech surfaces and to examine the consequences of not removing wood anatomy on the evaluation of roughness parameters.

METHOD, MATERIALS AND EQUIPMENT

a) Method to separate the processing roughness from wood anatomy

The actual distribution of the profile heights can be calculated from the Abbot curve of a roughness profile. The Abbot-curve is constructed by sorting the data points in descending order. It allows the profile to be divided into three sections: the peaks, a middle plateau and the valleys. Statistically outlying peaks and valleys appear as non-linear regions in the Abbot-curve, and therefore can be excluded. The method of thresholding the data is described in detail by Gurau *et al*. (2007).

The core data is assumed to represent the height variation caused by sanding, but inevitably includes the portions of anatomical features located within the thresholds, which cannot be separately identified. Data points above the upper threshold represent the fuzziness, which is mainly dependent on wood characteristics: species, density and moisture content, and to a lesser extent on the grit size (Stewart 1980). Data points below the lower threshold represent the anatomical features that exist on the surface independently of the sanding process.

Fig. 1 shows an oak roughness profile represented as data points, where upper and lower thresholds delimit the core data. These high-density data that appear well delimited from fuzziness and pores were considered to characterize the processing. To separate the data points outside the thresholds from the core data, they can be replaced with zeroes, which can easily be excluded from the calculation of roughness parameters.

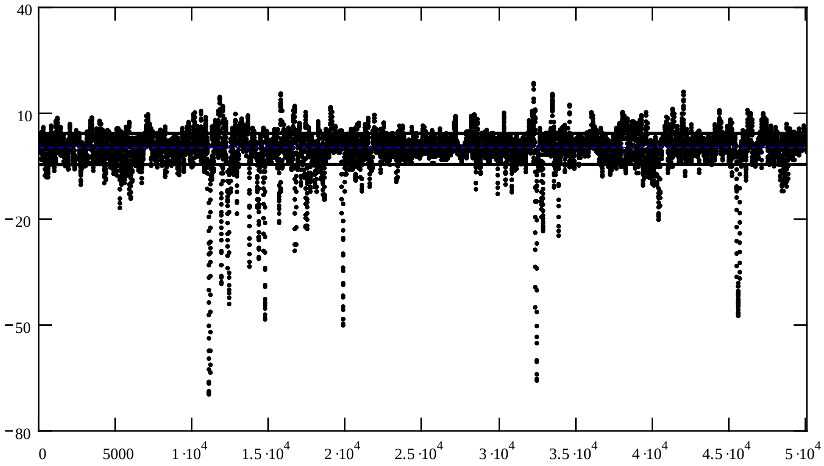

Fig. 1

Core roughness data delimited by thresholds for oak sanded with P120 (all values are in μm).

b) Experimental design

One set of species was European oak (*Quercus robur*), as a common ring porous commercial species with large earlywood pores. Oak surfaces are inherently difficult to analyze since they contain groups of deep pores that must be separated from the recorded profile if the processing roughness is to be properly evaluated. Tangential surfaces were prepared, to give the greatest variation in the surface features. The other set of species for analysis was beech (*Fagus Sylvatica*) as a commercial diffuse-porous wood species, with relatively homogeneous anatomic structure, which was prepared by sanding courtesy to Dr. Csilla Csiha from Sopron. Species were conditioned to a uniform moisture content of approximately 12% by storage in a climate-controlled environment. In case of oak, one specimen was prepared from each of two boards and 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.

In case of beech, six boards measuring 200x100mm were sanded with a Makita portable belt sander Toptech Siawood 2920 aluminium oxide closed-coated cloth belts measuring 75x533mm. To reduce the vibration, the sanding machine was kept fix and fed by means of a temporary adjusted belt with a feed speed of 7m/min.

Before the specimens were sanded, the new sanding belts were worn by continuous sanding for 30 min 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, P150, P180, P240. P120, P150 and P180 are commonly used in the furniture industry for the final sanding before coating. New finishing techniques can require even finer grit sizes from P220 to P280, so P240 was included as an example of such fine commercial sanding.

The surface measurements were carried out in case of oak specimens on a Taylor Hobson instrument (TALYSCAN 150) at 3M, Atherstone, UK. The scanning head was a stylus with 2.5µm tip radius and 90° tip angle, which 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). For beech specimens, a Mahr Perthen SP3 instrument endowed with a stylus tip with 2.5µm radius was used.

