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THE INFLUENCE OF MILLING AND SANDING ON WOOD SURFACE MORPHOLOGY

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ABSTRACT

The influence of milling and sanding on surface morphology of beech and spruce wood is investigated in the paper. Wood morphology was assessed through roughness and waviness parameters. The experimental results showed that the two wood surface machining techniques studied differed in their impacts on the wood roughness and waviness. Lower roughness was obtained by milling, with the milling parameters (rotation rate, specimen feed speed) not influencing the roughness significantly. The roughness of sanded surfaces was noticeably higher, with the prominent influence of the sanding grit size. In all cases, the roughness was significantly higher perpendicular to grain. The roughness-related results showed that the differences between beech and spruce wood were noticeably reduced by the mechanical treatment. Despite this fact, the impact of wood species was confirmed. The porous character of wood is the cause of the higher roughness of the wood external surface. This implies that wood surface roughness can be smoothed by an appropriate mechanical treatment, but an absolutely smooth surface cannot be acquired.

Key words: beech wood, spruce wood, sanding, milling, surface morphology, roughness, waviness.

INTRODUCTION

Wood surface structure (morphology, chemistry) and physical properties of wood structure affect wood surface gluing or treatment with film-forming materials, by influencing substantially wood wetting with film-forming materials, as well as the adhesion of these materials to wood. This is why this issue is very much discussed also today (AYRILMIS 2010, GÁBORÍK and ŽITNÝ 2010, VÁZGUEZ *et al*. 2011, SANTONI A PIZZO 2011, CSIHA and GURAU 2011, HUANG *et al*. 2012, QIN *et al*. 2014, BEKHTA and KRYSTOFIAK 2016, KÚDELA *et al.* 2016a, b, 2017a).

Complex morphology of wood surface follows its heterogeneous anatomy at macro-, micro- and sub-micro-levels. This morphology depends on several factors (wood species, mechanical treatment of the surface, various purpose-oriented pre-treatments of the surface, moisture content, ageing and similar). In the case of realistic surfaces, also the effect of tool is reflected. Considering these facts, absolutely smooth surface in terms of physics remains an ideal, impossible to reach in real life.

Wood surface morphology needs to be assessed both anatomically and physically. The physical approach means quantifying roughness and waviness parameters (CZANADY and

MAGOSS 2011, GURAU 2013, KÚDELA *et* al. 2016a, GURAU and IRLE. 2017, MOLNÁR *et al*. 2017).

Roughness, also referred to as the primary wood surface texture, is the combined outcome of the wood anatomy as well as the way of its surface treatment. Consequently, dealing with an actual wood surface there is also necessary to involve technological parameters of the given machining method as well as the parameters of the cutting tool used (CZANADY and MAGOSS 2011, GURAU 2013, FOTIN *et al*. 2011, 2013 and others).

Waviness, also referred to as the secondary surface texture, generated by mechanical treatment in interaction between the cutting tool and wood, represents unevenness patterns repeated regularly, while the wavelength of these patterns is bigger than the sampling length of the measured segment investigated in roughness. This is especially typical for milled surfaces. In this case, the waviness depends on the cutting tool´s parameters, its rotation rate and specimen feed speed as well as on the treated wood quality, heterogeneity, anisotropy and similar (AICHOUH 2003, ISPAS *et al*. 2016, KÚDELA *et al*. 2017b, GÁBORÍK *et al*. 2017).

Various types of mechanical surface treatment do not only affect the surface morphology but also its chemical structure, and consequently wood wetting and its thermodynamic characteristics (GARDNER *et al*. 1991, LIPTÁKOVÁ *et al*. 1995, KÚDELA a LIPTÁKOVÁ 2005, SANTONI a PIZZO 2011, HUBBE *et al*. 2015, PETRIČ and OVEN 2015, KÚDELA *et al*. 2016b, 2017a) affecting the quality of wood surface finished with coating materials (ŠTRBOVÁ 2015, SALCA *et al*. 2017)

The objective of this part of the work was to assess surface geometry in milled and sanded spruce and beech wood through some roughness and waviness parameters.

MATERIAL AND METHODS

The experimental measurements were carried out on specimens prepared from radial and tangential spruce and beech timber wood. The impact of milling was studied on test specimens sized 200 × 100 × 35 mm (Fig. 1a). The total number of test specimens was 60, representing by15 for radial as well as tangential surface equally in in spruce and beech. The impact of sanding was studied on specimens 40 × 40 × 40 mm in size (Fig. 1b). The total number of the specimens was 80, representing by 20 for the two surfaces and species. This size was in compliance with dimensions and set-up of the equipment for surface sanding. The test specimens were conditioned at a relative air humidity of 65 % and a temperature of 20^{o} C to an equilibrium moisture content of 12 %.

