WOOD RESEARCH
62 (5): 2017
751-762

EVALUATION OF WOOD SURFACE QUALITY DEPENDING ON THE EMBOSSING PARAMETERS

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(Received April 2016)

ABSTRACT

This paper deals with changes in roughness and crack formation after surface embossing of aspen wood. Embossing was based on pushing a wedge with 45° angle into three embossing depths, i.e. 2, 4 and 6 mm. The surface roughness before and after embossing was evaluated on the basis of the arithmetical mean deviation of the roughness profile, R_a. Surface quality measurements were carried out in perpendicular (transversal), parallel (parallel) and perpendicular/parallel to the wood grain. (Embossment area quality was evaluated by the mean of portion of cracks in embossment). This evaluation was based on a digital image of the embossed area and a subsequent calculation of the portion of the cracked area in relation to the total evaluated area. Increasing the embossing depth has a positive impact on the quality of the embossed surface, i.e. the highest quality was generally achieved with an embossing depth of 6 mm. The worst surface quality was achieved with the perpendicular orientation of the wedge regardless of the direction of the roughness measurement.

KEYWORDS: Roughness, cracks, shape of wedge, embossing, surface quality, depth of embossing

INTRODUCTION

Wood is a flexible, strong and light material with good thermal-insulation parameters, capable of withstanding loading and absorbing vibrations, and it can be easily machined with cutting tools as well as joined. These properties of wood allow its use in various industries, such as construction and the production of furniture or musical instruments, which are manufactured by means of chip machining (Požgaj et al. 1997). Increasing the embossing depth has a positive impact on the quality of the embossed surface, i.e the highest quality was generally achieved with an embossing depth of 6 mm.

The wood machining process is characterized by an intricate physical and chemical mechanism of the tool interaction with the machined material. The size, shape and mutual configuration of the irregularities are given by the tool edge shape and condition, and therefore by the cutting parameters, which affect the tool cutting edge movement in relation to the machined surface (Dubovská 2000).

Each process leaves typical surface irregularities, which may affect the required function of these areas. In fact, the machined area is not perfectly smooth and its shape is not that of an optimal surface. Factors related to the wood's physical properties and factors given by the process conditions affect the resulting geometry of the machined surface – *i.e.* the height, shape, configuration and dominant orientation of the irregularities (Lisičan 1988, Dubovský 1993).

The surface roughness is formed by its irregularities with small mutual distances. Such irregularities must be evaluated and quantified from both macrogeometric and microgeometric points of view. On the other hand, the corrugation consists of periodically recurring elevations and depressions of approximately identical dimensions and shape (Lisičan 1988). The difference between the roughness profile and corrugation profile is shown in Fig. 1.

The roughness analysis based on the surface roughness parameters typical for irregularities in the vertical direction, horizontal irregularities and profile irregularities (Shape mean considerable qualitative change) for a quantitative evaluation of the surface micro geometry (Ondra et al. 1996).

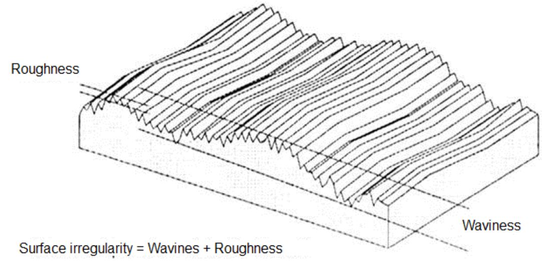


Fig. 1: Surface irregularity composition.

When evaluating the roughness, it is crucial to distinguish between roughness along the wood grain and roughness perpendicular to the wood grain. These differences are mainly due to the wood morphology, i.e. to the mutual orientation of the wood elements, which are mostly oriented in a parallel direction (Bumbálek et al. 1989). Therefore, the surface quality evaluation is often based on the parallel roughness, perpendicular roughness and perpendicular/parallel roughness, as well as the crack formation after the treatment of the wood's surface.

The process of surface formation by molding usually consists of three stages, namely plasticizing, molding and conditioning. The plasticizing includes a plasticizing medium (mostly steam or a chemical agent). During the molding stage, an embossed shape is created in the wood (the tool pressing stage), which is stabilized due to the heat and pressure action (stabilization phase). During the conditioning, the wood moisture content and temperature are balanced, and eventually the plasticizing chemical agent is leaking or neutralized (Kafka 1989). This process results in a product with certain typical processing properties (embossment quality, shape and dimensional stability, etc.) (Gáborík and Dudas 2008).

