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EVALUATING OF THE SURFACE ROUGHNESS OF SANDED WOOD

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ABSTRACT

Abrasive sanding is one of the most important operations in order to achieve high quality surfaces in the wood industry. Sanding is an unusual cutting process due to its cutting edge profile with negative rake angle and random position of grits to each other. Detailed theoretical and experimental analysis was undertaken to clear the various distinct effects on the surface roughness of different wood species and the clogging effect of cutting edges. The negative rake angle of the cutting edge is inclined to compress the upper layer of the surface which can be detrimental concerning surface stability.

Theoretical considerations and experiments have shown that especially the thickness of the core depth R_k is very sensitive on deformations caused by the cutting edge and it is uniquely correlated to the grit size. Using the experimental results, a generally valid overview diagram is given for the average peak-to-valley height R_z.

Experimental results show that the roughness after sanding may be smaller than the anatomical roughness of the given wood species. It happens as a consequence of clogging due to surface deformation by the grits.

KEYWORDS: Sanding, grit size, grit and edge mechanics, core depth, clogging.

INTRODUCTION

In order to achieve a smooth high quality surface in the wood industry, the sanding of machined surfaces is a common practice. The sanding process, due to its distinct cutting edge of nearly spherical form, is a complicated phenomenon hardly allowing an accurate mathematical description. Nevertheless, using the general laws of contact mechanics some general rules have been derived (Csanády and Magoss 2012).

In the earlier time several experimental research works have been done to determine the surface roughness at sanding for different wood species and operational parameters (Westkamper and Riegel 1993, Scholz and Ratnasingam 2005, Siklienka and Očkajová 2001). Earlier experiments have shown that the grit size (the radius of edges) has a distinct effect on the core depth of the material ratio curve R_k (Westkamper and Riegel 1993, Magoss and Sitkei 2001). Depending on the grit radius the surface layer may be compacted or even clogged. The determination of a minimum roughness due to the internal (anatomical) structure of wood (Magoss and Sitkei 2000) revealed that a clogging phenomenon may really exist at sanding which results in lower roughness values than the anatomical roughness.

It is a well-known fact that surface roughness is a latent property of solid wood and composite products. They do not exhibit a significant problem unless they are exposed to high humidity condition (Zhong et al. 2012, Hiziroglu and Barbu 2009).

The stylus type equipment can be employed to quantify the surface roughness of solid wood species sanded with different grit sizes (Hiziroglu et al. 2013). To separate the processing roughness it is important to apply the proper filtering method (Henderto et al. 2006).

Earlier study has appointed that the aluminium oxide grit material produces higher roughness and better conditions for liquid spreading, than those obtained with silicon carbide (Moura and Hernandez 2006). The roughness parameters are sensitive to the grit sizes, and the R_k parameter is a good indicator of the roughness by sanding (Gurau 2009).

In this detailed investigation program theoretical considerations and experimental measurements were undertaken to clear the effects of wood species, grit size and operational parameters on the surface roughness. Wood species characterisation occurred by using measured anatomical characteristics of each wood species.

The sanding is a special cutting process using a more or less round edge profile and negative rake angle Fig. 1 (Magoss 2013). Furthermore, in the holding tissue a great number of spherical grits are embedded overlapping each other in random positions. The negative rake angle play an important role in exerting compressive stresses in the surface avoiding grain pull-up.

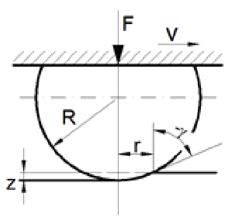

Fig. 1: Deformation under a spherical grit.

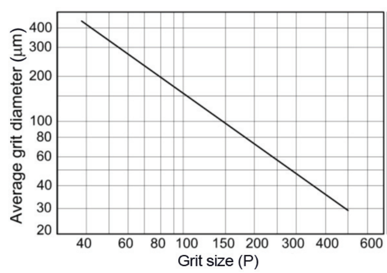

Fig. 2: Average grit diameters as a function of standard grit size.

The grit size is determined by the number of meshes per inch of the sieves used for screening. The real size of the grits is generally taken as normal distributed between two successive sieves. In practice, the average grit size diameter is used as given in Fig. 2 (Magoss 2013) as a function of standard grit size notation.

The grits are embedded in the base carrying material in great numbers and, therefore, they overlap each other many times in their path way. The most important operational parameters are the surface pressure, the feed speed, the grit size and the cutting speed. Beside of these factors, several other influencing parameters may be mentioned such as the hardness of the abrasive material, its heat conduction coefficient, the contact lengths of the sanding etc.

