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MEASUREMENT OF THE ROUGHNESS OF THE SANDED SURFACE OF BEECH WOOD WITH THE PROFILE MEASUREMENT SOFTWARE OF THE KEYENCE VHX-7000 MICROSCOPE

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ABSTRACT

Sanding is the most important way of reducing unevenness and preparing the surface for the final treatment. To optimize sanding, it is necessary to quantify the effect of abrasive grit size on surface roughness. The paper deals with the methodology of measuring the surface roughness parameter R_a of beech wood (*Fagus sylvatica* L.) using a Keyence VHX-7000 digital microscope. After milling, the samples were sanded with abrasives with grit size from P40 to P150, using an eccentric sander. Roughness was evaluated in two directions according to ISO 21920 (2022) standards. Using a two-factor analysis of variance the positive effect of grit size on roughness was proven. It improved on average by 38% in the direction perpendicular to the grain and by 20% parallel to the grain. The theoretical knowledge about equalizing the unevenness of the surface by sanding and reducing the difference between the roughness in two directions is proven in the paper.

Keywords: surface roughness, Keyence VHX microscope, optical profilometer, eccentric sander, beech wood.

INTRODUCTION

The quality of the machined surface is an important and often discussed issue. It is a complex system that significantly affects the marketability of the product, but also the processes of the machining itself (Zhong *et al.* 2013). On the one hand, it is about achieving the desired state of the workpiece surface so that it can be followed up in subsequent machining operations. In the practice of woodworking, this means compliance with the prescribed shape and dimensions, determined in technical standards or woodworking drawings. On the other hand, it is a process of constant control of individual operations so they do not leave large irregularities on the surface. These, as a form of unwanted deviations from the intended (nominal) surface, would not only cause the production of inaccurate workpieces (semi-finished products) or final products, but would also have a significant impact on the aesthetic point of view, i.e., the overall appearance of the product surface. This is often a decisive factor in a highly competitive market that must be considered. The quality, i.e., the state of the surface, is thus the result of operations with pre-defined technological parameters on the workpiece material itself. With the help of measurements and analysis of unevenness, it provides technologists with an important information output, thanks to which it is possible to retrospectively optimize these machining parameters. However, it is necessary not to forget that a physically completely smooth surface can never be achieved. It is caused by the kinematics of the movement of tools used for cutting and machining (Kvietková *et al.* (2015 a,b), Gaff and Kaplan (2016), Kubš *et al.* (2016), (Kaplan *et al.* 2018 a,b) as well as the essence of wood as a material (type of wood, wood moisture, macro-, micro-, sub-micro-structure) (Kúdela *et al.* (2018), Kminiak (2014), Sandak and Negri (2005), Magoss (2008), Gurau *et al.* (2005). For this reason, wood roughness is a combination of anatomical roughness and processing roughness (Gurau *et al.* 2015). In the wood industry, quality is often evaluated by measuring with a contact or non-contact method (optical methods). We take into account the state of the surface after the last operation, for example after sanding, or the state of the surface after the application of the coating substances.

Sanding, as a type of woodworking process, is the most frequently used finishing operation, the essence of which is to improve the quality of the surface (reducing the values of the surface unevenness parameters). This change can be achieved by scraping, or by smoothing the surface of the wood using sanding tools – discs, belts or different types of sanding tools with a specific grit size. From the point of view of woodworking, sanding is then divided into rough pre-sanding (removal of the unevenness of the surface with sandpaper with coarse grain P40 or medium grain P60 to P80) and fine sanding (preparation of the surface for the application of coating materials with sandpaper with fine grain P100, P120 or very fine grain P150). According to the sanding theory, the grit size of the abrasive is an expression of the size of the grains, which are fixed on the substrate with a binder. Gradual sanding with an abrasive with a larger grit size results in a decrease in the unevenness of the surface. The choice of the type of sanding equipment is a significant factor influencing roughness of the surface. In woodworking practice, we distinguish between manual electric sanders, for example belt sanders, eccentric (orbital) sanders or detail sanders. They differ not only in the amount of material removed during the sanding process, but also in the effect of the sanding tool on the created surface. When comparing the two most common sanders - eccentric and belt sanders, a qualitatively different surface can also be assumed from a theoretical point of view. The most significant differences in unevenness can be found when using abrasives with a smaller grit size, especially P40. In this case, the surface after the belt sander is very fragmented, also represented by deep grooves after the action of the abrasive. From a kinematic point of view, the grooves are oriented in the direction of belt movement. Since sanding is most often carried out in the direction of the wood grains, uneven removal of material will occur along the width of the sanding belt. This will be caused by the tool itself (different grit size), but also by the different density of earlywood and latewood within the annual ring. Assuming the same technological parameters, uniform pressure of the sander and the use of an abrasive of the same hardness, softer and less dense earlywood will show greater abrasion. For this reason, there will be visible height differences between less removed latewood and earlywood. When measured in the direction perpendicular to the grains, these are manifested by an increase in the value of all roughness parameters. (Gurau (2010), Kúdela *et al.* (2018)). At the same time, it will be possible to observe a higher standard deviation of the measurement. In the case of a manual eccentric sander, the surface after sanding with P40 grit size will also be formed by traces of abrasive. The main advantage of the eccentric sander is a sanding pad which simultaneously rotates and oscillates in an elliptical pattern. Due to the influence of the pad oscillation, surface irregularities will be better smoothed out. Therefore, from a theoretical point of view, a surface sanded with an eccentric sander shows better quality (lower roughness parameters) than a surface sanded with a belt sander.

