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EVALUATING OF WETTING-INDUCED EFFECTS ON THE SURFACE STABILITY OF SANDED WOOD

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ABSTRACT

A sanding is a common woodworking operation to smooth the surface prior to apply surface finish or coating materials. All cutting processes damage the upper layer of wood surface and sanding also creates a deformation zone. This deformation zone is sensitive to artificial or environmental actions, especially to wetting. In order to determine the effect of wetting on the surface properties, to get insight into the dynamics of surface movement as a function of time during the wetting, special 3D surface roughness measurements were carried out and evaluated. For sanding of samples the most common grit sizes were selected and P100 and P180 sand papers were used. Measuring the weight of the samples the dynamics of evaporation of the applied water was also determined.

The surface modification after wetting is caused by moisture gradients in the upper layer associated with swelling and shrinkage resulting in permanent deformations. For this layer the most characteristic roughness parameters are the average roughness S_a and the Abbott parameters S_{pk}, S_k and S_{vk}. The extent of roughness variation due to wetting is characterised by the ratio of roughness after wetting to the initial roughness value.

The measurement results have shown that the simultaneous infiltration and evaporation rate has a definite influence on the surface roughness modification. The most stable wood species with the least modification were the ring-porous species, following by the diffuse-porous and conifers species. The evaporation rate measured followed the same sequence for wood species investigated.

KEYWORDS: Sanding, surface stability, grit size, surface roughness.

INTRODUCTION

Producing smooth wood surface is an important industrial task, one for which sanding processis often is used, especially with regard to grain raising caused by wetting. Koehler (1932) was the first to publish a preliminary study regarding surface movement caused by wetting, according to which the grain raising of wood is the result of wetting. The study also states that some species are more prone to fibre splintering than others. Later, Marra (1943) identified the three main causes of the phenomenon: cell damage caused by wood processing, fibre swelling, and fibre separation. Marra also reported that sanding perpendicular to the fibres leads to a greater degree of grain raising, and noted that the extent of the phenomenon is more pronounced near the heartwood than near the bark. It has been observed that sandpaper grit size also significantly influences the number of raised fibres. Nakamura and Takachio (1961) achieved similar results using various sanding parameters. In their investigations, coarse grain (60-80) sandpaper caused a greater amount of grain raising than finer gritted sandpaper did (150-240). Schadoffsky (1996) studied meranti surfaces produced with several sanding parameters. Using the parameter R_z, the study compares the quality of the surfaces developed. As a result, he found that the R_z values of coarse sandpaper-treated surfaces were higher than with finer gritted sandpapers. The surfaces were then coated with 60 $g \cdot m^{-2}$ hydride varnish, which resulted in elevated R_z values for polished surfaces. The degree of change was more significant on surfaces sanded with coarse-gritted sandpaper. Hoffmeister and Riegel (1998) compared the effects of wetting and aqueous varnish on the roughness of beech samples. Test results showed that more fibres were raised from the surface by wetting than when using aqueous varnishes. Evans (2009) concluded that the grain-raising rate is more significant for lower density wood species and less significant in higher density tree species. Further conclusions described that during the sanding operation, the fibres generated on the surface swell because of moisture content, but this swelling is much less than the swelling due to cell wall damage. He also found that the extent of grain raising, following the wetting of sanded wood surfaces is proportional to the grit size used, but fibrillation can be reduced by choosing sanding parameters appropriate for each species. Landry et al. (2013) studied grain raising on sanded Yellow birch (*Betulaalle ghaniensis*) surfaces by electron microscopy and 3D optical roughness measurements depending on whether the surface was treated with a solvent-based or water-based surface treatment agent. Based on electron microscopy, they stated that surface roughness is greater after the application of water-based treatments than it is with solvent-based treatments. The primary cause of this is called grain raising. Fibres from sanding can also be observed on the surface after solvent-based treatment, but they tend to lean toward the plane of the surface, and then emerge from the surface after water treatment. This agrees with the earlier finding that surface movement is predominantly caused by the deformation zone and that the increase in sanded parts is less significant.

