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INFLUENCE OF DIVERSE CONDITIONS DURING ACCELERATED AGEING OF BEECH WOOD ON ITS SURFACE ROUGHNESS

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ABSTRACT

Degradation effects of accelerated ageing were studied on radial and tangential surfaces of beech wood. The resulting changes to the wood surface geometry were expressed through the roughness parameters *Ra* and *Rz*. The beech wood examined was exposed to accelerated ageing for 600 hours. The experimental results showed that the degradation effects during accelerated ageing without water, in the so-called dry or water-free regimen, caused only a slight increase in roughness, while the regimen simulating rainy episodes resulted in a considerable roughness increase.

These results imply that water has an important role in wood ageing process. In presence of water, the influence of radiation, oxidation and heat is more intensive and more pronouncedly reflected in the wood surface degradation and in changes to its morphology. In case of water-free regimen, the wood surface is subject to chemical changes due to UV radiation and heat-induced effects, but there need not be major changes to the wood morphology.

Key words: accelerated ageing, ageing regimens, beech wood, anatomical direction, morphological changes, roughness.

INTRODUCTION

Wood is a natural, heterogeneous material. In addition, it is anisotropic, porous and hydrophilic. These facts are considerably reflected in its surface properties.

The wood heterogeneity underlies the high variability in its properties. The diversely shaped and arranged wood anatomical elements create a complex heterogeneous porous system resulting in a vast internal surface and external surface roughness. Consequently, an absolutely smooth surface is not possible to obtain in non-abstract wood surfaces (KÚDELA 2012).

The wood surface morphology is reflected in its surface geometry. Hence, this parameter is evaluated from the viewpoint of anatomy and physics. From the physical viewpoint, the surface geometry is expressed though its roughness and waviness. The surface geometry in solid materials is assessed qualitatively and quantitatively, through discrepancies between the actual surface in evaluation and the standard established by agreement.

In real wood surfaces, the impact of the finishing tool and many other factors are to consider as influencing the surface geometry. One of them is wood ageing. The ageing in materials is in general defined as their slow degradation over a certain time period, due to effects of various radiation types, moisture and heat in their mutual interactions. During ageing, these factors induce changes to the surface morphology and chemistry, which affects the wood wetting with liquids as well as the wood colour (HON 1981, FEIST 1990, WILIAMS *et al.* 2001, REINPRECHT 2008, TOLVAJ *et al.* 2011, HUANG *et al.* 2012, KÚDELA and IHRACKÝ 2013, ŠMÍRA *et al.* 2014).

Understanding the mechanisms driving the natural changes to wood surface properties in the ageing process will give knowledge applicable in improvement of quality of surface treatment and gluing of these surfaces as well as in seeking approaches leading to better wood colour stabilisation. Several works suggest (PANDEY and VUORINEN 2008, FAN *et al.* 2010, CHEN *et al.* 2012, etc.) that the rate and degree of wood surface photo-degradation should also depend on the wood species.

The aim of this work was experimental study of roughness changes associated with morphological changes on beech wood surface during accelerated ageing process.

MATERIAL AND METHODS

The accelerated ageing was performed on beech (*Fagus sylvatica*, L.) test specimens 15 × 60 × 100 mm in size. The radial and tangential surfaces were treated by milling. Before the ageing, the specimens were acclimated to an equilibrium moisture content of 12 %.
The accelerated ageing was performed in a xenotest Q-SUN Xe-3-HS (Fig. 1). The test specimen were uniformly spaced in the testing chamber. To provide all of them with the same radiation intensity and temperature, the specimens were rotated regularly according to a recommended schedule (Fig. 1).

Fig. 1 Equipment Q-SUN Xe-3-HS and specimens´ rotation during accelerated ageing

A xenotest enables the natural ageing conditions to adjust at different levels. In our case, we followed the Standard ASTM G 155. We chose two regimens for outdoor conditions, so called „water-free regimen“ and „wet regimen“. The first regimen models the conditions under which the wood is exposed to radiation but protected against rain, the second regimen corresponds to the conditions under which the wood is exposed to radiation and rain, equally. ASTM G 155 is the primary standard for setting the parameters of accelerated ageing in non-metal materials, with the aid of a xenon discharge tube. The parameters for non-metal materials set in our tests are in Tables 1 and 2.

Table 1 The ageing parameters set according to the Standard ASTM G 155 "water-free regimen".

