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THE EFFECT OF THERMAL MODIFICATION OF BEECH WOOD ON THE QUALITY OF MILLED SURFACE

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ABSTRACT

Steamed wood is currently increasingly used in the woodworking industry. Wood treated in this way eliminates growth stresses, offers higher resistance to weathering and partially better machinability resulting from its more increased fragility. The article quantifies the influence of the degree of thermal treatment on the quality of the created surface on beech wood (*Fagus sylvatica* L.). The samples were created by milling technology with a shank positive spiral milling cutter on a CNC machining center at specified values of cut depth and feed rate. The basic task of the experiment is to verify that thermally modified wood shows a higher surface quality compared to thermally untreated wood, which the authors defined through the values of the arithmetical mean deviation of the roughness profile – R_a and the arithmetical mean deviation of the waviness profile – W_a. Both parameters were measured using a laser profilometer LPM-4. The evaluated samples partially pointed to the assumption of the literature research into a decrease in roughness and waviness (due to the effect of thermal modification) and, thus also to the assumption of improved surface quality. In the case of roughness, there was an increase in surface quality at a steaming temperature of 105 °C (by 9.78 %) and 125 °C (by 22.80 %). In the case of waviness, an increased surface quality was found at a wood steaming temperature of 105 °C (by 43.12 %). In both cases, already higher temperatures of thermal modification caused a re-increase in roughness and waviness. The stated results mean a specific progress in understanding the role of thermal modification by steaming, as it can, in addition to improved physical, mechanical and chemical properties, fundamentally influence the future quality of the surface of the semi-finished or finished product.

Key words: surface roughness, surface waviness, steamed beech wood, laser profilometry, CNC machining.

INTRODUCTION

The quality of the surface of wood products is one of the most important factors affecting their sales after the pricing (ZHONG *et al.* 2013). Therefore, this area is currently receiving increased attention. KMINIAK (2014) understands the quality of the machined surface as the occurrence of characteristic microscopic changes such as roughness and waviness and macroscopic changes represented by torn fibers, scratches, or pits. These are generally considered as unevenness and the result of technological parameters in which the integrity of the wood is violated due to processing. SANDAK and NEGRI (2005) in turn define surface quality as a set of specific surface properties defined by peaks and pits. These features can also be named as surface topography. Until now, the character of the surface of materials was defined by the standard STN EN ISO 4287 (1999), which, compared to the previous standard, precisely defined the difference between surface unevenness (evaluated from the primary profile), roughness (evaluated from the roughness profile) and waviness (evaluated from the waviness profile). Referring to its wording, we can define the real surface (skin model) of wood as the model of the physical interface of the workpiece with its environment. In practice, the arithmetical mean deviation of roughness - R_a and the arithmetical mean deviation of waviness - W_a are most often used to define the quality of the surface. According to KVIETKOVÁ *et al.* (2015 a,b), GAFF and KAPLAN (2016), KUBŠ *et al.* (2016) the waviness is a consequence of kinematic causes caused by the cycloidal shape of the relative movement of the cutting edge of the knife in wood. This shape is caused by the sliding movement of the workpiece and at the same time the rotational movement of the tool itself, which take place linearly (KAPLAN *et al.* 2018 a,b). At the same time, the waviness can be considered as an unevenness of the 3rd order. By roughness we mean unevenness of the 4th and 5th order, arising mostly because of technological reasons (for example, cutting of vessels, fibers, annual rings or as a result of higher humidity or type of wood) or technical reasons (vibration of the tool, wear of the cutting edge). In addition to the mentioned factors, the roughness and waviness are largely influenced by the feed rate and depth of cut. From the literature search, it follows that in most cases, with increasing feed rate and depth of cut, the values of roughness and waviness also increase. Thus, we can claim that the quality of the surface deteriorates. For the needs of the given article, we will follow the theory of chip formation and the theory of phenomena during wood cutting. According to them, with increasing depth of cut, the thickness of the cut chip also increases. There are greater force ratios in the cut and more damage occurs below the parting plane. For the feed rate, we will base it on the theory that with its increase, the feed per tooth will also increase and the thickness of the cut layer will increase again. This article investigates the influence of the mode of wood steaming (as a type of thermal treatment) of beech on the value of roughness R_a and waviness W_a. It is a technological operation, during which a change in the physical, mechanical, and chemical properties of wood is assumed. These changes can be divided into two groups: permanent (irreversible) and reversible (reversible). Permanent chemical changes occur when heat is applied to wet wood. REPELLIN and GUYONNET (2007), KUČERKA and OČKAJOVÁ (2018) report that these changes increase with increasing temperature and increasing time. The first chemical change inside the wood is the extraction of water-soluble substances, the partial hydrolysis of hemicelluloses and the formation of hydrolysis products (acetic acid, formic acid) (AHO *et al.* 2022), which subsequently initiate the degradation of polysaccharides in the wood. The premise of this experiment is the claim that by changing the chemical structure of wood as a result of thermal treatment, the wood becomes more fragile, and during its processing, the more fragile wooden elements are separated more easily, while the damage below the division plane is milder (there are no deeper pits below the manufacturing plane). At the same time, DUDIAK and DZURENDA (2021) state that due to the steaming of beech wood, the density slightly decreases. The decrease in density depending on the increase in temperature can also be observed at higher temperatures of heat treatment (OČKAJOVÁ *et al.* 2019). With an increase in temperatures and the time of operation of the wood steaming mode, this decrease increases.