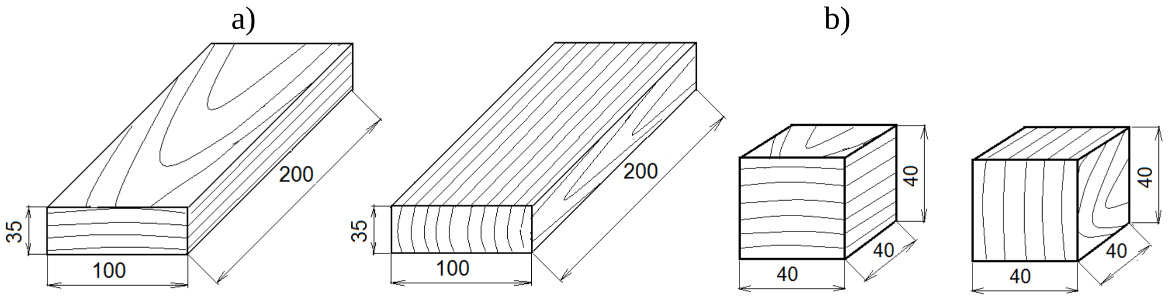

Fig. 1 Shape and dimensions of specimens for. a) milling, b) sanding.

After the conditioning, one specimen series were milled on their lateral radial and tangential sides with the aid of a milling cutter ELU MOF 177E with a power of

1800W/1100W. There were used three rotation speeds:

1st degree – 14,130 rpm;
2nd degree – 17,500 rpm;
3rd degree – 20,400 rpm

and two specimen feed speeds – 315 and 630 mm/min. The depth of cut was 2 mm and it was constant for the entire experiment.

The surface sanding was performed with a grinding machine SKIL Baseline – type 1100, with a power of 560 W (Fig. 3). The abrasion belt dimensions were 76 × 457 mm, the grit sizes were three: P80, P120 and P150. The processing speed was 200 m/min, the adherence force was 41 N.

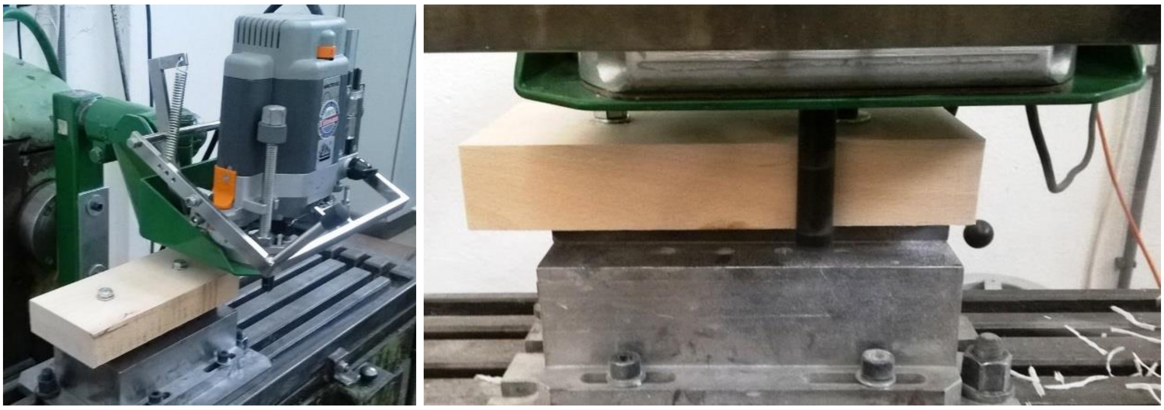

Fig. 2 Milling of specimen's lateral surface. a) vertical milling cutter ELU MOF 177E with a specimen fixed, b) lateral surface milling detail.