The main aim of the paper is to observe the influence of the grit size of sanding discs (P40, P60, P80, P100, P120 and P150) on the surface roughness of beech wood using the optical method of measurement with a digital microscope. The task of the paper is to confirm the theoretical assumptions about the reduction of R-parameter values when using larger grit sizes of sanding discs.

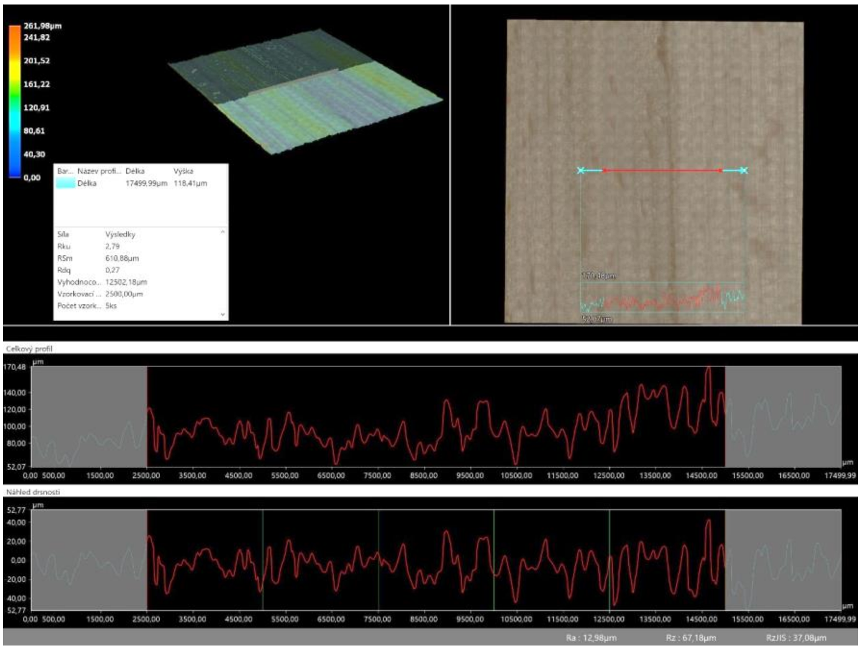
MATERIALS AND METHODS

Preparation of sanded beech wood samples

Dimensions of samples 12 × 70 × 70 mm (thickness × width × length) from beech wood (*Fagus sylvatica* L.) were used, which were equalized in thickness using a thickness milling machine with a spiral cutter head. The surface of the samples was subsequently modified by sanding with a Festool ETS 125 REQ-PLUS eccentric sander with an ergoPAK Essential Tool Kit pressure force monitoring device. Rubin 2 sanding discs with grit sizes of P40, P60, P80, P100, P120 and P150 were used. All samples were cleaned with a compressor air gun before the measurement due to the influence of roughness by wood dust particles. 4 samples with radial surface were prepared from each grit size with the subsequent 30 measurement tracks. The change in surface roughness was related to the surface roughness of 4 reference unsanded samples (R). The samples were conditioned to an equilibrium moisture content of 8 ± 2 %.

Methodology for surface roughness evaluation

The change in the roughness of the surface of beech wood by sanding with different grit sizes was defined by the shift in the R_a, R_p, R_v and R_t parameters in the direction perpendicular to the grain and parallel to the wood grain. For roughness measurement, values of 2.5 mm for the L-filter (λc) and 8 μm for the S-filter (λs) were chosen. The evaluation length was 12.5 mm (five times the value of λc – the section length in accordance with the standard STN EN ISO 21920-3 (2022)) and the total traverse length was 17.5 mm. The measuring device for roughness evaluation was the Keyence VHX-7000 digital microscope. The implemented software tool (VHX-H5M) for roughness measurement was used in the microscope (Fig. 1). It is a non-contact optical method of surface observation using incident and reflected light. Its main advantage is the speed of parameter evaluation and good measurement repeatability. The disadvantage is the considerable time required to join the frames into a complete image (3D image stitching). The time duration of stitching is in the range of 5 to 6 minutes per image. The created 3D image was 18 × 18 mm in size (2880 × 2160 px). The measurement itself then takes place by simply translating vertical or horizontal profile lines or lines with a fixed length according to the STN EN ISO 21920-3 (2022) standard. In this case, R_a, R_p, R_v parameters separately on each of the five section lengths according to the technical standard are evaluated using the Keyence microscope. Then one final value of the selected parameter using the arithmetic average is calculateted. Parameter R_t was evaluated on evaluation length according to the technical standard.