Step	Regimen	Radiation intensity (W/m²)	Black panel temperature (°C)	Air temperature (°C)	Relative air humidity (%)	Time (min.)
1	Radiation	0.35	63	48	30	102
2	Radiation-free	–	–	38	–	18
3	End, turn to step 1					

Table 2 The ageing parameters set according to the Standard ASTM G 155 "wet regimen".

Step	Regimen	Radiation intensity (W/m²)	Black panel temperature (°C)	Air temperature (°C)	Relative air humidity (%)	Time (min.)
1	Radiation	0.35	63	48	30	102
2	Radiation + water spraying	0.35	63	48	90	18
3	End, turn to step 1					

Following the Standard, the radiation intensity was set to 0.35 $W \cdot m^{-2}$, at the radiation wave length of 340 nm. This value corresponds to the average annual radiation intensity in the temperate zone, The temperature controlled on the black panel is the maximum air temperature. The air temperature determined in this way should accelerate the changes onto wood surface.

Tables 1 and 2 show that in both accelerated ageing regimens, one cycle lasted 120 minutes and consisted of two steps. Under the „water-free regimen", when water did not enter the accelerated ageing process, the differences in the relative moisture between the two steps were very slight, which allows a conclusion that the morphological changes under this regimen should not be very striking.

Under the „wet regimen", the relative air humidity was comparatively low during the first, dry step (102 minutes), and, conversely, very high during the second step with water spraying over the wood surface (18 minutes). Accordingly, we studied the performance of beech wood surface after the transition from low air humidity to the high and *vice versa*.

The wood surface properties were compared before the accelerated ageing and during ageing after 100, 200, 400 and 600 hours of the ageing process.

The test beech wood specimens were evaluated in their surface roughness based on the parameters *Ra*, *Rz*. The measurements were done with a contact profilometer SURFCOM 130A (Fig. 2), on radial and tangential surfaces of all test specimens, before their placing into the testing chamber, and then at the time intervals stated above, over the ageing process. The roughness was assessed along the grain as well as across the grain, on a length of 40 mm. The roughness parameters were measured on three sampling lengths – 0.8 mm, 2.5 mm and 8 mm. From these, the length the most suitable for our purposes was chosen based on the parameters *Ra* and *Rz* obtained (Table 3).

Table 3 The sampling length determined based on Ra and Rz (STN EN ISO 4288).

***Ra* (μm)**	***Rz* (μm)**	**Sampling length *lr* (mm)**	**Evaluation length *ln* (mm)**
(0.006) > Ra ≤0.02	(0.025) > Rz ≤ 0.1	0.08	0.4
0.02 > Ra ≤0.1	0.1> Rz ≤ 0.5	0.25	1.25
0.1 > Ra ≤2	0.5 > Rz ≤ 10	0.8	4
2 > Ra ≤10	10 > Rz ≤ 50	2.5	12.5
10 > Ra ≤80	50 > Rz ≤ 200	8	40

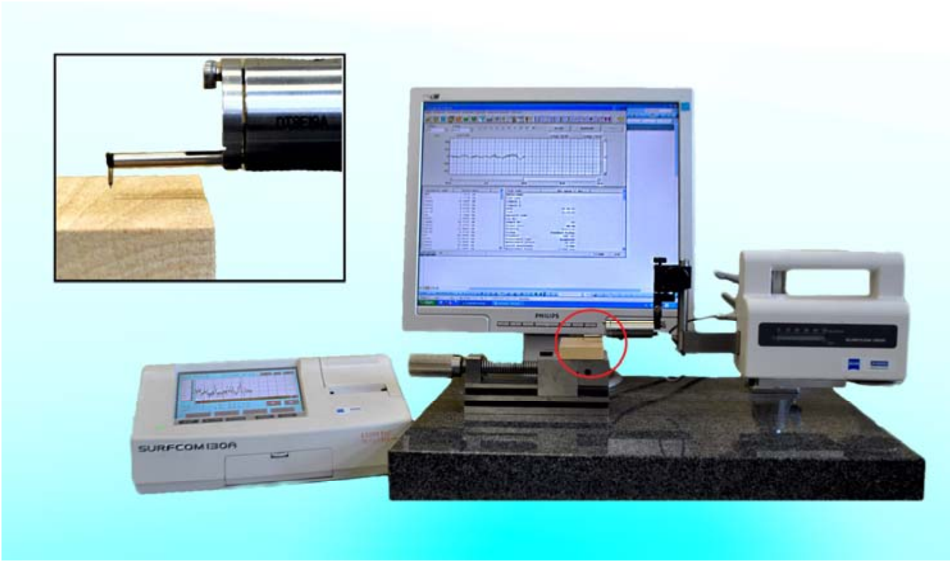

Fig. 2 Profilometer SURFCOM 130A

RESULTS AND DISCUSSION

The roughness parameters *Ra* and *Rz* were evaluated with three sampling lengths – 0.8, 2.5 and 8 mm. The evaluated length of the profile measured was always the same − 40 mm. Therefore, the number of the sampling lengths evaluated varied: for the sampling length of 8 mm it was five, then, the shorter was the basic sampling length, the bigger was the number of lengths evaluated.