To provide data for the roughness parameters, three areas were randomly chosen on the surface of each oak specimen. Each area contained 5 profiles of 50mm length, which was considered sufficient to characterize the wood anatomical variability (Gurau 2004). This provided 30 profiles and each profile was sampled at a resolution of 5µm, which had been found suitable for wood surfaces (Gurau 2004), while the spacing between consecutive profiles was 500µm. For beech, from each surface of the 6 specimens being prepared with the same grit size 2 roughness measurements were performed at a resolution of 2.17µm, the length being limited by the instrument capability to 12.5mm.

Data for both 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 separation of processing roughness from the other irregularities of the surface followed the method that uses the Abbot-curve (Gurau 2004), in which outlying peaks and valleys were replaced with zeros, which were neglected when the roughness parameters were calculated.

The processing roughness and the total roughness were evaluated with the roughness parameters *Ra, Rq, Rt, Rsk, Rku* and *RSm* from ISO 4287 (1998).

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.

In contrast to the previous parameters, which are measures of the height of the irregularities, the parameter *RSm* is a measure of their width. To calculate *RSm* for the processing roughness, the profile was compacted in areas where the outliers had been replaced with zeros. *RSm* from the standard was modified for calculating the processing roughness parameter, and called *RSmw*, in that the minimum height and spacing requirements for a profile element were disregarded. If they are not, then the width and depth of the anatomical features can obscure the processing features.

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.

RESULTS

a) Comparison between processing roughness of oak and beech

The results are contained in Tables from Table 1 to Table 3 and Figures, from Fig. 2 to Fig. 8.

Height processing roughness parameters were higher for beech than for oak with 18.5-30% for *Ra*, 27-36% for *Rq* and 34-42% for *Rt* (Table 1 and Fig. 3). Their values decreased linearly with the grit size correlating well with an R^2 of 0.99 for beech and app. 0.94 for oak (Fig. 4).

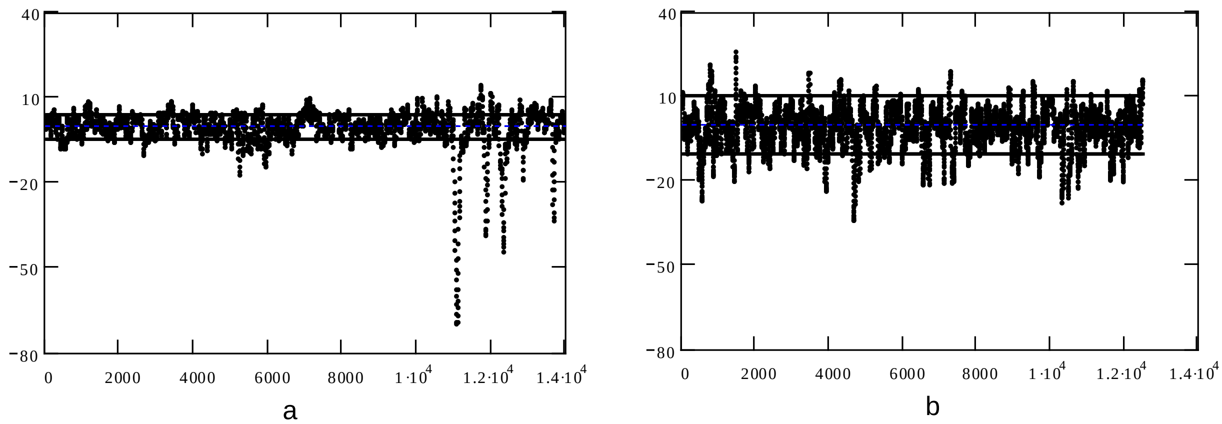

Fig. 2
Separation of processing roughness from wood anatomy for surfaces sanded with P120 grit size a-oak profile; b-beech profile (all values are in μm).

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Table 1

Processing roughness parameters of sanded oak and beech (in µm)
(in brackets mean percentage coefficients of variation)