Bar...	Název profi...	Délka	Výška
	Délka	17499,99µm	118,41µm

Síla	Výsledky
Rku	2,79
RSm	610,88µm
Rdq	0,27
Vyhodnoco...	12502,18µm
Vzorkovací ...	2500,00µm
Počet vzork...	5ks

Ra : 12,98µm Rz : 67,18µm RzJIS : 37,08µm

Fig. 1 Measuring of the roughness of the beech surface (profile).

Construction of the measuring device

The main part of the microscope is the 100× to 1000× zoom lens (VH-Z100R), which is connected to the VHX-7020 camera and placed on the VHX-S650E free-angle observation stand, which allows the lens to be tilted from + 60° to 90° (Fig. 2). The lens and the camera are connected to the observation stand by means of a motorized part that enables movement of the lens within the Z axis. One of the main parts of the stand is the eccentric XYθ motorized stage, which also includes a monochromatic circular plate of white or black color, which can be replaced with glass plate. The most important part of the microscope is the main unit with a UHD LCD monitor. Coaxial illumination is an equally important part of the microscope. It allows us to observe the sample by travelling the light through the half mirror. A half mirror reflects half of the light and transmits the rest. A light reflected from the surface travels into the camera and CCD image sensor. The illumination used in roughness measuring was partial coaxial 1 (illumination from one side).

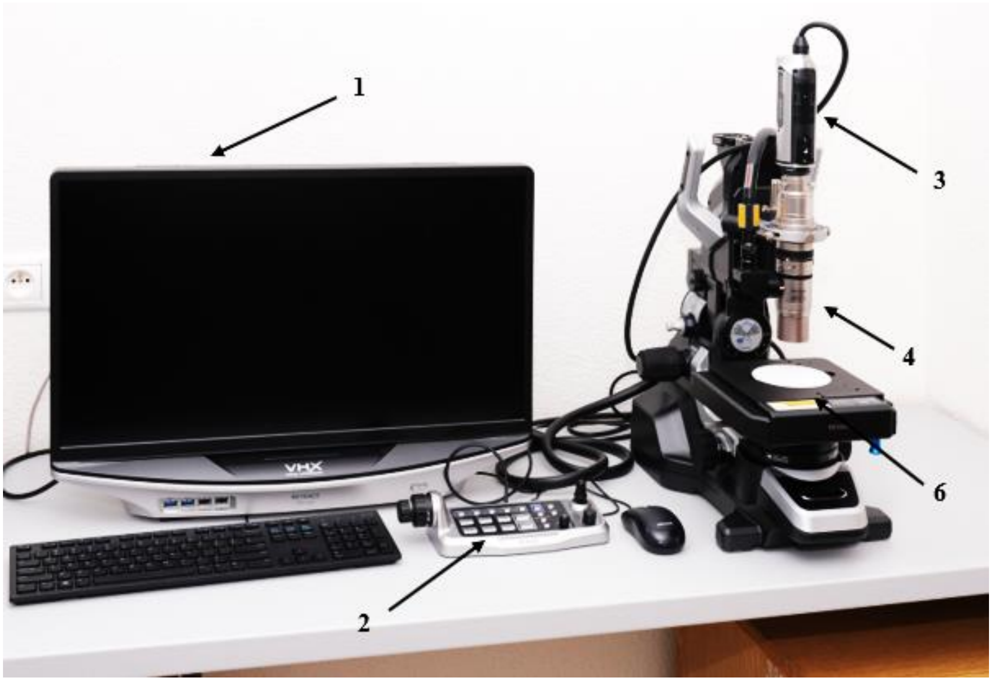


Fig. 2 Construction of the Keyence VHX-7000 digital microscope.

1 – Main unit, 2 – Console, 3 –Camera, 4 – Wide-range zoom lens, 5 – Free-angle observation stand, 6 – XYθ eucentric motorized stage

RESULTS AND DISCUSSION

Before the data were subjected to statistical analyses using the STATISTICA 12 software, the outliers were removed from the data set that significantly biased the results of the parametric tests.

In the first step, the input data matrix was evaluated using descriptive statistics methods. From the results of 1680 measured values in Tab. 1, an improvement in the quality of the sanded surface was observed, i.e., a reduction in the surface roughness evaluated by the parameter R_a from an average of 4.46 µm (milled surface N) to 2.78 µm (sanded with abrasive P150) in the measurement direction perpendicular to the grain (improvement of surface roughness by approximately 38 %) and a reduction in surface roughness from an average of 3.36 µm (milled surface N) to 2.69 µm (ground with P150 abrasive) in the direction parallel to the grain (improvement of surface roughness by about 20 %).