The aim of the article is to determine the influence of wood steaming modes on the resulting quality of the created surface (roughness R_a and waviness W_a) under specified cutting conditions (feed rate and depth of cut).

MATERIALS AND METHODS

Tangential sections of European beech (*Fagus sylvatica* L.) with dimensions: thickness h = 40 mm × width w = 80 mm × length l = 600 mm. 180 samples, were divided into 4 groups and each group consisted of 45 samples. The initial moisture content of the given samples was in the range from w = 54.7 % to w = 58.2 %. The samples in the 1^{st} group were not heat-treated (0). The samples in the 2^{nd} group were heat-treated with the steaming mode I., the samples in the 3^{rd} group were heat-treated with the steaming mode II. and the samples in the 4th group were heat-treated with the III steaming mode. The heat treatment of blanks was carried out in industrial conditions in the company Sundermann s.r.o., Banská Štiavnica, Slovak republic. Steaming was performed with saturated steam in the pressure autoclave APDZ 240 from the manufacturer Himmasch AD, Bulgaria. Fig. 1 shows the process of thermal treatment of samples with saturated steam, and the technical parameters of individual modes are listed in Table 1

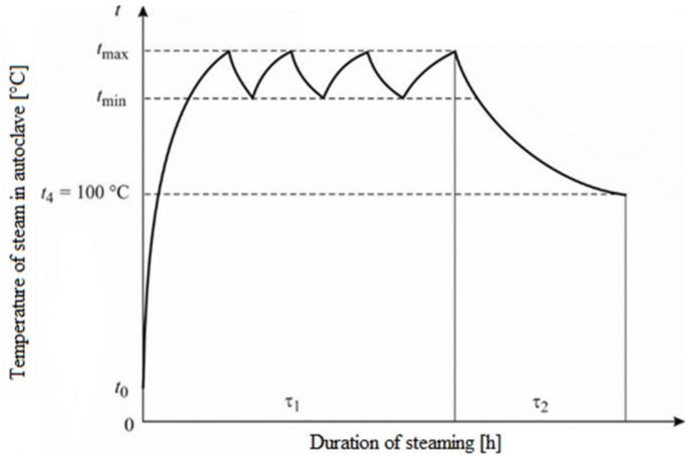

Fig. 1. Temperature diagram of the steaming process in the pressure autoclave.

Temperatures t_{min} and t_{max} are the intervals between which saturated water vapor is supplied to the autoclave for the implementation of the technological process (Fig. 1). The temperature t_4 in the figure is the saturated steam pressure parameter in the autoclave for which the steam pressure in the autoclave must be reduced before the pressure device can be safely opened.

Tab. 1. Modes of modification of blanks saturated with water vapor.

Modes	Saturated steam temperature [°C]			Duration of steaming [h]		
	t_{min}	t_{max}	t_4	τ_1 - phase I	τ_2 - phase II	Total time
Mode I.	102.5	107.5	100	9.0	1.5	10.5
Mode II.	122.5	127.5	100			
Mode III.	132.5	137.5	100			

Non-thermally treated, but also thermally treated blanks were dried in a low-temperature mode without affecting the color change of the wood to a moisture content of w = 12 ± 0.5 % in a conventional hot air dryer from the manufacturer SUZAR s.r.o., Slovakia (SUZAR KC 1/50) (DZURENDA 2022).