In all woodworking operations the spherical edge of the knife exerts a stress field in the underlying material causing distortions and ruptures (Csanády and Magoss 2012). This stress field may influence the resultant surface roughness considerably depending on the edge geometry and material properties. The negative rake angle of the cutting edge is inclined to compress the upper layer of the surface which can be detrimental concerning surface stability.

The surface roughness has three characteristic components which are the reduced peak height R_{pk}, the core depth R_k and the reduced valley depth R_{vk}. Experiments have shown that especially the R_k-layer thickness is very sensitive on deformations caused by the cutting edge.

The thickness of R_k-layer is determined by the combined effect of vertical and horizontal loading stresses acting just under the working edges (grit elements, knife edge). An interesting problem is the comparison of the effect of a grit element and a knife edge on the deformation of wood structure just under the sliding edges (Magoss 2013). These theoretical investigations based on the engineering mechanics have clearly shown that a given surface stress exerted by an edge acts under the knife deeper than under a spherical grit, supposing that knife and grit have the same radius. To prove of this theoretical finding is one of the goals of recent investigations. A further aim is to find interrelations among the roughness parameters, grit size and wood species.

MATERIAL AND METHODS

In this study five different wood species (spruce-*Picea abies*, larch-*Larix decidua*, beech-*Fagus sylvatica*, black locust-*Robinia pseudoacacia* and oak-*Quercus robur*) were selected to carry out the experimental work. Seven 20 x 5 x 1.5 cm samples were cut tangentially from each wood species. All samples were conditioned in a climate chamber with a temperature of 20°C and a relative humidity of 65 % until they reach equilibrium moisture content. They were subjected to sanding using a belt sander. The sanding velocity was 24.6 m.s^{-1} with surface pressure between 0.25 – 0.35 N.cm^{-2}. Four grit sizes were selected: Aluminium oxide P-80, P-120, P-150 and P-240. The samples were sanded lengthwise while roughness measurements were taken crosswise. Twenty repeated measurements were made with 0.1 mm offset on each sample to ensure reliable results.

For the measurement of roughness a MAHR stylus unit (Model S2, PZK MFW 250) was used. The pick-up has a skid type diamond stylus with a tip radius of 2 µm. The active tracing length is 12.5 mm. Each measurement was represented by surface profile, the Abbott-curve and the calculated standard roughness parameters.

The samples came from the same boards used in earlier experiments when the anatomical properties were determined. These properties were used to calculate the structure number *ΔS* (Tab. 1) (Magoss and Sitkei 2001).

Tab. 1: Structural property of specimens.

Wood species	Early wood			Late wood		
	$\bar{d_i}$ (µm)	$\bar{n_i}$ (piece/cm^2)	$\bar{a}$	$\bar{d_i}$ (µm)	$\bar{n_i}$ (piece/cm^2)	$\bar{b}$
Spruce	30.0	111 335	0.8478	19.0	160 400	0.1522
Pine	28.0	125 100	0.6694	20.0	135 840	0.3306
Larch	38.0	65 490	0.6310	17.5	145 000	0.3690
Beech (vessel)	66.0	15 740	0.7000	48.0	14 020	0.3000
Beech (tracheid)	8.2	342 890		6.4	490 290	

B. locust (vessel)	230.0	546	0.5800	120.4	1 500	0.4200
B. locust (tracheid)	15.0	270 000		9.6	280 000	
Oak (vessel)	260.0	400	0.5900	35.7	12 000	0.4100
Oak (tracheid)	22.5	120 000		19.6	85 000	

Notations: $\overline{d_i}$ is the average diameter of vessels and tracheids, $\overline{n_i}$ is the average number of vessels and tracheids in the unit cross-section, $\bar{a}$ is the average portion of early wood, $\bar{b}$ is the average portion of late wood.

Based on the structural properties of wood species, the structure number *ΔS* of each wood species was calculated. The structure number uniquely characterizes a given timber material concerning its anatomical roughness (Magoss and Sitkei 2000, 2001). We recall shortly the essence of this method in Fig. 3.

The area of the valleys has a connection with the number and diameter of structure elements measured on a given unit of length in the processing direction, which is expressed in the following equation:

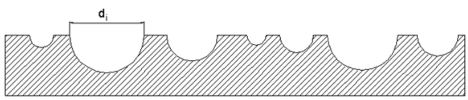

Fig. 3: The model of structural surface roughness.

$$\Delta S = \frac{\pi}{8}\left[a \cdot \left(\sqrt{n_1} \cdot d_1^2 + \sqrt{n_2} \cdot d_2^2\right) + b \cdot \left(\sqrt{n_3} \cdot d_3^2 + \sqrt{n_4} \cdot d_4^2\right)\right] \quad (cm^2.cm^{-1})$$

where: n_1, n_2 - the number of vessels and tracheids in the early wood in the unit cross-section;
n_3, n_4 - the number of vessels and tracheids in the late wood in the unit cross-section;
d_1-d_4 - the diameter size of vessels and tracheids in the early and late wood respectively;
a, b - portions of early and late wood.