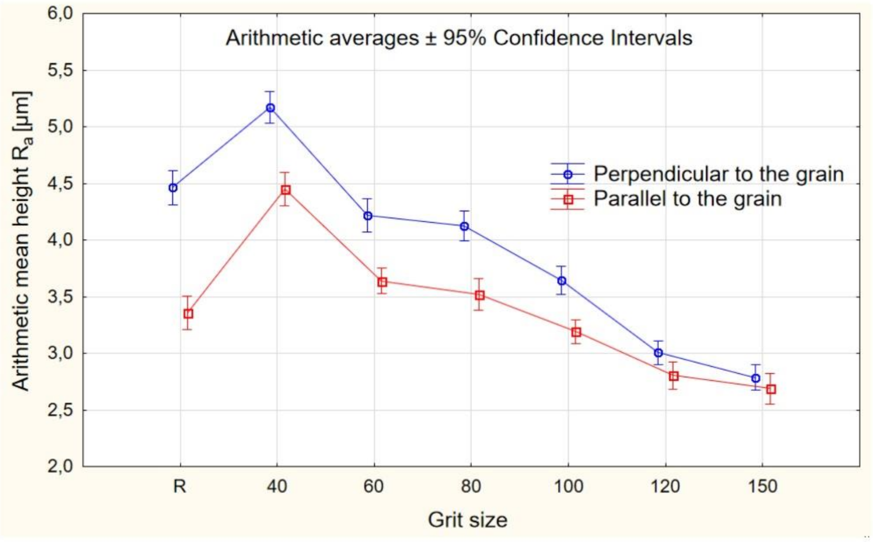
Tab. 1 Basic statistical characteristics (n = 120).

Grit size	Measurement direction	R_a Average [µm]	R_a St. Dev [µm]	R_a -95,00 % [µm]	R_a +95,00 % [µm]
N	perpendicular	4.46	0.84	4.31	4.62
40	perpendicular	5.17	0.77	5.03	5.31
60	perpendicular	4.22	0.82	4.07	4.36
80	perpendicular	4.12	0.72	3.99	4.25
100	perpendicular	3.65	0.67	3.52	3.77
120	perpendicular	3.01	0.58	2.90	3.11
150	perpendicular	2.78	0.62	2.67	2.90
N	parallel	3.36	0.83	3.21	3.51
40	parallel	4.45	0.82	4.30	4.60
60	parallel	3.64	0.62	3.53	3.75
80	parallel	3.52	0.77	3.38	3.66
100	parallel	3.19	0.58	3.09	3.30
120	parallel	2.80	0.65	2.69	2.92
150	parallel	2.69	0.74	2.55	2.82

Subsequently, an analysis of variance (ANOVA) was performed. When using ANOVA, it is necessary to fulfil conditions of normality, equality of variance and independence of measurements. Using the Shapiro-Wilk test, the normality of the distribution of random variable values was tested for all groups (combinations of factors affecting surface roughness). The test results showed a Gaussian distribution of values. The second test was Levene's test of equality of variances at individual factor levels. In this case, the null hypothesis about the equality of variances was not confirmed, which may be caused by the considerable heterogeneity of the wood structure. The ANOVA method is a robust technique. It means that the assumptions can be violated to some extent, but the method can still be applied. The last and, at the same time the most important assumption for the use of ANOVA is the independence of the values of the measured quantity, which in our case is sufficient to be evaluated by a logical assessment. Based on the results of the two-factor analysis of variance with interaction in Tab. 2, it can be stated that both investigated factors – direction and grit size – have a significant effect on the examined roughness and that in an interaction (p= 0.000). The effect of one factor is conditioned by the effect of another.

Tab. 2 Two-Factor analysis of variance (ANOVA).

Effect	SS effect	DF effect	MS effect	F-test	p-level
Grit size	712.02	6	118.67	227.09	0.000
Measurement direction	121.35	1	121.35	232.22	0.000
Grit size*Measurement direction	40.51	6	6.75	12.92	0.000
Error	870.60	1666	0.52		