The surface quality evaluation was based on the roughness with a parallel ($_{\mathrm{II}}$), perpendicular (⊥) and parallel/perpendicular (≠) wedge orientation, as well as on the proportion of cracks formed during the wood surface embossing.

MATERIAL AND METHODS

Materials

European aspen trees (*Populus tremula* L.) were logged from the Poľana region in the center of Slovakia. Parts located at an equal distance from the pith, were chosen for the experiment. These wood parts were cut into boards. From the boards, samples with a width of 100 mm and length of 100 mm were produced. The sample thickness was 15 mm.

The clear wood samples were conditioned to a moisture content of 8 % in a conditioning chamber using the principle of equilibrium moisture content (EMC) (Tab. 1). The samples were conditioned for more than four weeks before testing. After conditioning, the surface of samples was unified on a thickness-equalizing belt sander with 80-grit.

Tab. 1: Conditioning parameter.

Required initial moisture content (%)	Average values of EMC after conditioning (%)	Conditions during conditioning	
		Relative moisture content (%)	Temperature (°C)
8	8.42	40	78

Embossing

The embossing was carried out by the pressing of wedge with 45° rake angle (Fig. 2) into three depths 2, 4 and 6 mm (Fig. 3) at tangential surface of sample. The parallel, perpendicular and mitre (parallel/perpendicular) orientation of the wedge, in relation to the direction of the wood grain, was used.

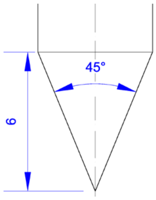


Fig. 2: Embossing wedge with a 45º rake angle.

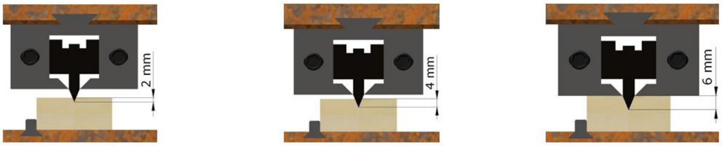


Fig. 3: Principle of embossing in three depths.

The embossing was carried out in standard tensile-pressing machine FPZ 100/1, which contained a special jig for the fixation of the steel wedges. The experiment was carried out at a temperature of 20 °C. First, the testing samples were fixed in the bottom plate, and then the wedge was pressed into the wood surface with three wedge directions in relation to the wood grain (Fig. 4). During pressing, the force was measured and recorded using a sensor and data logger Almemo 2690, which was connected to a laptop.

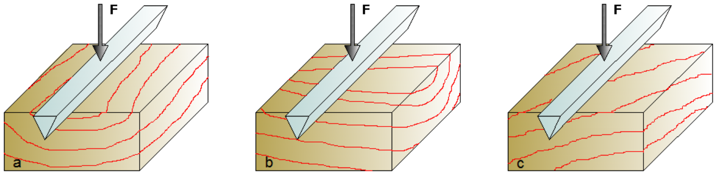


Fig. 4: Orientation of embossing wedge .
a – parallel orientation, b – perpendicular orientation, c– perpendicular/parallel (mitre) orientation.

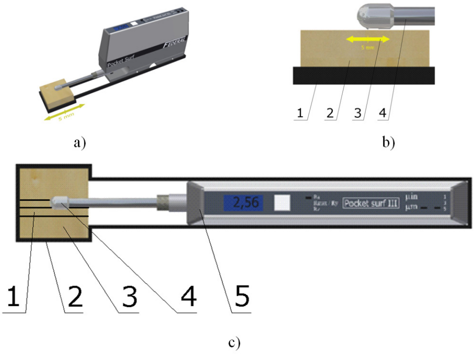
Measurement and evaluation

Roughness measurement

The roughness measurements were carried out using roughness meter Pocket Surf, according to ISO 4287 (1997). The surface roughness was evaluated by the arithmetic mean deviation of the roughness profile, R_a. R_a, the mean roughness, is an arithmetic average of the height of the bothside rough irregularities referred to the central line within the length being evaluated.

A measurement was carried out before embossing in three tracks equidistant in the sample width with a track length of 60 mm and the track oriented in longitudinal and transversal direction (Fig. 4). The goal of this test was to find the change in roughness after the embossing (Fig. 5), i.e., after the wedges were pushed into the sample area. After embossing, the roughness was measured in inclined surface of embossment (Fig. 6), also in the longitudinal and as transversal direction in relation to the embossment length.