The value *ΔS* defined with the equation is called structure number, which gives an accurate definition of each wood species based on the size and specific number of cavities in the wood structure. In the case of conifers the vessels are lacking and in Eq. their number and size are zero.

RESULTS AND DISCUSSION

The processing method of recent experimental results substantially follows that of earlier experiments related to machined surfaces (Magoss and Sitkei 2000, 2001; Csanády and Magoss 2012). These earlier experiments supplied new relationships among the influencing factors and roughness parameters and these results serve as a basis to make some comparison between machined and sanded surfaces.

The average roughness Ra as a function of the sum (R_{pk}+R_k+R_{vk}) in Fig. 4 shows a quite similar picture compared to the machined surface investigated earlier (Magoss and Sitkei 2001). However, a fine sanding (P-240) results in a slight lower average roughness. The curve for a machined surface coincides with the curve for P-80. The curves are valid for all wood species tested.

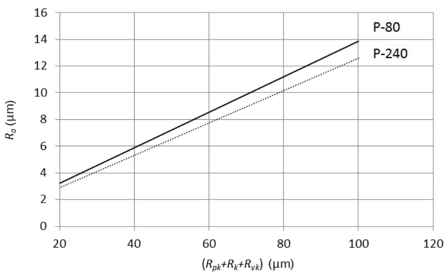

Fig. 4: The average roughness R_a as function of the sum (R_{pk}+R_k+R_{vk}).

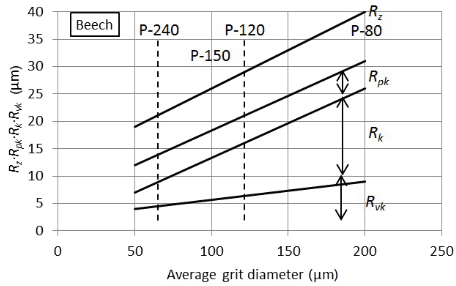

Fig. 5: Effects of grit size on the surface roughness parameters for beech wood.

The representation of roughness components for beech wood is given in Fig. 5 as a function of average grit size diameter. The relationship is almost linear for all roughness components. The strong dependence of the R_k- layer is striking. This finding refers to the strong influence of the grit diameter on the crushing depth in the surface layer.

The smoothness of a surface is considerably determined by the reduced peak heights. This relationship for spruce and beech is given in Fig. 6 on double logarithmic scale. The decrease of grit size allows achieving low R_{pk} values which would give a good possibility for polishing using wax or light-coloured oils. The polishing ability of a surface plays a definite role in the colour enhance of a given wood species (Sitkei 2013).

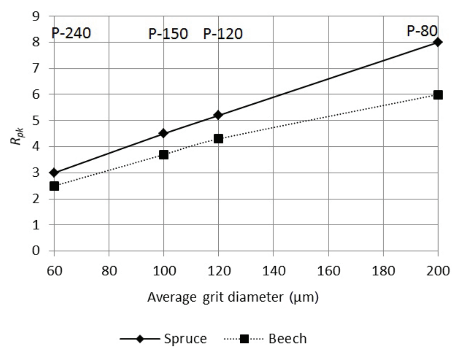

Fig. 6: Relationship between the reduced peak heights R_{pk} and grit size.

Fig. 7 show the R_k/R_z-ratio as a function of structure number ΔS. The relationship is similar to those of machined surfaces and the P-240 curve almost coincides with the curve valid for machined surface. This later result supports the earlier statement that the knife exerts a given pressure deeper compared to the spherical edge of the same radius. We have used an average edge radius of 20 µm for knives, while the average grit radius for P-240 is 30 µm, and they produced the same roughness.

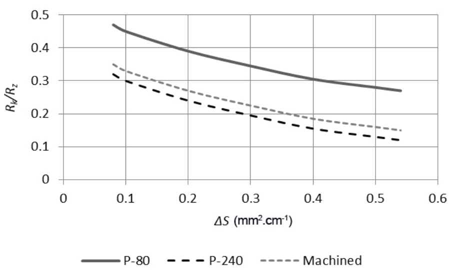

Fig. 7: Relative core depth as a function of structure number ΔS.

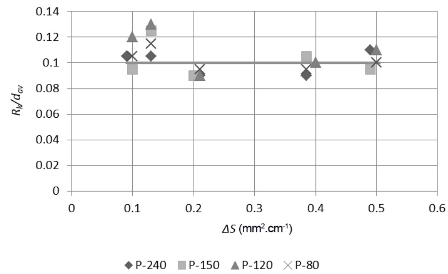

Fig. 8: Core depths and grit diameter ratio depending on the structure number ΔS.