MATERIALS AND METHODS

The physical and mechanical properties of different types of anatomically structured wood species (coniferous, ring-porous deciduous, diffuse-porous deciduous) vary greatly. The primary criterion for the selected species for this study is at least one species has been selected that from each of the three groups. Accordingly, the selected wood species are:

- Conifers: Norway spruce (*Picea abies* Karst.), larch (*Larix decidua* Mill.), Scots pine (*Pinus sylvestris* L.),

- Ring-porous wood species: Sessile oak (*Quercus petraea* Liebl.), Black locust (*Robinia pseudoacacia* L.),
- Diffuse-porous wood species: beech (*Fagus sylvatica* L.), Quaking aspen (*Populus tremula* L.).

Size and number of specimens was implemented in accordance with the MSZ 6786-1: 1976 standard. Specimen size was 100 x 100 x 25 mm, each has annual rings with grains parallel with the longitudinal axis (Fig. 1). The samples originated from the same strain of tree species and their surface is free of wood defects. Prior to machining, rough boards were dried to 12% moisture content.

(a) *(b)*

Fig. 1: Scots pine (a) and oak (b) samples.

The sanding was completed with a KÜNDIG Brilliant 2/1350 -CEd-L wide-belt sanding machine using IHD (Institutfür Holztechnologie Dresden) sanding instructions (IHD 2012), and Tab. 1 displays the sanding parameters.

Tab. 1: Sanding parameters.

Wood		Cut thickness (mm)	Feed rate ($m \cdot min^{-1}$)	Belt speed ($m \cdot s^{-1}$)	Grit size
Hardwood	1.step	0.2	7	10	P100
	2. step	0.1	7	8	P1800
Softwood	1. step	0.2	8	11	P100
	2. step	0.1	8	9	P1800

After the surfaces were machined specimens with 10 x 10 cm surface were cut. These identical sample surfaces were then wetted using a reproducible method (Molnár et al. 2018). Depth of machining zone on the surfaces is strongly influenced by the tree species and the operation method used, but on average the depth of the compacted cells by blunt tool is approximately 50-100 μm (Fisher and Schuster 1993). We preferred to complete the wetting in this range. For this, 100 x 100 x 0.1 mm, i.e. 1000 mm^3 of distilled water was applied to the surface of the specimens, which results in 100 μm of water layer thickness. This quantity corresponds exactly to the recommended amount of water-based surface treatment agents (e.g. Remmers) used by the industry, which is usually 80 to 120 $ml \cdot m^{-2}$. Distilled water (1 g) was accurately measured using a flask bottle and precision scales accurate to the thousandths (MC1 LC 620 S). This quantity of liquid was applied as droplets via a plastic pipette on the surface of specimens; after this, the droplets were uniformly dispersed with a pre-moistened brush (Fig. 2).

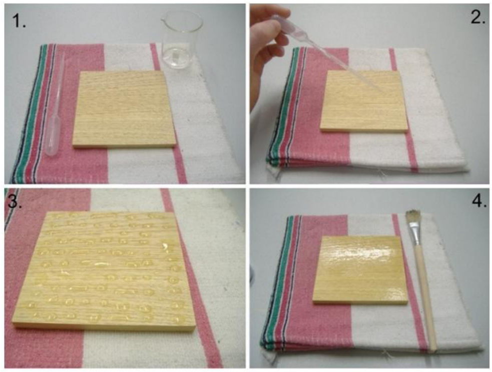
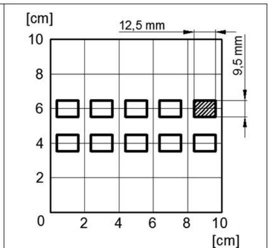


Fig. 2: Wood surface moistening.

The surface was monitored by a GF Messtechnik Micro CAD type 3D optical surface roughness-measuring instrument of IHD. Measurements were based on phase measuring fringe projection (GF Messtechnik 2008). Measured surface was 12.5 × 9.5 mm, providing 23 different 3D parameters (S_a, S_q, S_k etc.). One place was selected on one sample to monitor the changes during wetting. The exact positioning of samples is crucial, therefore a raster table-adjustable in two directions was used to enable the measuring of exactly the same area during monitoring. To determine the exact measurement schedule, preliminary measurements were made on the spruce, beech and oak species applying 1 ml of distilled water. Based on the preliminary tests, the measurements were made according to the measurement schedule depicted in Fig. 3.