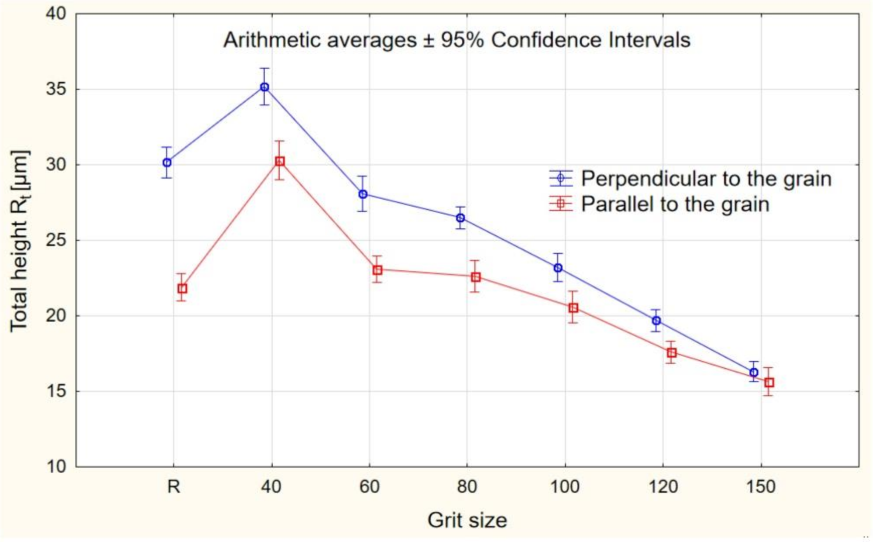
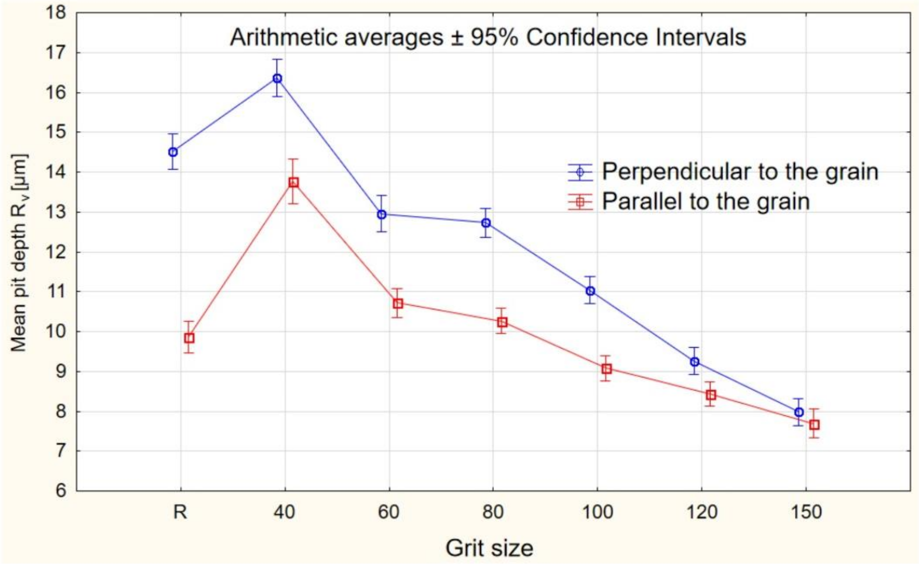


Fig. 4 The effect of grit size on the R_a and R_t parameter in the direction perpendicular and in the direction parallel to the wood grain.

From Fig. 4, on which 95% confidence intervals were presented for the average value of R_a, at individual levels of the factor, a decrease in the surface roughness in both measured directions due to the grit size of the used sanding tool results. In the direction parallel to the grain, the roughness was lower for the milled surface (reference surface) as well as for the sanded surfaces. The measured higher roughness in the direction perpendicular to the wood grain is in accordance with the literature (Kúdela *et al*. (2018), Gurau *et al*. (2006), Vitosyté *et al*. (2015), Gurau *et al*. (2019)). In the case of the reference samples, the graph shows that the surface milled with a thickness milling machine with a spiral cutter head shows approximately similar roughness as after eccentric sanding with P60 and P80 grit in the measurement direction parallel to the grain and only slightly worse than with P60 grit in the direction perpendicular to the grain. Therefore, it is possible to claim that milling using a spiral cutter head creates a high-quality surface (if the quality is defined by surface irregularities, in our case by the roughness parameter R_a), partially comparable to the state of the surface after sanding with smaller grit sizes. Similar results after milling with a router were also achieved by Kúdela *et al*. (2018). Subsequent use of the P40 grit size caused a sharp increase in roughness in both measured directions. The probable cause is the scratching of the surface by larger abrasive grains, which, at the same time, created deeper and wider grooves on the surface. In this case, the roughness in the direction perpendicular to the grain increased by 0.71 μm and in the direction parallel to the grain by 1.09 μm. The further effect of the P60 abrasive resulted in a sharp decrease in surface roughness. The sanding tool thus reduced surface irregularities in both directions. In the case of the direction perpendicular to the grain, these irregularities were lower than in the reference milled surface, while in the case of the direction parallel to the grain, no improvement in surface roughness compared to the milled surface were achieved at this stage. The existing differences between the values of the R_a parameter in the perpendicular direction and in the direction parallel to the grain at P60 grit size are evidence of the still present heterogeneity of the investigated surface. However, the subsequent use of P80 grit size, according to Fig. 4, did not cause a significant reduction in roughness values. In a more detailed analysis using Duncan's post-hoc test, a statistically significant difference was not found ($p = 0.319$ for the direction perpendicular to the grain and $p = 0.208$ for the direction parallel to the grain) in the averages between the P60 and P80 groups. This phenomenon would need to be confirmed with a larger number of samples with a higher number of roughness measurements. Even if a significant difference wasn’t detected, the use of P80 in the sanding process in steps from P40 to P150 is questionable, given the time-consuming operation compared to only a slight improvement in surface quality. By further using grit sizes P100 and P120, a significant reduction was achieved in the roughness parameter R_a. The fine grain of the abrasive gradually smoothed the unevenness of the surface both in the direction perpendicular to the grain and in the direction parallel to the grain. A post-hoc test also showed some significance in the use of P150 grit after P120 grit in the direction perpendicular to the grain. However, the surface improvement was only very slight ($p = 0.022$) and statistical significance was not demonstrated for the direction parallel to the grain ($p = 0.240$). The largest decrease using the P150 grit was in the direction perpendicular to the grain (0.23 μm reduction). In the direction parallel to the grain, the roughness at P150 was reduced by only 0.11 μm compared to P120. Duncan's test did not show a statistical difference between the surface roughness in the direction perpendicular to the grain and in the direction parallel to the grain ($p = 0.297$), which means that the roughness with the P150 grit size in both directions gradually equalized. In addition to equalizing the differences between the two measurement directions, the evidence of a smoother surface is also the decreasing values of the standard deviation. These can be interpreted as a smaller dispersion of the values from the average, i.e., a smaller difference between the roughness values in the individual measurement traces. Since the measurement traces were evenly distributed within the sample (a condition for surface evaluation from STN EN ISO 4288 (1999)), different measurement values and thus also different values of the standard deviation are proof of the heterogeneity of the beech wood surface. The decreasing standard deviation thus also indicates a decrease in the heterogeneity of the surface, i.e., the levelling of the unevenness with the sanding tool in both directions.