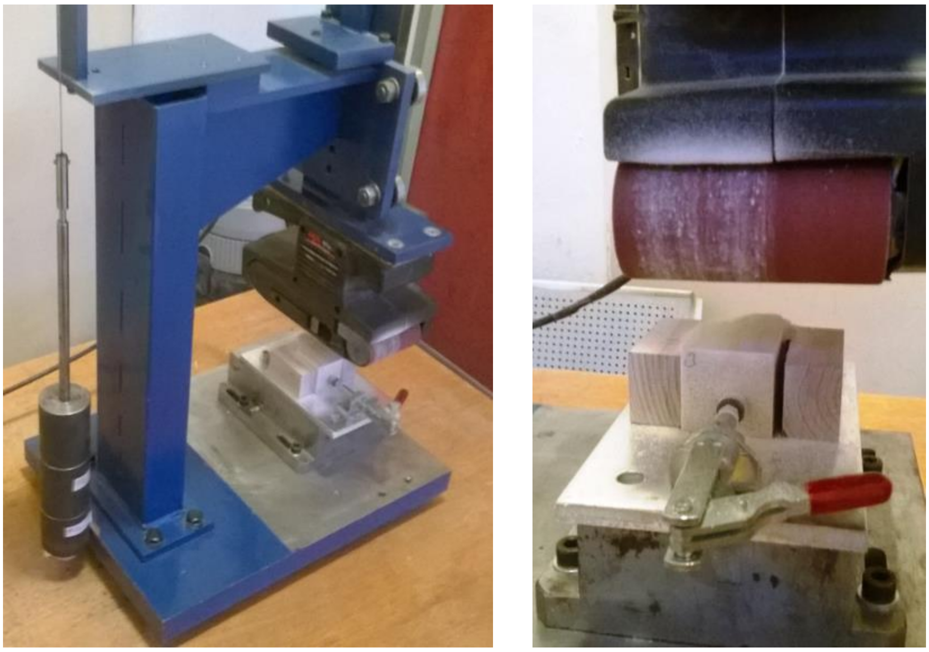

Fig. 3 Specimen sanding. a) grinding machine SKIL Baseline – type 1100, b) fixing detail.

The roughness and waviness parameters were assessed on radial and tangential surfaces, parallel and perpendicular to the grain. The roughness was evaluated through the following roughness parameters of the profile: *Ra* – arithmetic mean deviation, *Rq* – root-mean-square deviation, *Rz* – maximum height of the assessed profile within a sampling length, *RSm* – mean distance between the valleys (EN ISO 4287). The waviness was evaluated through the *Wa* – arithmetic mean deviation. The sampling length (λ_c) was 2.5 mm, the total measured length was 12.5 mm. The roughness and waviness parameters were measured with a profilometer Surfcom 130A. The scanning stylus tip had a radius of 2 μm, the horizontal resolution was 0.3 μm. The measurements were repeated twice on each specimen.

Fig. 4 Roughness measuring with a profilometer Surfcom 130A.

RESULTS AND DISCUSSION

The morphology of wood surface machined by milling and sanding was assessed based on the values of roughness and waviness parameters obtained experimentally. For each treatment the impact of the wood species (beech, spruce), surface (radial, tangential) and anatomical direction (perpendicular or parallel to the grain) were also evaluated.

The influence of milling parameters, especially rotation rate and specimen feed speed were also analysed on the milled surfaces.

The impacts of the investigated factors on the individual roughness parameters of surfaces treated by milling were evaluated with the aid of four-way variance analysis (Table 2).

The four-way variance analysis resulted in confirming significant influence of the all studied factors on the arithmetic mean deviation Ra, the mean arithmetic deviation Wa and the maximum height of the assessed profile within the sampling length Rz. There were no significant differences between the two species in the values of root-mean-square deviation Rq and mean distance between the valleys RSm.

Table 2 shows that in most cases, there were also important effects of factors acting in interactions on the inspected roughness and waviness parameters.

The influence of milling parameters was found significant, there was, however, observed no dependence of the roughness and waviness parameters on the rotation speed or the specimen feed speed (Fig. 5).

The roughness parameters Ra, Rz, Rq and RSm of beech wood perpendicular to the grain were significantly higher than parallel to grain, which is mainly implied by the cell elements orientation. The measurement errors were of secondary importance only.

The same trend was observed in the spruce wood. Higher roughness values were obtained on radial surfaces than on tangential ones. These differences were more pronounced in spruce, which can be explained by more differing properties between spring and late wood bands in this species. No similar differences, however, were observed in the longitudinal direction (Fig. 5). The experiment results (Fig. 5) show that the Ra values were always higher than 0.5 μm. This means that the beech and spruce wood surface is characterized by occurrence of coarse unevennesses. The cause of the high variability is the diverse structure of cell elements. Also the way of surface mechanical treatment has an important role.

Tab. 2 The results of four-way variance analysis (milling).

Factors	Roughness and waviness parameters				
	Ra	Rq	Rz	RSm	Wa
	Significance level "p"				
{1}milling parameters	0.000	0.000	0.000	0.010	0.000
{2}wood species	0.021	0.389	0.000	0.089	0.000
{3}surface (radial, tangential)	0.000	0.000	0.004	0.000	0.000
{4}anatomic direction	0.000	0.000	0.000	0.000	0.000
Milling parameters *wood species	0.000	0.000	0.006	0.200	0.000
milling*surface	0.011	0.017	0.013	0.012	0.000
Wood species*surface	0.198	0.354	0.833	0.018	0.772
milling*direction	0.000	0.004	0.231	0.267	0.000
Wood species*direction	0.000	0.000	0.635	0.111	0.000
surface*direction	0.000	0.000	0.001	0.000	0.009
Milling *wood species*surface	0.010	0.011	0.000	0.031	0.076
milling*wood species*direction	0.000	0.017	0.673	0.020	0.317
milling*surface*direction	0.000	0.009	0.298	0.458	0.000
Wood species*surface*direction	0.000	0.000	0.007	0.004	0.037
1*2*3*4	0.000	0.016	0.605	0.386	0.356