The roughness parameters *Ra* and *Rz* before the ageing process as well as during this process, performed under different conditions, are displayed in Figs 3 and 4. These figures show that the roughness parameters varied with the sampling length. The bigger was the sampling length, the bigger were the roughness parameters *Ra* and *Rz*. Equally before the ageing process and during this process, the surfaces manifested characteristic occurrence of coarse unevennesses. The roughness data obtained show a considerable variability in each anatomical direction. This variability was due to the heterogeneous anatomical structure of beech wood, especially variably-composed cell wall elements building a considerably diverse texture at macro- and micro-scale.

Comparing our results with the results obtained by KÚDELA and LIPTÁKOVÁ (2005) we found that in our case, the mean arithmetical deviation of the profile unevenness *Ra* as well as the maximum height of the profile unevenness *Rz* in milled beech wood surface were several-fold higher, both parallel to the grain and perpendicular to the grain, than the values reported by these authors. In our case, this was due to the fact that we worked with the sampling lengths of 0.8 mm, 2.5 mm and 8 mm, while the authors cited used 0.075 mm. The results obtained by REŠETKA (2013) have also confirmed that the roughness was considerably enhancing with increasing sampling length. The results we obtained for roughness of beech wood before ageing process, for three sampling lengths, were in good accordance with the results reported by the last cited author.

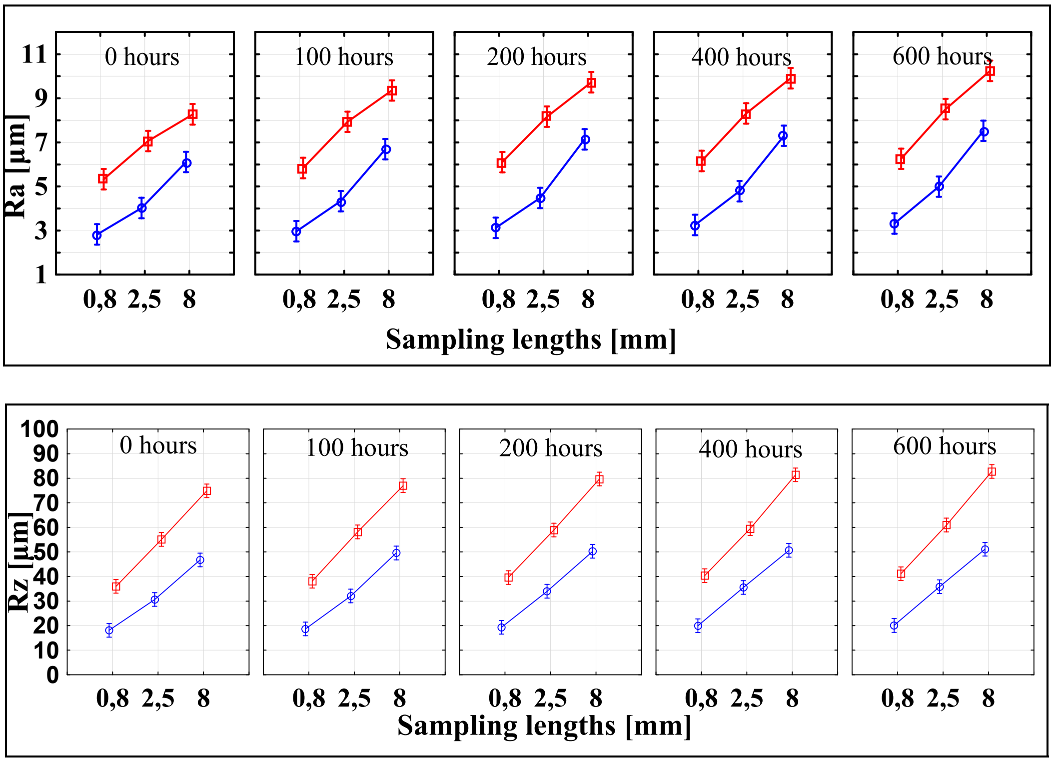

Fig. 3 Changing Ra and Rz during ageing for three sampling lengths, water-free regimen