This measurement was carried out using a template with both the roughness meter and sample placed inside so that the measured points were identical before and after the embossing. The measured values were processed and exported via PC. The difference between the roughness values measured before and after the embossing was converted to a percentage of the change in roughness so that the result showed either an improvement or deterioration of the measured surface quality.



a)
b)
c)

Fig. 5: Roughness measurement with template: a) overview, b) roughness meter movement range (1 – template, 2 – sample, 3 – movement range of 5 mm,
4 – roughness meter measuring head), c) template top view, (1 – embossment, 2 – template, 3 – sample, 4 – roughness meter measuring head, 5 – roughness meter).

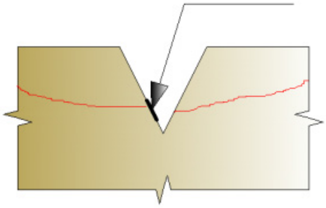


Fig. 6: Measured point in the cross section.

The average roughness change was calculated according to Eq. 1.

$$\Delta R_a = R_{a1} - R_{a2} \tag{1}$$

where: ΔR_a - roughness change (µm),
R_{a1} - roughness of surface before embossing (µm),
R_{a2} - t roughness of the inclined surface in the embossment after embossing (µm).

A positive value (+) expresses improving quality, while a negative value (-) reflects a deterioration in the quality of the surface.

The effect of various factors on the surface roughness was statistically evaluated using ANOVA (Fisher's F-test) analysis, in STATISTICA 12 software (Statsoft Inc.; USA).

Portion of cracks evaluation

The method for determining the embossment area quality was based on the scanning of the embossment into a digital image. This was subsequently copied to PC and the embossment area quality was evaluated with of specific software. The aim of this procedure was surface identification based on the suggested method, and the determination of the effect of selected factors on the structured surface quality.

A greater or lesser amount of cracks characterize the embossed piece surface. The cracks differ from the undamaged surface in color as well. The "Surface" software (developed by us) calculated the cracked area percentage in relation to the area being evaluated, as well as in mm^2.

The work procedure can be divided in the following parts:

1. Embossment creation.
2. Calibration photo scanning with a digital camera (Fig. 7).

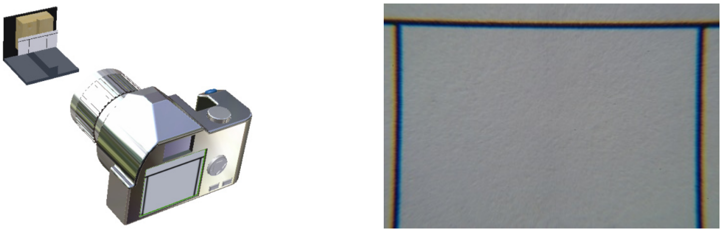


Fig. 7: Principle of sample photographing (left) and calibration photo (right).

The "Surface" software, the calibration photo serves for the correct scale conversion. Therefore, the photo must be taken from the same lens (focus) distance as the test sample.

3. Sample area scanning by digital camera after embossing.
4. Evaluation of sample's scanned area with "Surface" software (Fig. 8).

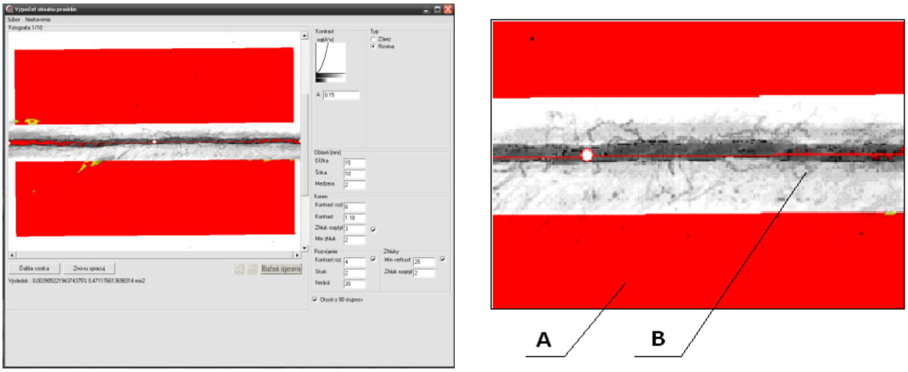


*Fig. 8: Area quality in "Surface" software, software evaluation (left), ratio of areas (right) (***A** *– undamaged,* **B** *– damaged).*