Elapsed time after wetting (min)	The number of measure-ments	Elapsed time after wetting (min)	The number of measure-ments
Dry	10	35	10
6	2	40	10
7	2	45	10
8	2	50	10
9	2	60	10
10	4	80	10
12	4	100	10
15	10	120	10
20	10	180	10
25	10	24 hour	10
30	10	1 week	10

(a)



(b)

Fig. 3: The established measurement schedule (a) and measurement area locations (b).

In addition to the change in surface roughness of the test specimens, the change in mass of each sample body was also registered. By continuously weighing the specimen mass, important information about the liquid evaporation rate on the surface can be recorded. Thanks to continuous weighing, the amount of liquid present in the specimens was known during the tests. In all cases, pre-wetting mass values served as a reference value. Specimen mass was recorded during the time determined in the measurement schedule for roughness measurements using an MC1 LC 620 S thousandth-gram precision scale placed next to the measuring device. Weighing could be done within thirty seconds; thus, there was no significant time loss during the roughness tests. However, through the mass loss, i.e. evaporation of moisture from the surface, the amount of the applied water infiltrated into the wood can be determined.

RESULTS AND DISCISSION

It is a proven fact that a single roughness parameter does not provide a comprehensive description for three-dimensional analysis of processed surfaces, even in the case of homogeneous metal surfaces (Donget al. 1994). A more exact characterization a given wood surface is, therefore, possible only by considering several parameters together. Among the roughness parameters of the EN ISO 25178-2 (2012) standard, parameters that characterize surface movements in a relevant way were evaluated.

Part of the moisture placed on a wood surface will begin to penetrate into the interior of the wood while another part immediately evaporates. It is well known that the free water surface has the highest evaporation rate at a given environmental condition. If infiltration is slow then evaporation is faster. The process of surface liquid evaporation was monitored by the continuous registration of the specimen mass. Fig. 4 shows the differences among the tree species. Mass of specimens decrease suddenly and dramatically just after wetting; but the decrease becomes more gradual as time elapses. However, the different tissue structure of each species affects the absorption rate, which is indicated by the different courses on the evaporation graphs. Ring-porous oak and black locust test specimens lose their excess water the fastest, followed by the diffuse-porous beech and aspen and, lastly by the three conifers species.

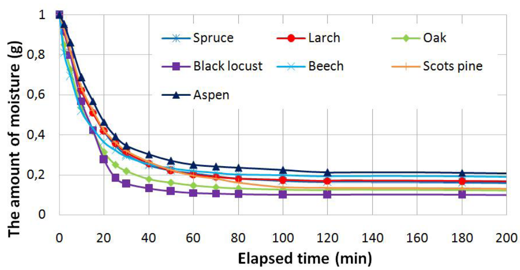


Fig. 4: Mass reduction of sanded specimens after wetting.

After three hours, evaporation and the resulting mass reduction are extremely slow for all species, although most samples still contain significant amounts of liquid applied. As the free water disappears on the surface, the molecular forces appear and slow down the evaporation rate. Although not visible on the graphs, the mass of specimens continue to decline steadily after 3 hours while their original mass did not recover even after several weeks. The following Tab. 2 summarizes the results:

Tab. 2: The half-time of evaporation and moisture after 60 min.

Wood	Half-life (minutes)	ΔG, after 60 minutes
Norway spruce	16 - 18	0.22 - 0.26
European larch	15 - 17	0.20 - 0.23
Scots pine	15 - 18	0.21 - 0.26
Black locust	8 - 10	0.09 - 0.10
Oak	10 - 11	0.15 - 0.18
Beech	11 - 15	0.20 - 0.22
Aspen	16 - 18	0.20 - 0.22

The half-times given in Tab. 2 indicate the time required to evaporate half the total moisture content (1 g) applied to the surface. The surface of black locust specimens evaporated the half of moisture within 8 to 10 minutes; for Norway spruce this time was 16-18 minutes. The third column contains the amount of moisture the specimens still contained after 1 hour. Here, a significant differences appear between ring-porous trees and pine trees too. It is interesting to note that the oak specimens have a half-time almost identical to Black locust, after which the evaporation slows down relative to the black locust and, after 1 hour, the oak species contained far more moisture content. The roughness of the selected 10 measuring surfaces was recorded prior to wetting. Later, these data serve as reference or baseline values, and well illustrate the surface roughness differences among the individual species. One of the most commonly used parameters is the average roughness parameter Sa, which is used for general surface characterisation.