Parameter/ grit size	**OAK**				**BEECH**			
	P120	P150	P180	P240	P120	P150	P180	P240
Ra	2.24 (8.32)	2.03 (8.05)	1.86 (9.56)	1.34 (6.36)	3.09 (8.43)	2.69 (13.44)	2.41 (11.76)	1.91 (9.64)
Rq	2.65 (7.14)	2.4 (7.33)	2.19 (8.44)	1.6 (5.63)	4.07 (7.99)	3.52 (11.96)	3.16 (10.78)	2.53 (7.89)
Rsk	-0.15	0.05	-0.07	-0.14	0.06	-0.11	-0.22	-0.20
Rku	2.18	2.22	2.17	2.18	2.67	2.72	2.67	2.67
Rt	10.8 (7.55)	9.89 (8.71)	8.85 (9.32)	6.5 (6.74)	18.16 (8.36)	15.88 (13.36)	14.02 (11.78)	11.28 (7.30)
Rk	7.60 (4.65)	6.52 (4.23)	5.96 (4.92)	4.50 (3.12)	7.29 (11.43)	6.83 (17.15)	6.16 (30.54)	4.54 (14.84)
Rpk	1.24 (20.02)	1.22 (18.23)	1.01 (16.12)	0.71 (18.78)	3.94 (22.22)	3.49 (8.51)	2.81 (20.46)	2.49 (5.64)
Rvk	1.86 (13.32)	1.89 (20.36)	1.62 (21.89)	1.08 (16.67)	5.16 (7.72)	4.17 (26.28)	4.00 (10.04)	3.29 (3.55)
RSmw	78.4 (5.18)	74.4 (4.04)	65.2 (5.07)	47.6 (3.31)	61.37 (9.32)	61.14 (5.80)	57.81 (11.53)	47.21 (7.45)
RSm	81.5 (5.06)	77.66 (4.13)	69.16 (4.98)	51.39 (3.62)	70.57 (7.75)	69.34 (4.38)	67.38 (8.51)	59.34 (4.70)

Table 2

Total roughness parameters of sanded oak and beech(in µm)

Parameter/ grit size	**OAK**				**BEECH**			
	P120	P150	P180	P240	P120	P150	P180	P240
Ra	4.78	6.13	4.73	4.76	5.33	4.33	4.10	3.63
Rq	9.1	13.19	10.5	12.6	7.13	5.73	5.50	5.00
Rsk	-4.05	-4	-4.97	-5.13	-1.16	-0.95	-1.40	-1.50
Rku	30.5	21.13	35.3	33.3	5.30	4.90	4.77	5.78
Rt	115.5	129.3	120.8	136.2	59.39	45.56	38.22	38.49
Rk	9.96	9.02	7.98	6.03	15.45	12.83	11.72	10.02
Rpk	7.28	6.66	4.64	3.89	5.70	4.72	3.09	3.42
Rvk	19.8	31.3	24.8	34.1	2.68	7.26	13.22	10.88
RSmw	104.2	106.9	87.9	64.9	78.83	78.52	71.81	65.81
RSm	213.7	283.4	251	262.1	93.60	93.85	84.74	76.90

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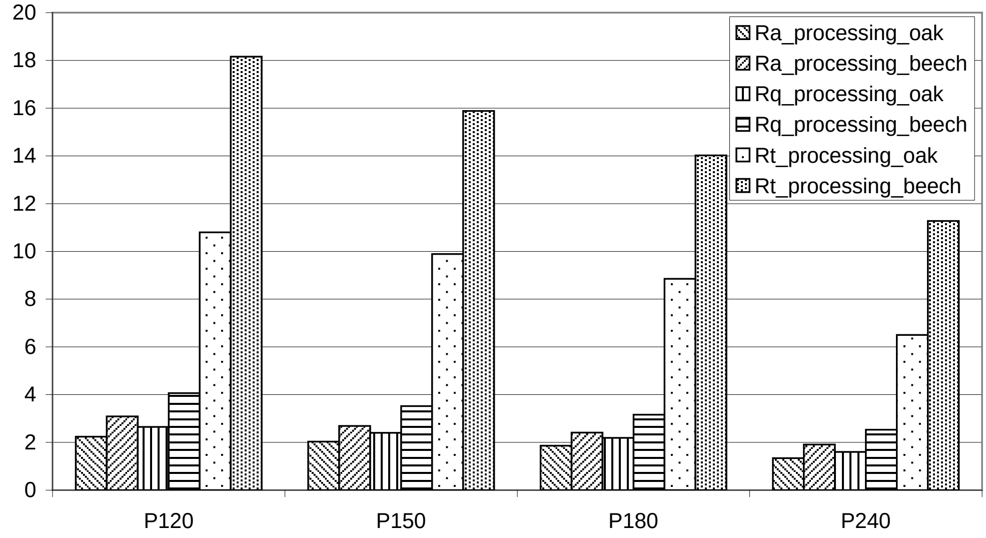

Fig. 3
Comparison of processing roughness parameters of oak and beech surfaces sanded with various grit sizes (all values on y are in µm).