RESULTS AND DISCUSSION

Roughness changes in the longitudinal relative direction to the embossment length

Tab. 2 shows the results of a two-factor analysis evaluating the effect of the individual factors as well as the effect of their interaction on the values of surface roughness change in the longitudinal direction relative to the embossment length. Based on the significance level "P", only the wedge orientation in relation to the wood grain direction was proven to have a statistically significant effect. The embossing depth as well as the monitored interaction of both factors can be deemed as statistically insignificant based on the results.

Tab. 2: The effect of factors and their interaction on the roughness of the embossed surface in the longitudinal direction relative to the embossment length.

Monitored factor	Sum of squares	Degrees of freedom	Variance	Fisher's F - Test	Significance level P
Intercept	7.12	1	7.11507	2.24642	0.133998
Wedge orientation	158.34	2	79.16900	24.99574	0.000001
Embossing depth	6.47	2	3.23381	1.02100	0.360321
Wedge orientation * Embossing depth	18.18	4	4.54622	1.43536	0.219509
Error	13,654.23	4311	3.16730		

Fig. 9 (left) shows the effect of the wedge orientation, in relation to the wood grain direction on the values of surface roughness change after embossing. As shown in the graph, no significant change of surface roughness occurred in the case of parallel wedge orientation. When embossing with a wedge in perpendicular orientation, a statistically significant deterioration of the surface quality occurred. On the other hand, when embossing with a mitre orientation of the wedge, the surface roughness values decreased, i.e. the quality of the embossed surface was better.

Fig. 9 (right) shows the effect of the embossing depth on the roughness change values. These results confirm the statement that the embossing depth did not have a statistically significant effect on the roughness change values after the embossing of the wood surface. Differences in roughness change at different embossing depths were insignificant.

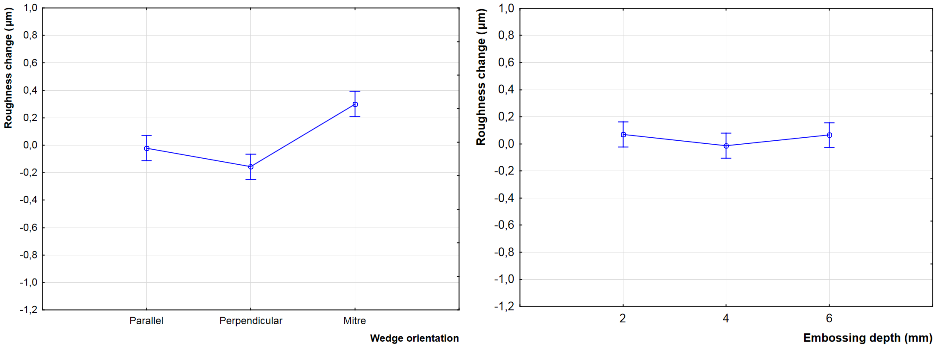


Fig. 9: The effect of wedge orientation (left) and embossing depth (right) on surface roughness change after embossing.

The roughness change caused by the interaction of both monitored factors is shown in Fig. 10. The results prove that the increase in embossing depth had no statistically significant effect. Slightly higher statistically insignificant differences can be seen with the mitre orientation of the wedge in comparison with the parallel and as perpendicular orientation. In the case of the mitre orientation, there was an improvement in the surface quality for all embossing depths. The course of the curves for each depth was very similar. As the embossing depth increased, from 2 mm to 4 mm, the roughness also increased slightly. However, for embossing depth 6 mm, the course has changed.

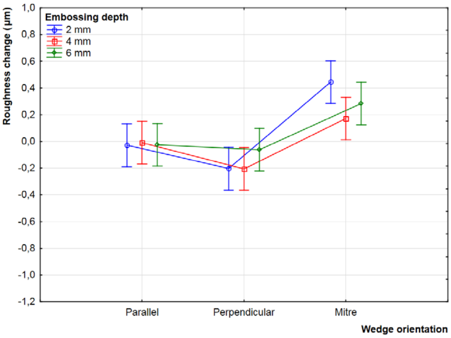


Fig. 10: The effect of the mutual interaction of wedge orientation and embossing depth on the surface roughness change after embossing.