The corresponding cell wall elements in beech and spruce are clearly different, our results, however, do not allow to declare unequivocally which of the two species displayed more roughness for the given milling parameters. This may be due to the high variance of the results implied by the heterogeneity of the materials tested. Our results suggest that milling can, to some extent, eliminate the roughness differences between the two species, beech and spruce wood.

KÚDELA and LIPTÁKOVÁ (2005) report that the damage to cell walls was the slightest in microtomed wood. The surface treated in this way was most akin to the ideal smooth surface – the theoretic surface determined by the wood anatomic structure exclusively (Figs 6a, c). As we can see in Fig. 6a, beech wood surface consists of vessels of early and late wood and libriform fibres, with majority of them cut longitudinally and of transversally cut multi-layer pith rays; spruce wood surface consists of tracheids of early and late wood also cut longitudinally and of transversally cut uni-layer pith rays. Kúdela and Liptáková (2005) suggest this surface for using as a standard for evaluation the changes arising in milling and sanding.

Comparison between milled and microtomed beech wood surfaces (Fig. 6a, b) resulted in finding that plane-milling of beech induced cell walls distortion and, as a consequence, their imperfect cutting (Fig. 6b), which is in accord with LIPTÁKOVÁ *et al*. (1995) and with KÚDELA and LIPTÁKOVÁ (2005). The last authors report that the plane milling can cause, under common performance conditions, considerable distortion of cell walls, their compression and imperfect cutting, followed by wood fibre tearing off. In our laboratory conditions, these phenomena were not as obvious as those reported by the cited authors. In practice, cell wall distortion may be even more pronounced, due to cutting edge blunting in common steel tools.