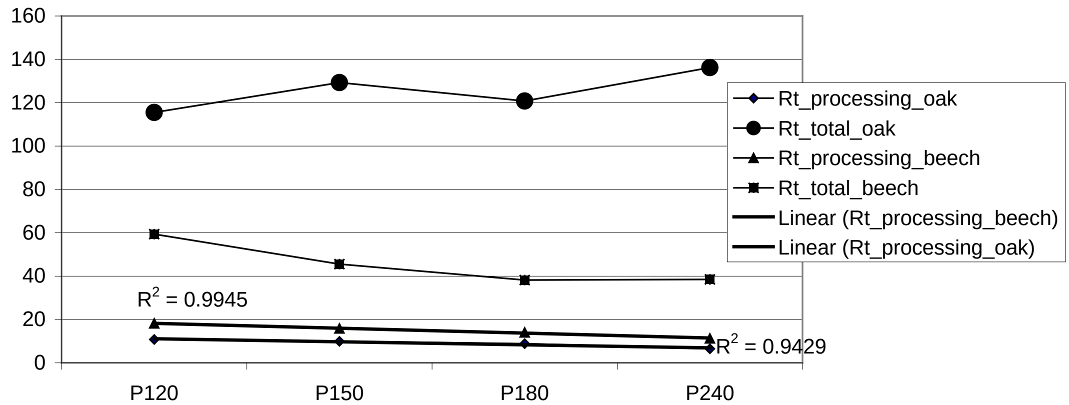

Fig. 4
Comparison of processing and total Rt roughness parameter for sanded oak and beech (all values on y are in µm).

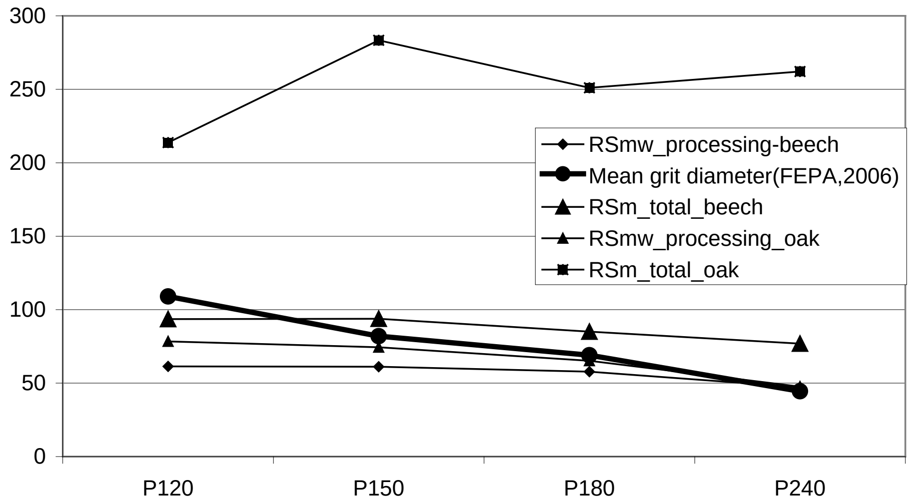

Fig. 5
Comparison of the spacing parameters RSm_total and RSmw_processing of sanded oak and beech surfaces with the mean grit diameter as given in FEPA (2006) (all values on y are in µm).

Rk, measured from the total roughness data, which is an approximate measure of the core roughness, confirmed for all grit sizes 30-40% greater values for beech than for oak. It was interesting, though, to observe the Abbot-curve parameters after the separation of wood anatomy. The core data, evaluated by *Rk*_processing was similar for both species. *Rpk*_processing and *Rvk*_processing, were however, smaller for oak than for beech, which had a wider spead of data around the core (Fig. 2). The two species have different microscopy, with larger pores for oak (latewood: 30-70-140µm; earlywood: 150-270-350(500)) compared to beech (8-45-85µm), but with more numerous pores for beech (80-125-160/mm^2, 24.6-39.5-52.5%) compared to oak (5-8-13/mm^2 in earlywood, over 25/mm^2 in latewood, 3.9-7.7-13% for wide annual rings and 23.5-39.4-43.7% in narrow annual rings)-Wagenführ (2000). It is possible that the separation thresholds have included in case of beech, some high frequency anatomical features (pores), which can only ultimately be decided by a surface microscopic analysis. It also, may be that a longer evaluation length in case of beech, of at least 50mm, may narrow the location of present thresholds if covering wider anatomical variation.