Roughness changes for transversal direction to embossment length

Based on the significance level "P", the wedge orientation in relation to the wood grain direction can be considered a statistically significant factor influencing the roughness change values in the transversal direction in relation to the embossment length (Tab. 3). The effect of the embossing depth was proven to be a factor with medium statistical significance, as seen from the significance level „P“ values.

The values listed in Tab. 3 also prove that the interaction of both monitored factors had no statistically significant effect on the roughness change values.

Tab. 3: The effect of factors and their interaction on the roughness of the embossed surface in transversal direction to embossment length.

Monitored factor	Sum of squares	Degrees of freedom	Variance	Fisher's F - Test	Significance level P
Intercept	265.60	1	265.5981	25.75797	0.000001
Wedge orientation	707.37	2	353.6826	34.30050	0.000001
Embossing depth	78.75	2	39.3754	3.81867	0.022031
Wedge orientation * Embossing depth	29.04	4	7.2605	0.70413	0.589032
Error	44452.00	4311	10.3113		

The roughness change perpendicular to the wood grain affected by the wedge orientation is shown in Fig. 11 (left). As evident from the results, the greatest deterioration in the quality occurred when the perpendicular orientation of wedge was used. A less significant deterioration can be seen with the mitre orientation of the wedge. On the contrary, with parallel wedge orientation in relation to the wood grain, a significant increase in the surface quality can be observed after embossing.

The embossing depth factor was statistically significant for the roughness change (Fig. 11 right). Embossing to a depth of 2 mm caused a greater deterioration in the quality (60%), as for embossing depth 4 mm. However, differences in roughness measured at embossing depths of 4 mm and 6 mm were negligible, although the roughness was slightly higher at a depth of 4 mm, approximately 16%.

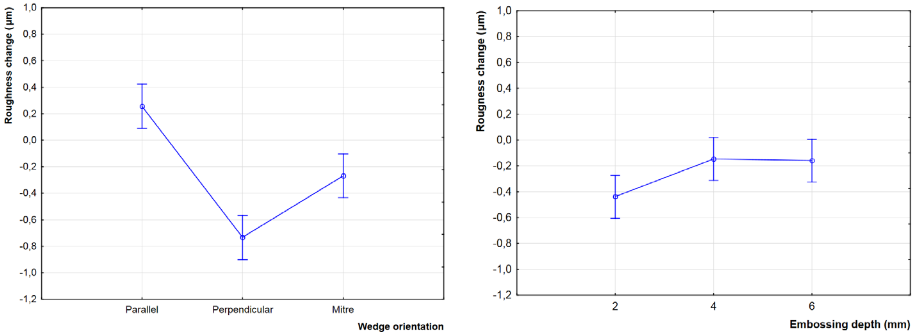


Fig. 11: The effect of wedge orientation (left) and embossing depth (right) on surface roughness change after embossing.

The effect of both monitored factors on the roughness change is shown in Fig. 12. As apparent from the values specified in the graph as well as Tab. 3, the interaction of both factors is statistically insignificant. The results prove that an improvement in surface quality only occurs with a the parallel wedge orientation, in relation to the wood grain, as well as at embossing depths of 4 and 6 mm. The worst surface quality was achieved with a perpendicular orientation of the wedge and a depth of 2 mm. As the of embossing depth increases the roughness change decreases, i.e. there is an improvement in quality.

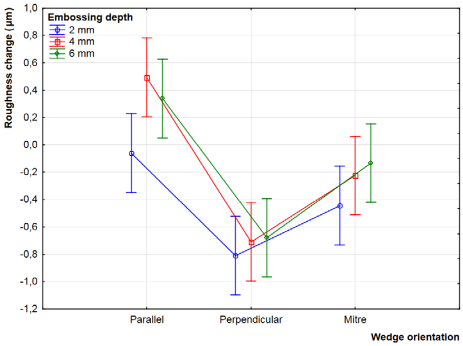


Fig. 12: Mutual interaction of wedge orientation and embossing depth on surface roughness change after embossing.

Tab. 4 contains the average surface roughness for all embossing depths as well as wedge orientations. These values are similar to those mentioned by Kilic et al. (2006), who investigated the surface roughness of aspen. They found an average roughness of 4.63 µm on the grinded tangential surface of aspen wood. The surface roughness of wood mostly depends on its structure. Dundar et al. 2008 found that the roughness is related to various factors, annual such as cross grain, annual ring width, ratio of early wood to late wood, rays, knots, juvenile and mature wood, reaction wood, and specific cell structures. Similarly, Novák et al. (2011), as well as Sandak and Negri (2005), found that the surface smoothness is affected by the anatomical structure of each material. According to Sulaiman et al. (2009), the surface roughness is also very important in other applications such as the utilization of adhesive in wood.