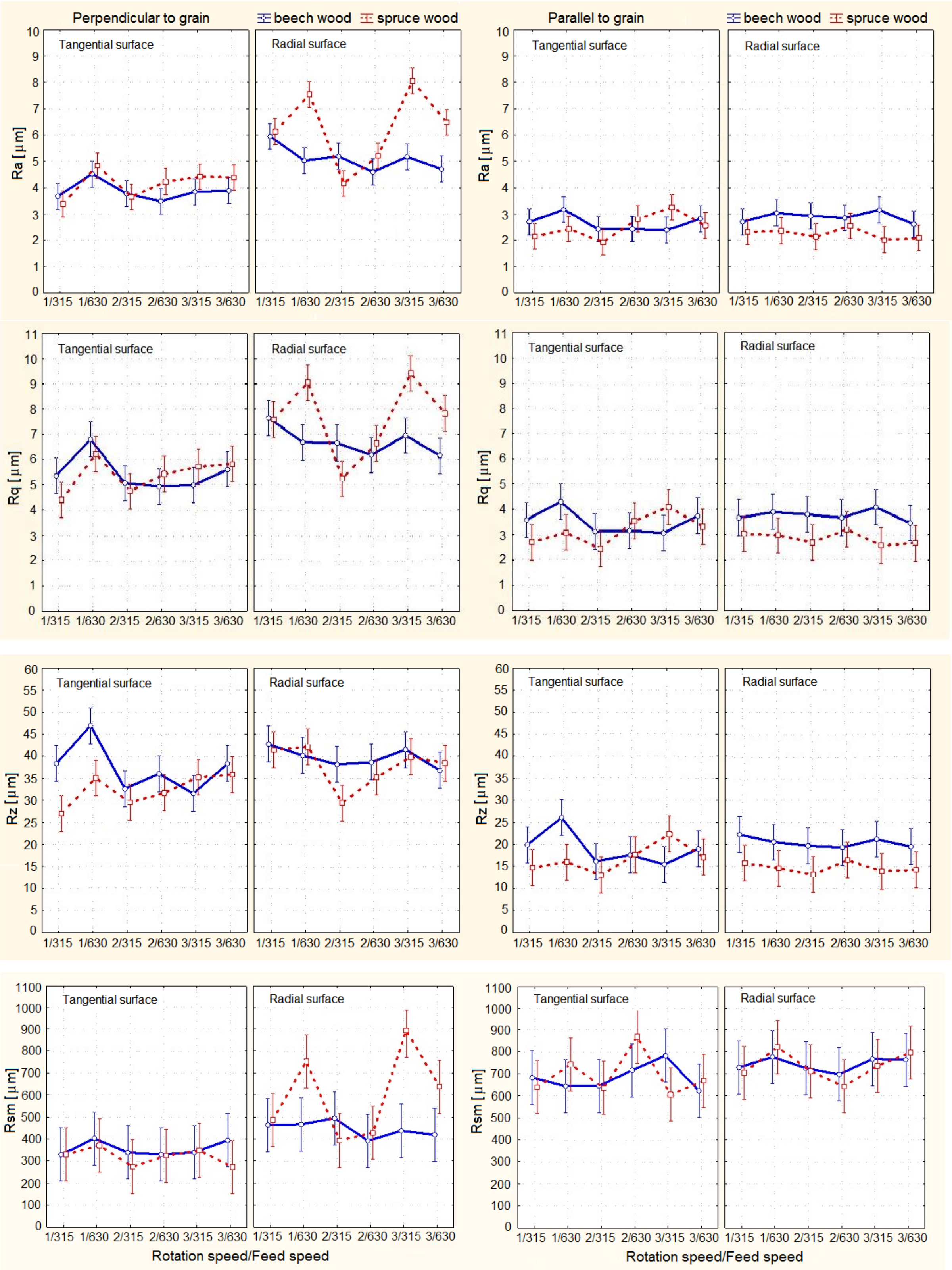

Fig. 5 Influence of anatomical direction and processing surface on roughness parameters for beech and spruce wood surface treated by milling.

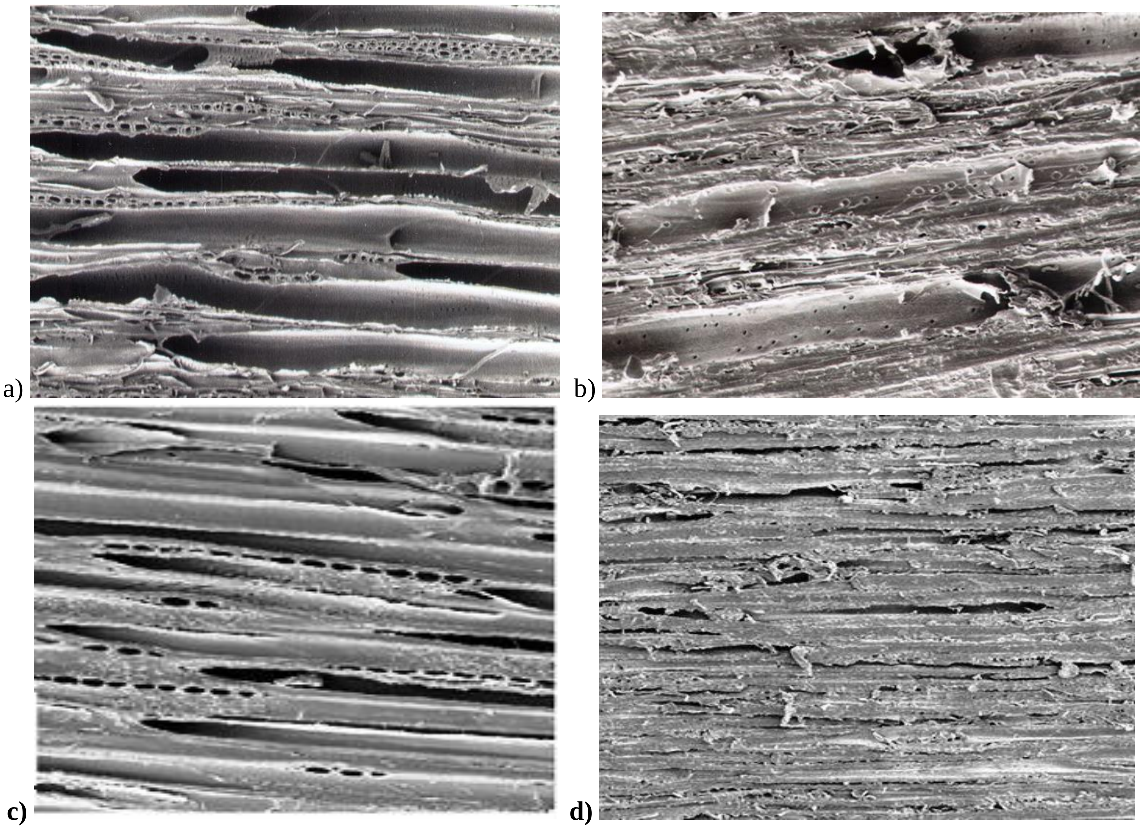

Fig. 6 Morphology of beech and spruce wood surface. a) beech microtomed, b) beech milled, c) spruce microtomed, d) spruce milled.