Compared to height parameters, the spacing parameters, *RSmw* and *RSm*, were close for oak and beech, higher with 22%, respectively 13% for oak in case of P120 grit size, the difference gradually smoothing with grit size (Fig. 5).

Slightly higher values for oak may be caused by larger anatomical features still retained in the evaluation. As the grit size becomes finer, the wood anatomy tends to obscure the processing. This is visible for P240 where the spacing parameter *RSmw* for oak and beech (47.5µm and 47.2µm) was slightly higher than the mean grit diameter given by FEPA (44.5µm)-Table 1.

The spacing parameters decreased with the grit size by following a second polynomial regression (R^2 app. 0.99).

b) Comparison of processing roughness and total roughness parameters

If not removed from the evaluation, the wood anatomy increases the roughness parameters indicating a surface rougher than in reality. The ratios total roughness/processing roughness show that *Rt* is the most affected parameter, greater in case of oak 10-20 times for total roughness compared to processing roughness and app. 3 times in case of beech (Table 3).

The influence of wood anatomy on the total roughness parameters is clearly shown by skewness and was greater for oak than for beech (Fig. 6). *Rsk*_total indicates the presence of deep pores in the surface, whereas the near-zero values of *Rsk*_processing indicate that the distribution of the processing roughness data as marks left by the grit particles on the surface is symmetrical around the mean line.

Similarly, kurtosis was influenced by wood anatomy and had high positive values indicating the presence of deep valleys below a smoother plateau, greater for oak than for beech (Table 1 and Table 2).

Table 3

The influence of wood anatomy on roughness parameters of sanded oak and beech surfaces measured by ratios total/processing

Species	Grit size	Ratio total roughness parameter/processing roughness				
		Ra	*Rq*	*Rt*	*RSmw*	*RSm*
oak	P120	2.13	3.43	10.69	1.33	2.62
beech		1.73	1.75	3.27	1.28	1.33
oak	P150	3.02	5.50	13.07	1.44	3.65
beech		1.61	1.63	2.87	1.28	1.35
oak	P180	2.54	4.79	13.65	1.35	3.63
beech		1.70	1.74	2.73	1.24	1.26
oak	P240	3.55	7.88	20.95	1.36	5.10
beech		1.90	1.98	3.41	1.39	1.30

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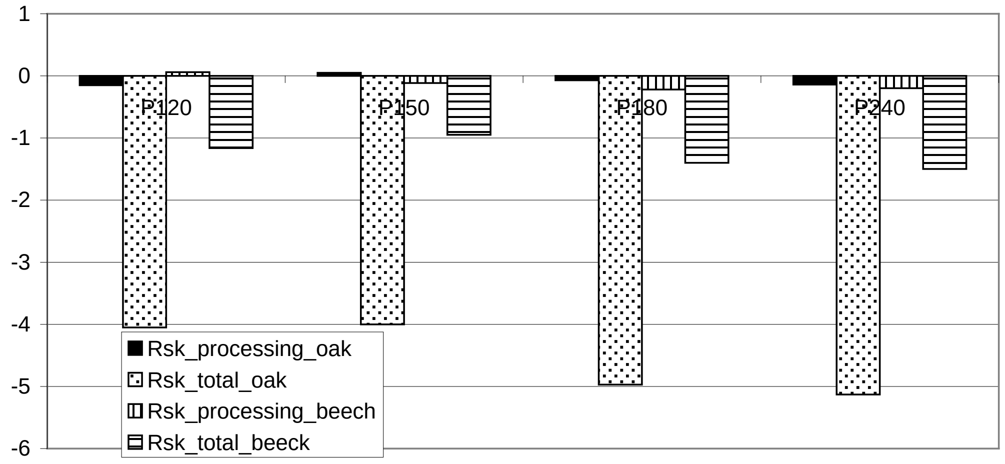

Fig. 6
Comparison of processing and total Rsk roughness parameter for sanded oak and beech.