parallel to the grain, perpendicular to the grain

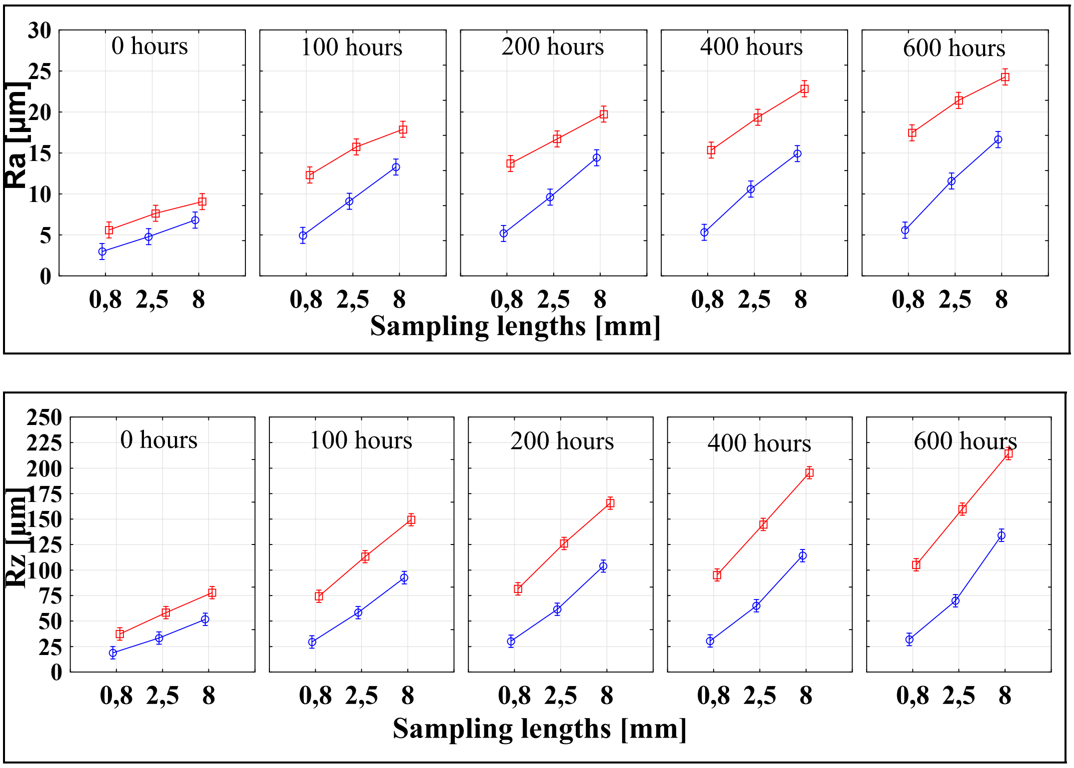

Fig. 4 Changing Ra and Rz during ageing for three sampling lengths, wet regimen

parallel to the grain, perpendicular to the grain

Therefore, the roughness changes are needed to evaluate with a single length only, which is also in accordance with the Standard STN EN ISO 4288. The comparison of the roughness parameters *Ra* and *Rz* calculated with the intervals for these parameters listed in Table 3 has revealed that the most suitable for our purposes was the sampling length *lr* = 8 mm. In the following text, we will constrain our evaluation of ageing effects and effects of other factors to this sampling length only.

The influence of the factors studied on the roughness parameters was evaluated through a four-way variance analysis. The results have confirmed that the roughness parameters were influenced significantly by the anatomical direction in which the measuring was performed, by the length of the accelerated ageing period and by the ageing regimen. There also have been confirmed significant differences in roughness parameters measured based on the same sampling length between the radial and tangential surfaces, as well as significant influences of interactions among the factors tested.

The experimental results imply that the original beech surface treated by milling exhibited the lowest roughness. This was true for both radial and tangential surfaces. The differences between these surface were insignificant in most cases. The few significant ones are not considered substantial for practical purposes.