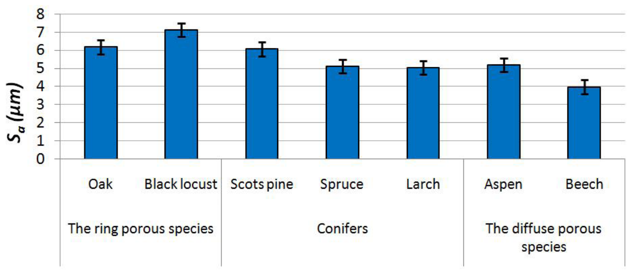


Fig. 5: Average surface roughness (Sa) parameter values for tree species measured on the surface after sanding.

Fig. 5 shows the means and standard deviations for Sa parameters originating from 10 surface measurements for 35 test surfaces after machining. Considerable differences can be observed in the examined wood species. It is well known that the ring-porous oak and Black locust provide higher roughness parameter values. Based on the obtained values, the larch is more homogeneous than the Scots pine and spruce. The lowest initial roughness values occurred on the surface of beech specimens. The differences in S_a parameter values can be explained by the anatomical structure of the individual species. This is demonstrated by the Abbott roughness parameters S_{pk}, S_k, S_{vk} from the material and void distribution curve (Fig. 6).

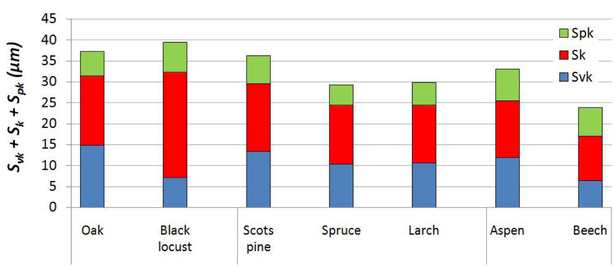


Fig. 6: S_{vk}, S_k and S_{pk} parameter values measured on the surface after sanding by tree species.

The S_{vk}, i.e. the reduced valley depth parameter, shows significantly higher values for large vessel wood species. The parameter best displays the valley clogging at oak wood following sanding, which can be observed with all other tree species, albeit to a lesser degree. While there are significant differences in the values of the S_{vk} parameter in the tree species, no significant differences in S_{pk} parameter values were observed between individual species. This suggests that machining roughness was of good quality; that is, the influence of the peaks (fibres) on the surfaces is considerably lower than the extent of the valleys. Surface movement after wetting can be monitored by the changing values of the roughness parameters. Trend of changes due to wetting is identical for each tree species, but in the extent of surface movements, there are differences (Fig. 7).

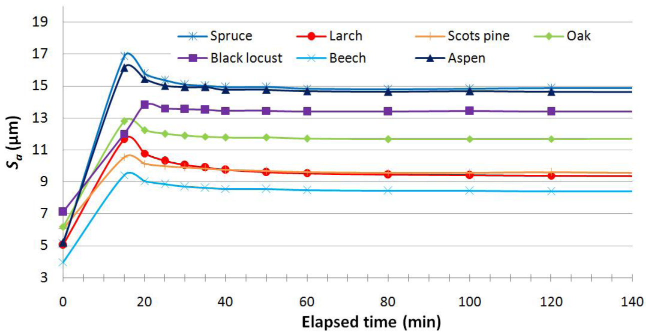


Fig. 7: Change of Sa parameter after wetting for wood species on 10 measuring surfaces after sanding.

In the first half hour, when the movement was most active, only four data from the 10 measurement surfaces of each specimen became available. However, the difference between the stability of each surface is still observable. For all tree species, the parameters reach maximum value near after 15-minutes; hence, on average, the 15 minute values are considered as surface movement maximums.

The biggest change was measured in spruce, the smallest in the black locust. For some species, the average surface roughness nearly doubled after wetting (e.g. spruce), while other tree species showed less surface change (e.g. black locust). This demonstrates that, despite the same test conditions, the surface response of each tree species differs considerably. For the practice, the permanent change in roughness values after drying is of importance. Due to swelling and shrinkage, and subsequent residual deformations, the wetted surface after drying does not recover its original shape. The extent of permanent changes depends, however, on the anatomical structure of timber and also on the dynamics of wetting process (infiltration and evaporation).