Tab. 4: Roughness values for all embossing depths and wedge orientations.

Wedge orientation in relation to the wood grain	**Average roughness (µm)**					
	Embossing depth					
	2 mm		**4 mm**		**6 mm**	
	Before embossing	After embossing	Before embossing	After embossing	Before embossing	After embossing
Parallel (II)	3.26 (1.78)	2.48 (3.01)	3.13 (2.47)	2.79 (1.99)	2.61 (4.11)	3.06 (2.27)
Perpendicular (⊥)	2.54 (2.24)	2.03 (1.19)	4.67 (4.01)	3.97 (2.11)	3.24 (1.12)	3.16 (0.25)
Mitre (≠)	3.76 (1.96)	3.71 (0.87)	4.63 (2.59)	4.12 (1.43)	5.40 (3.23)	4.91 (1.17)

Note: Numbers in parentheses are standard deviations

Portion of cracks

Tab. 5 shows the results of an analysis of variance evaluating the effect of wedge orientation as well as embossing depth on the percentage of cracks after surface embossing. As apparent from the significance level "P" values, the wedge orientation in relation to the wood grain, is astatistically insignificant factor. The embossing depth was the only significant factor.

Tab. 5: The effect of wedge orientation and embossing depth on portion of cracks on embossment.

Monitored factor	**Sum of squares**	**Degrees of freedom**	**Variance**	**Fisher's F - Test**	**Significance level P**
Intercept	4.26200	1	4.261999	1,065.025	0.000001
Wedge orientation	0.00822	2	0.004110	1.027	0.358112
Embossing depth	0.92651	2	0.463254	115.762	0.000001
Wedge orientation * Embossing depth	0.03775	4	0.009438	2.358	0.051301
Error	17.19566	4297	0.004002		

The percentage of cracks did not change significantly under the effect of different wedge orientations in relation to the wood grain direction (Fig. 13 left). The most important improvement was measured with a parallel wedge orientation, less was found in perpendicular orientation and the smallest in the miter orientation.

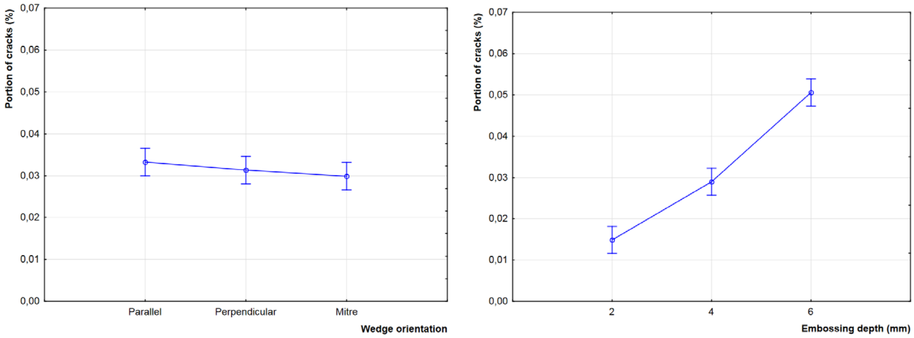


Fig. 13: The effect of wedge orientation (left) and embossing depth (right) on the portion of cracks after embossing.

Fig. 13 (right) shows that the embossing depth is a statistically significant factor influencing the percentage of cracks on the wood surface after embossing. The lowest percentage of cracks was found at an embossing depth of 2 mm (0.015%), while at an embossing depth of 6 mm, crack percentage as high as 0.052% was found on the measured area.

The effect of the interaction of the wedge orientation and embossing depth on the crack percentage was statistically insignificant. Unlike in another monitored combinations, a slight increase was found for the parallel wedge orientation and embossing depth of 6 mm (Fig. 14). However, the character of curves for all orientations of the wedge was very similar, because as the embossing depth increases the portion of cracks also increases.