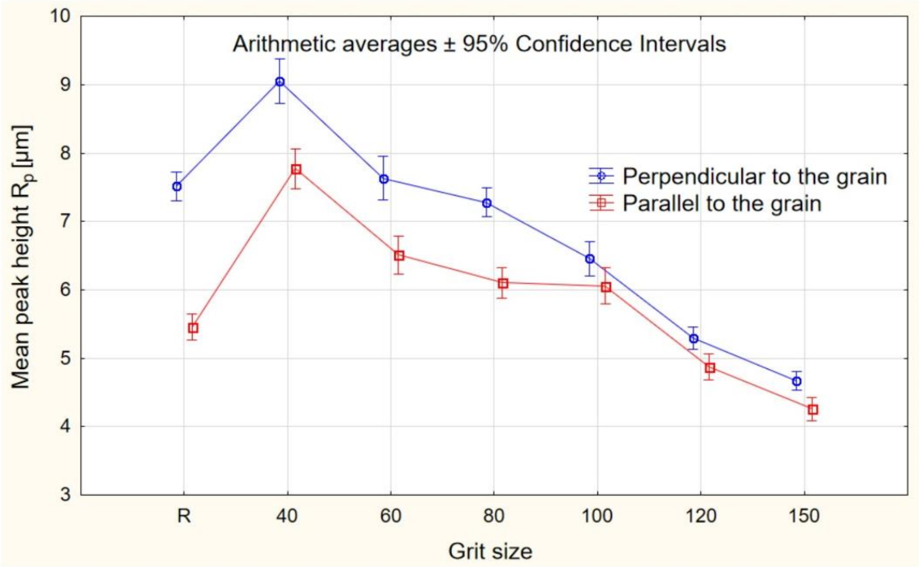


Fig. 5 The effect of grit size on the R_v and R_p parameter in the direction perpendicular and in the direction parallel to the wood grain.

The R_a parameter is considered one of the most stable roughness parameters in scientific papers. The reason is that it is an average of the heights of the roughness profile. However, R_a does not define the dimensions of the peaks and valleys of the profile. The roughness levels as well as the overall condition of the surface at individual grit sizes complement the other parameters, for example R_t (Fig. 4), R_p, R_v (Fig. 5). From Fig. 5, it is possible to observe the development of individual parameters in two measured directions. All three measured parameters are higher in the direction perpendicular to the grains. In general, Graph shows that in the measured parts of beech wood, the mean pit depth (R_v) reaches a higher value than the mean peak height (R_p). It can be deduced that the roughness profile in these parts is defined rather by the presence of deeper sanding marks, torn fibers or naturally occurring cellular elements of wood.