During plain milling, the cell walls are distorted, compressed and cut imperfectly (KÚDELA *et al.* 2004). Then the wood fibres are ripped out. These changes may be more pronounced in case of a blunt cutting edge in a machining tool made of common steel. The contact spot between the cutting tool and the substrate heats up to a very high temperature (PROKEŠ 1982). The effect of this temperature is just momentary, however, the thermoplastic polymers (primarily lignin) in the wood surface layer can be liquidised. The cell walls are deformed more severely and they are often covered with melt lignin (LIPTÁKOVÁ *et al.* 1995). Consequently, the wetting of milled wood surface with liquids is worse compared to the other surface mechanical treatment modes and also the polar share of its surface energy is lower (LIPTÁKOVÁ *et al.* 1995, 1997, KÚDELA *et al.* 2013).

The roughness values measured parallel to grain were significantly lower than perpendicular to grain, which is due to the structure of beech wood cell elements as well as due to the orientation of these elements (POŽGAJ *et al.* 1997). The measurement inaccuracies were of secondary importance only.

In the ageing process with „water-free“ regimen, increasing trends were observed for roughness in both anatomical directions on radial and tangential surfaces. Significant dependence of roughness on ageing process duration have only been confirmed for the direction parallel to grain on the tangential surface and for the direction perpendicular to grain on the radial surface, and this was only through higher values of mean arithmetical deviation of the profile *Ra*. The maximum peak of the profile unevenness did not manifest any impact of ageing during the „water-free regimen“ (Figs 5 and 6). These roughness changes are negligible from the practical viewpoint, too.

The different patterns were observed in the ageing process with the „wet regimen“. In this case, the wood surface roughness increased noticeably with increasing ageing period. The changes in surface roughness observed perpendicular and parallel to grain were similar. For this ageing regimen, there were also obtained significant differences between the radial and tangential surfaces. Figures 5 and 6 demonstrate that the mean arithmetical deviation values of the profile *Ra* measured on the tangential surface were clearly higher. In the case of the maximum peak of profile unevenness *Rz* , the results were not such unequivocal.

The longer was the duration of the beech wood ageing process, the more conspicuous were the degradation effects of this process as for this wood surface roughness. After 600 hours of ageing, the *Ra* values in both anatomical directions were 2−3 times more than before the ageing process. Similar trend was observed for the maximum profile´s peak *Rz*, however, with low-order higher values. The steepest increase in roughness was observed during the first one hundred hours of ageing.

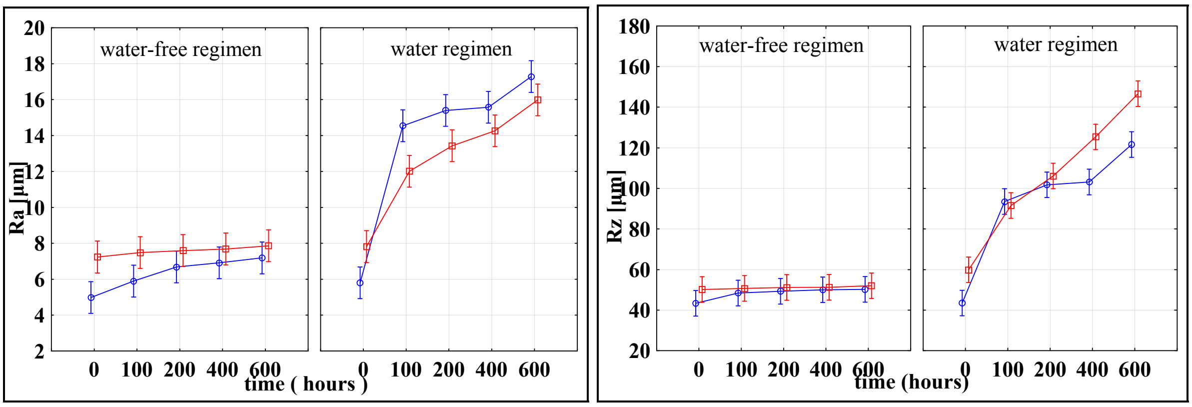

Fig. 5 Ra and Rz parallel to grain, affected by ageing, for water-free and wet ageing regimens
tangential surface, radial surface