Furthermore, the close interaction between the grit size and core depth R_k is supported by the fact that the core depth and grit diameter ratio is constant for all wood species.

This relationship is shown in Fig. 8 which gives a possibility to forecast the expected R_k-layer in advance or to select an appropriate grit size to achieve a given R_k-layer thickness.

The reduced valley depth R_{vk} related to the R_z-value shows also a strong correlation with the average grit diameter. Fig. 9 demonstrates this relationship for the wood species tested. The spruce, larch and beech have similar values, while black locust and oak show significantly higher R_{vk}-values.

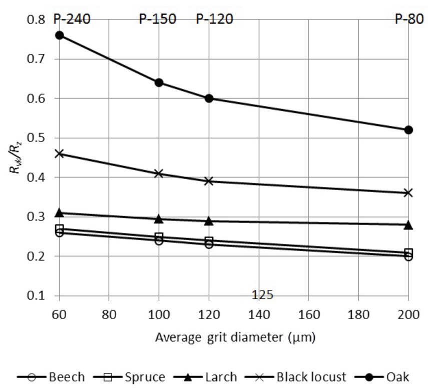

Fig. 9: The R_{vk}/R_zratio as a function of grit size.

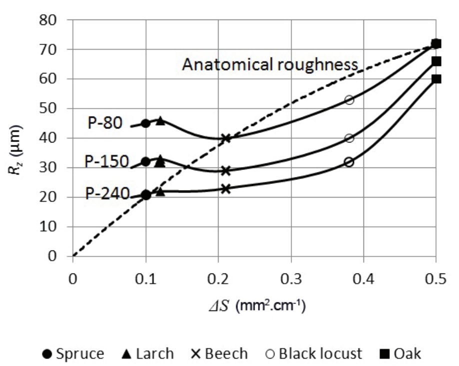

Fig. 10: An overview of R_z-values for all wood species as a function of structure number ΔS.

An overall view on the irregularity depth R_z for all wood species is given in Fig. 10, showing also the anatomical minimum roughness.

Measurement results clearly show that the average roughness R_z may be considerably less than the anatomical roughness (Magoss and Sitkei 2000, 2001) for most of the wood species, except confers. This is possible only in the case, if the surface layer undergoes a structural change due to cell deformation. Besides the crushing effect of the spherical edges, a clogging effect (compression) takes place decreasing the cavities in number and size which do appear in the roughness measurement result.

It is important to notice that the local compression of the material under the working edge depends on the local strength and not on the overall strength of the material. The local strength of wood materials today is not known, but estimation for comparison is possible using the structural properties of the wood materials in question. These structural properties are given in Tab. 1.

The beech seems to be very sensitive to the compression effect of the edge. Looking at the structural properties, we can see the very large number of tracheids both in the early and late wood. A large number of cavities in a given cross-section mean thinner cell walls which can be deformed and compressed easier decreasing the bigger cavities. As a consequence a clogging effect due to surface layer deformation occurs.

Comparing the black locust and oak, we can see a similar case: The number of tracheids of black locust in the early and late wood surpasses those of the oak twice to threefold. Therefore, the oak will be clogged much less than the black locust, in spite of the fact, that the structure numbers of black locust and oak are not far from one another. As a consequence, the black locust shows a much smoother surface compared to the oak for the same sanding.

Tab. 2: Relative scattering of measured roughness data.

	Spruce	**Beech**	**B.locust**	**Oak**
R_z	0.1	0.1	0.105	0.0905
R_{pk}	0.125	0.13	0.14	0.13
R_k	0.09	0.085	0.09	0.085
R_{vk}	0.09	0.11	0.1	0.15

Due to the high variability of structural properties even within a given species, the measured roughness data are prone to scatter. The relative scattering of particular roughness characteristic for the wood species tested is summarized in Tab. 2. The relative scattering is calculated as the ratio of standard deviation to the average value.

CONCLUSIONS

Based on the theoretical considerations and experimental results, the following main conclusions may be drawn:

- between the standard grit size P and the average grit diameter a hyperbolic relationship exists,
- it is proved experimentally that the core depth R_k strongly depends on the average grit diameter used,
- experimental results show that all three components of the Abbott-curve (R_{pk}, R_k, R_{vk}) are nearly linear increasing with greater grit diameters,
- related roughness parameters (R_k/R_z, R_{vk}/R_z) show definite relationships as a function of either the structure number ΔS or the average grit diameter,
- experimental results show that the roughness after sanding may be smaller than the anatomical roughness of the given wood species. This may happen only as a consequence of clogging due to surface deformation by the grits.

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