Furthermore, it is possible to claim from the graph that the gradual reduction of these parameters is the same as in the case of R_a (Fig. 4). Again, it is possible to demonstrate that the quality of the surface deteriorates with P40 grit size. Abrasive grooves cause a sharp increase in R_v, which are highest at P40 and then gradually decrease, approximately linearly. Even in the case of R_p, there is a sharp increase in values at P40. In addition to an uneven profile, high values of this parameter can also be caused by the fuzziness of the surface. The decrease in both measured parameters proves that the sanding process smooths the surface (and thus also smooths the roughness profile). This fact is also confirmed by the decrease in the total height parameter R_t, represented in Fig. 4. However, it is problematic to compare the results of measuring R_a, R_p, R_v and R_t with the measurements of other authors. The main complication among works dealing with the issue of surface quality can be considered the different choices of filter λ_c when evaluating the roughness profile. It is this value that determines which wavelengths will be attenuated during filtering. The high-pass filter λ_c separates the shorter wavelengths associated with roughness (these will be transmitted) from the longer wavelengths (these will be attenuated), which is defined as waviness. That is why the choice of this filter has a fundamental influence on the resulting measured values of the R_a parameter (for example, for λ_c = 8 mm, the roughness of R_a will be equal to 5.32 μm, for λ_c = 2.5 mm, the roughness in the same place will be equal to 4.44 μm, and for λ_c = 0.8 mm, R_a will be equal to 3.10 μm). The second frequent problem is the absence of the evaluated length value, which also fundamentally affects the resulting measured value. The measured values of the R_a parameter of the surface sanded with an eccentric sander were compared to the surface sanded with a belt sander. Tab. 3 shows that the belt sander creates a lower-quality surface. The mentioned phenomenon can be observed especially when using abrasives with a smaller grit size, where very rough abraded marks with frequent occurrence of non-separated standing needle-shaped fibres ("surface fuzziness") are manifested to a high degree. When using P100, P120 or P150 sandpaper in the direction of measurement parallel to the grain, the roughness of the surface after sanding with a belt sander is comparable to the surface after sanding on an eccentric sander. In the case of the direction of measurement perpendicular to the grain, the roughness of the surface after sanding with a belt sander remains significantly higher even when using abrasives with P100, P120 and P150 grit sizes.

Tab. 3 Comparison of the roughness parameter R_a (in different measurement directions and with different grit sizes) between individual authors.

Grit size	Measurement directions	Eccentric sander	Belt sander				
		This paper [μm]	Kúdela *et al.* (2018) [μm]	Gurau *et al.* (2019) [μm]	Gurau (2013) [μm]	Cota *et al.* (2017) [μm]	Aslan *et al.* (2008) [μm]
40	perpendicular	5.17	-	-	-	-	-
60	perpendicular	4.22	-	12.60	-	-	8.78
80	perpendicular	4.12	9.00	-	-	-	-
100	perpendicular	3.65	-	9.00	-	-	6.05
120	perpendicular	3.01	6.00	-	5.33	-	-
150	perpendicular	2.78	5.00	5.80	4.33	-	-
40	parallel	4.45	-	-	-	-	-
60	parallel	3.64	-	-	-	-	-
80	parallel	3.52	4.00	-	-	-	-
100	parallel	3.19	-	-	-	3.71	-
120	parallel	2.80	3.20	-	-	3.28	-
150	parallel	2.69	2.80	-	-	-	-

CONCLUSION

The measured average values of roughness prove the theory of sanding and the influence of abrasive grit size as a factor on the surface quality of beech wood, where the roughness parameter R_a was chosen as the dependent variable. The results presented show the following:

1. The grit size of the abrasive used significantly affects the resulting roughness of the sanded wood in mutual interaction with the direction of measurement. From an overall point of view, the roughness parameter R_a of the milled surface decreased from 4.46 µm to 2.78 µm in the measurement direction perpendicular to the grain and from 3.36 µm to 2.69 µm in the direction parallel to the grain.
2. Also, the grit size of the abrasive used significantly affects R_p, R_v and R_t. The roughness value decreased for each parameter.
3. Higher roughness was measured in the direction perpendicular to the wood grain. On the contrary, lower in the direction parallel to the grain (for all measured parameters).
4. The surface milled by a thicknessing milling machine with a spiral cutter head shows a surface roughness with a diameter approximately equal to the abrasive grit size P60 (in the direction perpendicular to the grain) or as P80 or P100 in the direction parallel to the grain.
5. Up to the P100 grit size, the roughness decreased at approximately the same rate in both measured directions, but the surface still showed considerable heterogeneity between the direction perpendicular to the grain and the direction parallel to the grain. With a higher used grit size, the differences in roughness between both measured directions were mitigated. While for P120 the difference in the direction perpendicular to and parallel to the grain was 0.21 µm, for P150 it was only 0.09 µm. This is to prove the theory that fine abrasive grains of higher grit really smooth out surface irregularities.
6. Duncan's post-hoc test did not show a significant surface improvement using P80 grit after P60. Statistical significance was not demonstrated even when analyzing the difference in roughness between surfaces treated with P60 and P80 grit sizes in the direction perpendicular to the grain ($p = 0.319$) or in the direction parallel to the grain ($p = 0.208$).
7. A decrease in roughness by using P150 grit after P120 grit was also demonstrated by 0.23 µm in the direction perpendicular to the grain and 0.11 µm in the direction parallel to the grain.

REFERENCES

Aslan, S., Coşkun, H., Kilic, M., 2008. The effect of the cutting direction, number of blades and grain size of the abrasives on surface roughness of Taurus cedar (Cedrus Libani A. Rich) woods. Building and Environment. 43(5), 696-701. http://doi.org/ 10.1016/j.buildenv.2007.01.048

Cota, H., Dritan, A., Habipi, B., 2017. The influence of machining process on wood surface roughness. In Agricultural Sciences. 16(7), 277-283.