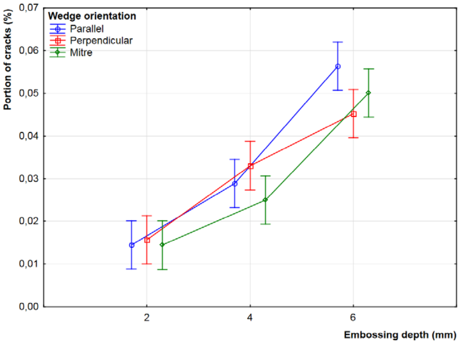


Fig. 14: The effect of the mutual interaction of embossing depth and wedge orientation on the portion of cracks after embossing.

CONCLUSIONS

1. When evaluating the roughness changes in the longitudinal direction in relation to the embossment length, the worst surface quality was measured at a perpendicular orientation of the wedge, while the best quality was measured at a mitre orientation. The differences in roughness change at different embossing depths were negligible, although the lowest values were found at an embossing depth of 4 mm.
2. The evaluation of the roughness change in the transverse direction in relation to the embossment length has shown that as in the previous case, the lowest roughness change was found at a perpendicular orientation of the wedge, while the best surface quality was found at a the parallel orientation. The lowest roughness change values were found at an embossing depth of 2 mm while the differences in roughness change values for embossing depths of 4 and 6 mm were negligible.
3. The portion of cracks did not change significantly under the effect of different wedge orientations. On the other hand, the embossing depth had a very strong effect on the portion of cracks in the embossment, i.e. the highest values were found at an embossing depth of 6 mm, while the lowest values were found at an embossing depth of 2 mm.

ACKNOWLEDGMENTS

The authors are grateful for the support of the University-wide Internal Grant Agency (CIGA) of the Faculty of Forestry and Wood Sciences, project No. B05/16. No. 2016 – 4309.

REFERENCES

1. Bumbálek, B., Odvody, V., Ošťádal, B., 1989: Drsnost povrchu (Surface roughness), SNTL, Prague, Czech republic, 338 pp (in Czech).
2. Dubovská, R., 2000: Niektoré poznatky o kvantifikácii drsnosti pri obrábaní dreva, Proceedings of Chip and Chipless Woodworking Processes, 19-21. 10. 2000, Starý Smokovec -Tatry, Slovakia (in Slovak)

3. Dubovský, J., 1993: Ohybové charakteristiky a kvalita dreva (Bending characteristic and quality of wood), Technical University in Zvolen, Slovakia, 77 pp. (in Slovak)
4. Dundar, T., Akbulut, T., Korkut, S., 2008: The effects of some manufacturing factors on surface roughness of sliced Makore (*Tieghemella heckelii* Pierre Ex A. Chev.) and rotary-cut beech (*Fagus orientalis* L.) veneers. Building and Environment 43(4): 469-474.
5. ISO 4287 -1997: Geometrical product specifications (GPS) - Surface texture: Profile method -- Terms, definitions and surface texture parameters.
6. Kafka, E., 1989: Dřevařská příručka (Woodworking handbook). SNTL, Prague, Czech republic, 483 pp (in Czech).
7. Kilic, M., Hiziroglu, S., Burdurlu, E., 2006: Effect of machining on surface roughness of wood, Building and Environment 41(8): 1074-1078.
8. Lisičan, J., 1988: Obrábanie a delenie drevných materiálov (Machining and cutting of wood materials), 3rd ed., VŠLD, Zvolen, Slovakia (in Slovak).
9. Novák, V., Rousek, M., Kopecký, Z., 2011: Assessment of wood surface quality obtained during high speed milling by use of non-contact method, Drvna Industrija 62(2): 103-115.
10. Ondra, J., Tykal, M., Uhrín, J., 1996: Moderní přístup v hodnocení drsnosti povrchu (The modern approach in the evaluation of surface roughness). In: Rozvoj technológie obrábania RTO 96. SF TU, Košice, Slovakia, 40 pp. (in Czech).
11. Požgaj, A., 1997: Štruktúra a vlastnosti dreva (Structure and properties of wood) Príroda, Bratislava, 485 pp (in Slovak).
12. Sandak, J., Negri, M., 2005: Wood surface roughness - What is it, Proceedings of the 17th International Wood Machining Seminar (IWMS 17), Rosenheim, Germany, Pp 26-28.
13. Sulaiman, O., Hashim, R., Subari, K., Liang, C. K., 2009: Effect of sanding on surface roughness of rubberwood, Journal of Materials Processing Technology 209(8): 3949-3955.

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