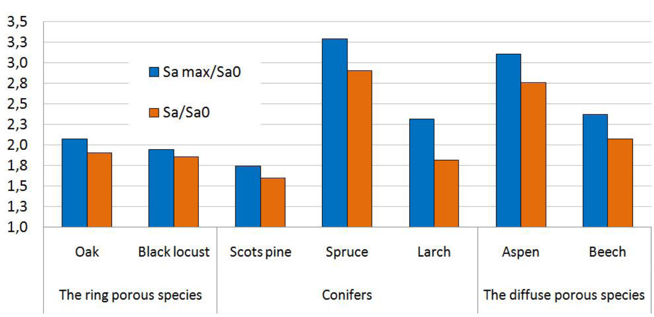


Fig. 8: The stability of sanded surfaces derived from the parameter Sa for tree species tested.

In the interest of the comparability of the consequent surface movements, i.e. surface stability, the ratio of the maximum ($S_{a\ max}$) and initial ($S_{a\ 0}$) values of the roughness parameter Sa was defined as a dimensionless ratio. In the same way, the permanent roughness after wetting divided by the initial value characterizes the permanent stability of the surface. Fig. 8 summarizes the obtained experimental results.

Several studies have been conducted analysing the sanding process with regards to various operational parameters and raised grain due to wetting or staining (Orvis and Grissino-Mayer 2002, Gurau et al. 2005, Ratnasingam and Scholz 2006, Varasquim et al. 2011, Tan et al. 2012, Laina et al. 2017, Kúdela et al. 2016, Magoss 2017, Ilce 2018). Systematic measurements focused on surface roughness determination have been carried out for thermo smoothed and precision planed surfaces (Molnár et al. 2018). Wood surfaces formed after sanding proved extremely unstable despite their initial low roughness. The permanent roughness ratios after one day in each case are lower than the ratios of the maximum and initial values. This shows that, after moisture infiltration and evaporation the surfaces trend to regenerate their original shape, but it is not possible due to the permanent deformation.

There are also significant differences between the stability of the individual tree species. The most stable were the ring-porous species with the highest initial roughness (oak, Black locust). Smaller movements could be registered on black locust surfaces. The surface movement of conifer and diffused-porous species is more significant. Roughness parameter values measured on sanded spruce and aspen surfaces are more than triple after wetting; these values barely change after drying. This implies a complete rearrangement of the surface structure due to permanent deformation.

3D surface profile images recorded at different times clearly show the changes as a function of elapsed time. In Fig. 9, a change on the sanded spruce surface can be followed at four typical time increments.

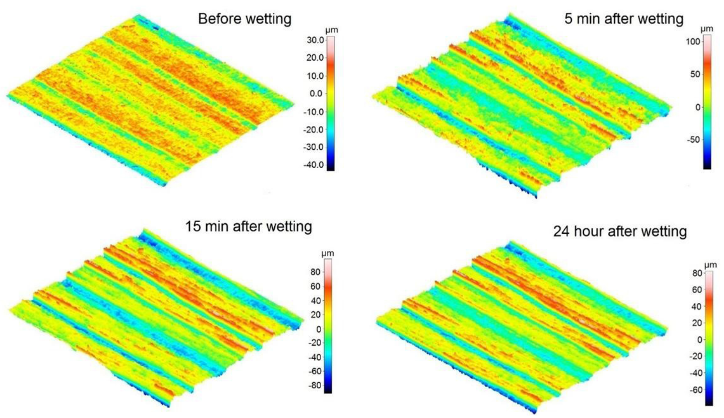


Fig. 9: Changes in 3D surface profile, as a function of time after wetting for spruce sample.

Compared to the initial smooth surface, in the fifth minute after wetting, the topography of the surface is significantly transformed due to grain raising. In the fifteenth minute, during which the roughness parameter S_a reaches its maximum, the surface is even more furrowed and uneven. After one day, as the surface movements disappear; the surface is somewhat more homogenous than it was 15 minutes after wetting, but it remains significantly different from the initial non-wetted surface.

CONCLUSIONS

Wettings and surfaces of natural wood significantly transform the surface topography. Surface changes due to wetting can be monitored by the measurement method elaborated and can well be characterized by the three dimensional roughness parameters and their ratios. Sanded surfaces are unstable due to wetting. The seven tested species also have different surface stabilities. Based on the measurement results, Black locust surfaces proved to be the most stable while spruce surfaces were the least stable.

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