Gaff, M. and Kaplan, L. 2016. The influence of feed and cutting speed on machining quality. Drevársky magazín. Banská Bystrica: Trendwood – twd, s.r.o., 16(3), 3-4. ISSN 1338-3701.

Gurau, L., 2010. An objective method to measure and evaluate the quality of sanded wood surfaces. The final conference of COSTaction E53: The future of quality control for wood and woodproducts. Edinburgh.

Gurau, L., 2013. Analyses of roughness of sanded oak and beech surface. In PRO LIGNO. 9(4), 741-750. ISSN-L 1841-4737.

Gurau, L., Csiha, C. & Mansfield-Williams, H. 2015. Processing roughness of sanded beech surfaces. In Eur. J. Wood Prod. 73, 395–398. https://doi.org/10.1007/s00107-015-0899-8

Gurau, L., Irle, M., Buchner, J., 2019. Surface roughness of heat treated and untreated beech (Fagus sylvatica L.) wood after sanding. BioResources. 14(2), 4512-4531. https://doi.org /10.15376/biores.14.2.4512-4531

Gurau, L., Mansfield-Williams, H., Irle, M. 2005. The influence of wood anatomy on evaluating the roughness of sanded solid wood. Journal of the Institute of Wood Science. 17(2), 65-74. https://doi.org/10.1179/wsc.2005.17.2.65

Gurau, L., Mansfield-Williams, H., Irle, M., 2006. The influence of wood anatomy on evaluating the roughness of sanded solid wood. Journal of the Institute of Wood Science. 17(2), 65-74. https://doi.org/10.1179/wsc.2005.17.2.65

Kaplan, L., Kvietková, M., Sikora, A., Sedlecký, M. 2018b. Evaluation of the effect of individual paramaters of oak wood machining and their impact on the values of waviness measured by a laser profilometer. Wood Research. 63 (1), 127-140. ISSN 2729-8906.

Kaplan, L., Sedlecký, M., Kvietková, M., Sikora, A. 2018a. The Effect of Thermal Modification of Oak Wood on Waviness Values in the Planar Milling Process, Monitored with a Contact Method. BioResources. 13 (1), 1591-1604. https://doi.org/10.15376/biores.13.1.1591-1604

Kminiak, R. 2014. Effect of the saw blade construction on the surface quality when transverse sawing spruce lumber on crosscut miter saw. Acta Facultatis Xylologiae Zvolen. 56 (2), 87-96. ISSN 1336-3824.

Kubš, J., Gaff, M., Barcík, Š. 2016. Factors affecting the consumption of energy during the of thermally modified and unmodified beech wood. BioResources. 11(1), 736-747. https://doi.org/10.15376/biores.11.1.736-747

Kúdela, J., Mrenica, L., Javorek, Ľ., 2018. The influence of milling and sanding on wood surface morphology. Acta Facultatis Xylologiae Zvolen. Zvolen, 60(1), 71-83. https://doi.org/10.17423/afx.2018.60.1.08

Kvietková, M., Gaff, M., Gašparík, M., Kaplan, L., Barcík, Š. 2015a. Surface quality of milled birch wood after thermal treatment at various temperatures. BioResources. 10(4), 6512-6521. https://doi.org/10.15376/biores.10.4.6512-6521

Kvietková, M., Gašparík, M., Gaff, M. 2015b. Effect of thermal treatment on surface quality of beech wood after plane milling. BioResources. 10(3), 4226-4238. https://doi.org/10.15376/biores.10.3.4226-4238

Magoss, E. 2008. General regularities of wood surface roughness. Acta Silv Lign Hung. 4, 81-93, ISSN 1787064X.

Sandak, J. and Negri, M., 2005. Wood surface roughness- What is it?. In Proceedings of the 17th International Wood Machining Seminar (IWMS 17). Rosenheim. 242-250.

STN EN ISO 21920-2, 2022. Geometrical product specifications (GPS) - Surface texture: Profile - Part 2: Terms, definitions and surface texture parameters (ISO 21920-2:2021).

STN EN ISO 21920-3, 2022. Geometrical product specifications (GPS) - Surface texture: Profile -

Part 3: Specification operators (ISO 21920-3:2021)
STN EN ISO 4287, 1999. Geometrical Product Specifications (GPS). Surface texture: Profile method - Terms, definitions and surface texture parameters.
STN EN ISO 4288, 1999. Geometrical product specifications (GPS). Surface texture: Profile method. Rules and procedures for the assessment of surface texture.
Vitosyté, J., Ukvalbergiené, K., Keturakis, G., 2015. Roughness of Sanded Wood Surface: an Impact of Wood Species, Grain Direction and Grit Size of Abrasive Material. Materials science. 21(2). 255-259. http://doi.org/10.5755/j01.mm.21.2.5882
Zhong, Z.W., Hiziroglu, S., Chan, C. 2013. Measurement of the surface roughness of wood based materials used in furniture manufacture. Measurement. 46, 1482–1487. https://doi.org/10.1016/j.measurement.2012.11.041

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