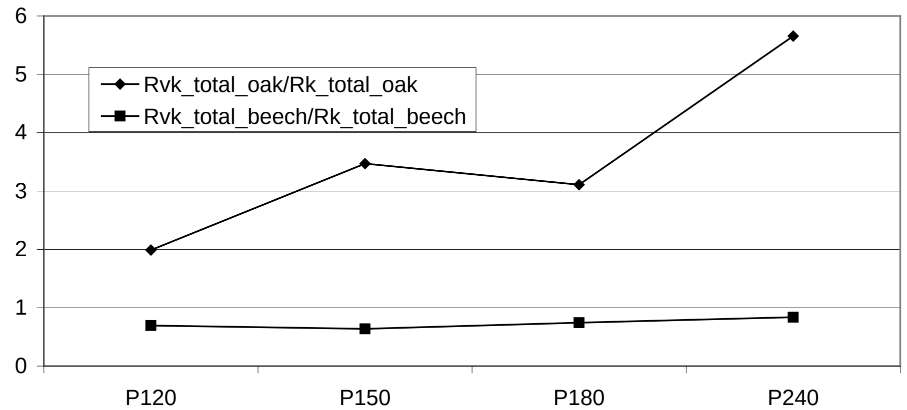

Fig. 7
The influence of wood anatomy in the total roughness profiles of sanded oak and beech visualized by the ratio Rvk/Rk.

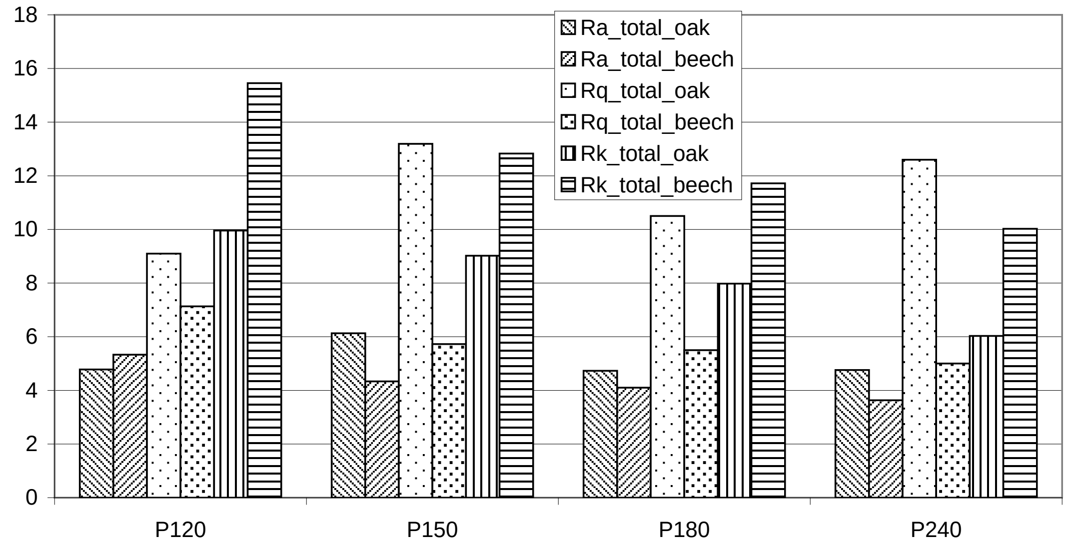

Fig. 8
Comparison of total roughness parameters of oak and beech surfaces sanded with various grit sizes (all values on y are in µm).

The biasing effect of wood anatomy on the evaluation of processing roughness is illustrated also by the ratio between *Rvk* total and *Rk* total, which increases with the grit size (Fig. 7). This shows that as the grit size becomes finer, the biasing effect of wood anatomy is stronger, especially in the case of a ring porous species as oak and is less in case of a diffuse porous species as beech.

The spacing parameters were greater when contained the anatomy and were clearly biased as their values were greater than the mean grit diameter (Fig. 5).

While processing roughness parameters were consistently greater for beech than for oak, the total roughness parameters had unpredictable trends because of the variable anatomy (Fig. 3 and Fig. 8).

CONCLUSIONS

The surface roughness of oak was analysed and compared to the surface roughness of beech when sanded with common grit sizes. In order to get only measures of processing, wood anatomy was removed with a method based on the Abbot-curve.

The results have shown that all roughness parameters have decreased with the grit size, showing smoother surfaces of oak compared to beech when judged from processing roughness parameters. The comparison was not relevant when total roughness parameters were used.

Anatomical irregularities should be removed from the evaluation if a reliable processing roughness is to be evaluated. The biasing effect of wood anatomy analysed by means of roughness parameters was by far greater for oak, as a ring porous species, than for beech, as a diffuse porous species. However, the separation of wood anatomy from processing is advisable for all species, since the sources of roughness variation apart from processing cannot be predicted.

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