There were found no differences between beech and spruce wood in the waviness parameter Wa values in the longitudinal direction, and neither beech nor spruce displayed differences between their radial and tangential surfaces (Fig. 7). In this case, the values of parameter Wa were determined by the cutting tool solely. Perpendicular to grain, higher Wa values were observed in spruce, which was mainly due to the differences in properties between the early and late wood.

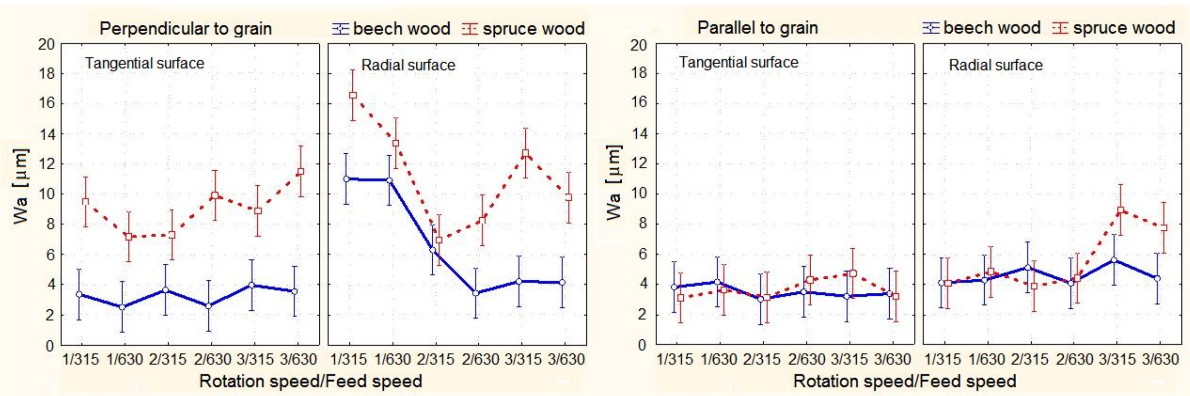

Fig. 7 Influence of studied variables on the arithmetic mean deviation of waviness profile in beech and spruce wood surface processed by milling.

In the case of sanded surfaces, the impacts of the same variables as in the case of milled surfaces were evaluated. Simultaneously, the impact of the sandpaper grit size was also evaluated. The results of four-way analysis of variance carried out on sanded surfaces are summarized in Table 3.

Tab. 3 The results of four-way variance analysis (sanding).

	Roughness and waviness parameters				
	Ra	**Rq**	**Rz**	**RSm**	**Wa**
Factors	**Significance level "p"**				
{1}grit size	0.000	0.000	0.000	0.000	0.018
{2}wood species	0.000	0.000	0.000	0.000	0.000
{3}surface (radial, tangential)	0.000	0.000	0.000	0.000	0.595
{4}anatomic direction	0.000	0.000	0.000	0.000	0.000
Grit size *wood species	0.149	0.520	0.001	0.051	0.001
Grit size*surface	0.236	0.147	0.346	0.412	0.580
Wood species*surface	0.124	0.095	0.013	0.139	0.002
Grit size*direction	0.000	0.000	0.000	0.106	0.301
Wood species*direction	0.002	0.000	0.000	0.176	0.568
Grit size*direction	0.414	0.725	0.908	0.945	0.283
Grit size *wood species*surface	0.497	0.542	0.814	0.882	0.934
Grit size*wood species*direction	0.232	0.378	0.268	0.748	0.011
Grit size*surface*direction	0.679	0.828	0.832	0.436	0.886
Wood species*surface*direction	0.109	0.073	0.112	0.030	0.031
1*2*3*4	0.933	0.864	0.868	0.780	0.463

The four-way ANOVA results confirmed significant impacts for each tested variable on each roughness parameter studied. Table 3 demonstrates that, unlike milled surfaces, most of the sanded ones did not display significant effects of interactions between the individual variables on the roughness parameters studied.

The major impact on the roughness parameters was found for the sandpaper grit size (Fig. 8). The figure illustrates that highest roughness parameters were obtained after sanding with a paper with P80, then the roughness decreased with decreasing grit size. Our results well correspond to VITOSYTE *et al* (2012) who studied roughness parameters in birch and ash sanded with papers with a grain size of 80 to 240.

All the variants of sanded surfaces showed higher roughness parameters than the milled ones. Smaller differences in roughness between sanded and milled surfaces were observed parallel to grain. The differences decreased with decreasing grit size.