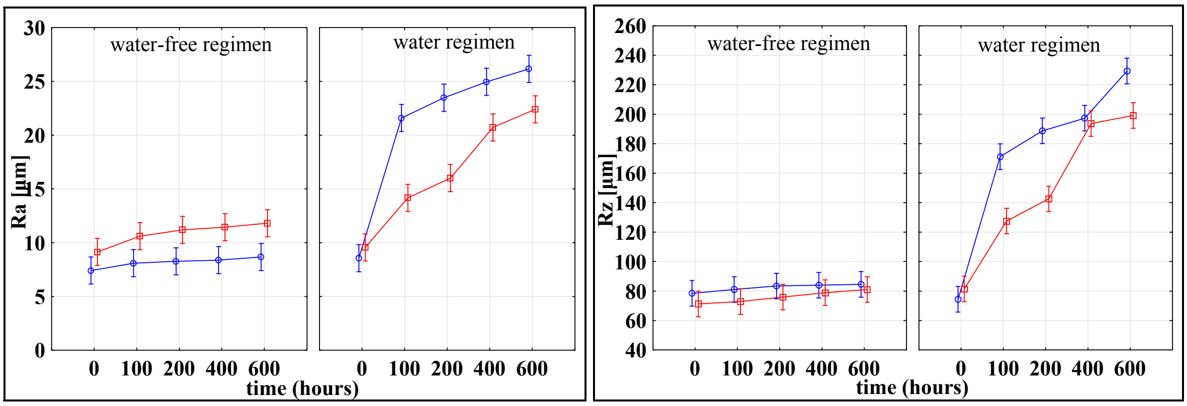

Fig. 6 Ra and Rz perpendicular to grain, affected by ageing, for water-free and wet ageing regimens
tangential surface, radial surface

These results allow us to conclude that water plays an important role in wood ageing process. With the water presence, the influence of radiation (UV radiation, infra-red radiation), oxygen and heat is more intensive, and more pronouncedly reflected on wood surface degradation and wood surface roughness (FEIST 1990, TEMIZ *et al.* 2005). Under the regimen „water-free“, the wood surface is only affected by the solar radiation spectrum (mainly UV radiation) and heat. The UV radiation initiates depolymerisation, primarily in lignin and partially polysaccharides, but does not cause their removal. Under the „wet regimen“, also hydrolytic reactions may occur. The hydrolysis mostly affects the acetyl groups in hemicelluloses (REINPRECHT 2008).

In the process of accelerated ageing, there were formed carbonyl groups. These were more abundant in case of dry regimen than under the wet regimen (IHRACKÝ 2014). A possible explanation is the extraction of carbonyl groups with water.

These ageing processes also cause distinct impairment of the middle lamella. This may result in loosing of cell elements in wood and formation of the so called „plastic wood structure“, mainly due to more progressive degradation of the early wood (FEIST 1990, WILLIAMS and FEIST 1999, ROWELL 2012). This is mainly typical for coniferous woods, but, as the last cited authors show, may be also observed in hardwood species.

We also need to consider the fact that the moisture content in wood during the water-free regimen is almost constant, and, consequently, the moisture-mediated changes in the wood dimensions are very small. During the wet regimen, contrarily, the surface layers of beech wood are exposed to constrained cyclic swelling and shrinkage.

Beech wood belongs to wood species with high swelling and shrinkage values, primarily in the tangential direction (KELLER, 1981, KURJATKO *et al*. 2010, KÚDELA and ČUNDERLÍK 2012). This may be reflected in permanently deformed surface layers and cracks observed in beech wood. These deformations caused by moisture content changes also explain why the roughness values measured on tangential surfaces were higher after ageing.

Additional study is necessary to find out which of the theories discussed provides the better explanation for the surface roughness. This is important because surface roughness influences wood wetting with liquids (LIPTÁKOVÁ *et al*. 1995, 2000), and in context of surface treatment or gluing, the higher roughness will also mean the higher expenses for the surface coating material or the glue.

CONCLUSIONS

The roughness values measured on the beech wood surface after having exposed to accelerated ageing for 600 hour allow us to conclude that.

The roughness parameters were notably influenced by the anatomical direction, accelerated ageing period and the accelerating ageing mode. There have also been confirmed differences in the roughness parameters investigated between the radial and tangential surfaces.

The degradation effects of accelerated beech wood ageing were manifested through enhanced roughness of its surface. In case of water-free accelerated ageing, these changes were slight only, while during accelerated ageing coupled with moisture effects, the wood surface roughness increased over the whole ageing process.

The qualitative course of roughness changes parallel to the grain and perpendicular to the grain were similar, however, on all cases, the roughness values perpendicular to the grain were significantly higher.

More distinct roughness changes were observed on tangential beech wood surfaces, which we may assign to bigger moisture-induced dimensional changes in the tangential direction.

The results have unveiled the important role of water in wood ageing process. Under the water´s presence, the influence of radiation, oxidation and heat is more intensive, and as such, more markedly reflected in the wood surface degradation and in the changes to wood morphology.

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