The roughness parameters Ra, Rz, Rq and RSmt parallel to grain were significantly higher than along the grain both in beech and spruce. This significant difference between the anatomical directions was caused by orientation of cell elements as well as by sanding parallel to grain. Despite significant differences in roughness between radial and tangential surfaces, no dependence could be identified. The influence of wood species was confirmed important in the case of roughness measured perpendicular to grain direction. This was due to the fact that the spruce early wood density is nearly 2.5 times lower than the latewood (MOLIŃSKI *et al*. 2014) and, as such, the early wood can be more eroded by the sanding tool.

In most cases, no significant differences in roughness parameters between beech and spruce wood were observed. As we have already mentioned, there are anatomical differences between beech and spruce wood elements, and the roughness is mainly dependent on the sanding grain size and the sanding direction (KÚDELA and LIPTÁKOVÁ 2005). The last cited work shows that the changes to wood morphology induced by sanding are different from the changes induced by milling. The sanded surface morphology is to a considerable extent determined by the grain size. This is the decisive factor why the sanding even more eliminated differences in processing roughness between beech and spruce wood in comparison with milled surfaces.

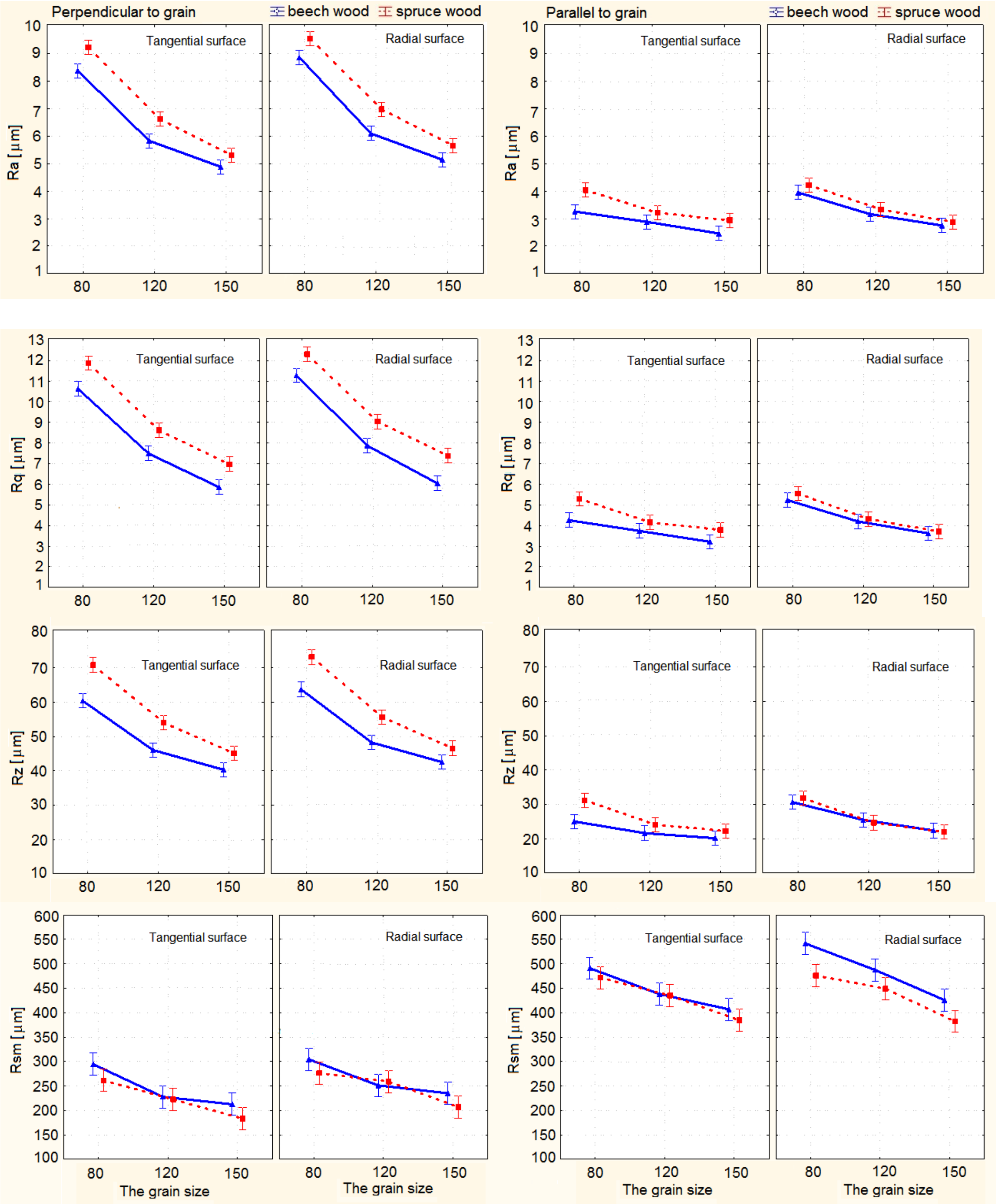

Fig. 8 Influence of studied variables on roughness parameters for beech and spruce wood surface treated by sanding.

Wood surface sanding causes release, mechanical distortion or even crushing of wood fibres and other cell elements. These particles, together with wood dust generated, are pressed into the pores, which may result in smoothed roughness. Important agents are grain size, sanding method (manual, machine) and sanding direction. On the other hand, the released wood fibre may swell and enhance the surface roughness, therefore, a new sanding of raised fibres is necessary.

The values of the waviness parameter Wa, unlike the roughness parameters, were significantly lower perpendicular to grain than parallel to grain (Fig. 9).

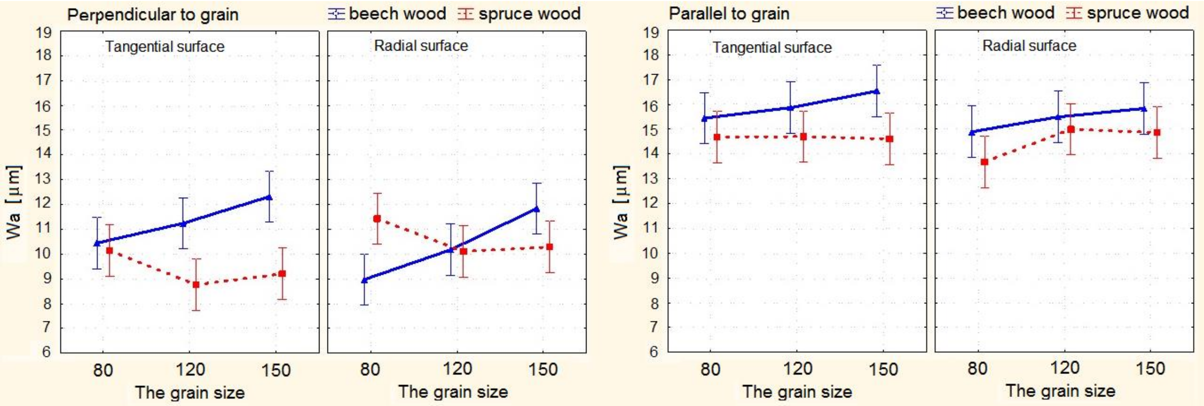

Fig. 9 Influence of studied variables on the arithmetic mean deviation of waviness profile in beech and spruce wood surface treated by sanding.

The treatment-induced effects on beech and spruce surface morphology are also reflected in the surface chemistry in these two species (RUDDICK *et al*. 1993, KÚDELA and LIPTÁKOVÁ 2005). The morphological and chemical changes influence wood wetting process with liquids, the surface free energy values and the components values of this energy (QIN *et al*. 2014, MRENICA 2015, KÚDELA *et al*. 2016b, 2017).

Compared to the microtomed wood surface considered as a standard, the milled surfaces displayed lower wettability and, owing to the used liquids, also the lowering of their hygrophilous nature. In the case of the milled surface, the wetting process was considerably lowered compared to the microtomed wood (KÚDELA and WESSERLE 2013).

KÚDELA *et al*. (2016b, 2017) found that milled surfaces manifested poorer wetting performance compared to the sanded ones. This was responded by longer time necessary for the testing liquid drop spreading over the milled beech and spruce wood surface and also by higher contact angle values. The milled surfaces also had lower surface free energy than the sanded ones. The wood surface morphology resulting from various mechanical treatment of the surface also affects the optical properties of the finishing treatment with coating materials SALCA *et al*. (2017).

The results document that both milled and sanded surfaces meet the requirements for beech and spruce wood surface treatment with coating materials.

CONCLUSION

The experimental results demonstrate that different machining ways of wood surface had different impacts on the surface morphology evaluated through roughness and waviness parameters.

Lower roughness was achieved at plane milling, the milling parameters (rotation rate and specimen feed speed), however, could not be confirmed influencing the roughness unequivocally.

The roughness of sanded surfaces was significantly higher and it was also significantly influenced by the sanding grain size.

In all cases, the wood surface roughness was higher perpendicular to grain than parallel to grain, despite the fact that the mechanical treatment considerably eliminated the roughness differences between these two directions.

This mechanical treatment also significantly reduced the roughness differences between beech and spruce wood.

In addition to the wood surface properties discussed in this work, several others are needed for the comprehensive description of wood surface subject to mechanical treatment. It is also necessary to identify the impact of the given mechanical treatment on wood surface hydrophilicity or hydrophobicity, as well as the impact of particular pre-treatment on adhesion of coating materials to wood and on the overall stability of the system wood – coating material.

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