For the purposes of the experiment, we milled the modified blanks on a CNC 5-axis center SCM TECH Z5 from the manufacturer SCM Group, Italy. For milling, we used the spiral milling cutter F193 – 16061 from the manufacturer IGM tools and machines from the Czech Republic. It is a tool with three cutting edges with the diameter of the working surface

D = 16 mm, with the length of the working surface B = 55 mm, the diameter of the clamping surface d = 16 mm and the total length L = 110 mm. We installed the mentioned cutter in a SOBO 302680291 GM 300 HSK 63F hydraulic clamp, manufactured by Gühring KG, Germany. We oriented the samples in the CNC machining center: in the direction of the "X" axis - length, in the direction of the "Y" axis - width and in the direction of the "Z" axis - thickness. The feed velocity vector coincided with the “X” axis and the removal was within the “Y” axis. High-speed milling process was carried out using the technological conditions in Tab. 2.

Tab. 2. Milling process parameters.

Parameter	Value
Feed rate (v_f)	2 m·min^{-1}
	4 m·min^{-1}
	6 m·min^{-1}
Depth of cut (e)	1 mm
	3 mm
	5 mm
Tool rotates (n)	18 000 rpm

We carried out non-contact measurement of surface unevenness on processed test samples using the laser profilometer LPM – 4, which was constructed in the company KVANT s.r.o. in cooperation with the Department of Woodworking (Faculty of Wood Sciences and Technology, Technical University in Zvolen). The LPM-4 profilometer works on the principle of triangulation laser profilometry. The Marlin F131B digital camera captures an image of the laser line at a certain angle, and based on the captured image, the cross-sectional profile of the object is subsequently evaluated. The roughness meter consists of an aluminum structure, which is also the supporting part and is fitted with powerful profilometer components. A horizontal beam is placed on the structure, which enables the positioning of the measuring head, which in turn enables the height adjustment and focusing of the camera (Fig. 2) (ŠUSTEK 2010).

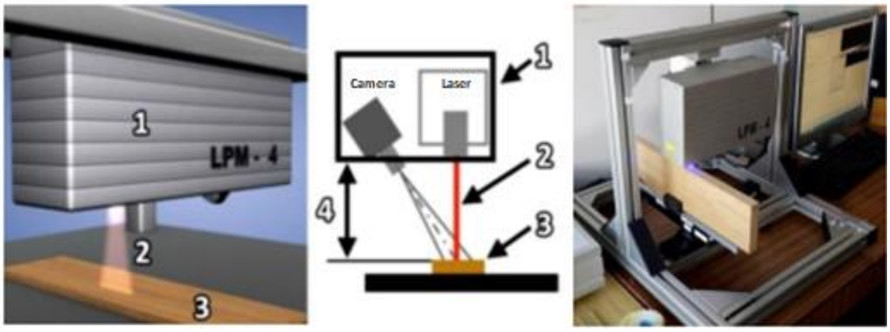

Fig. 2. Operating principle of the LPM – 4 (adapted from SIKLIENKA *et al.* 2008).
1 – camera, 2 – laser, 3 – sample, 4 – distance between LPM – 4 and measured object

We processed the measured data in the STATISTICA program and determined the individual significance of the factors using a multi-factor analysis of variance ANOVA.

RESULTS AND DISCUSSION

The arithmetical mean deviation of the roughness profile (R_a) and waviness (W_a) were measured, and their values were affected by the thermal modification modes, feed rate and depth of cut in the CNC machining center. We proved that the influence of all three investigated factors is significant. For the arithmetical mean deviation of the roughness R_a, the following order of importance of the factors follows from the analysis: 1. depth of cut, 2. feed rate, 3. modification mode. For the arithmetical mean deviation of the waviness W_a, the following order of importance of the factors follows from the analysis: 1. feed rate, 2. depth of cut, 3. modification mode.

We determined the average values of roughness R_a and waviness W_a for untreated beech wood as well as for all three modes of thermal modification (Tab. 3) or different cutting conditions (feed rate, depth of cut) (Tab. 4). It follows from the measured data that non-thermally treated wood has an average roughness of R_a = 7.874 µm. After thermal modification with the first mode (105 °C), the measured roughness was 9.87 % lower compared to untreated native wood. In the second mode of thermal modification (125 °C), the measured roughness values were lower by 22.80 % and in the third mode of thermal modification (135 °C) by 15.39 % less compared to untreated wood. In the case of waviness, the average value W_a = 71.98 µm was measured for untreated wood. After thermal modification with the first mode, the waviness decreased by 43.12 %. After the second mode of modification, the measured value was 28.84 % lower than in the case of untreated wood, and after the third stage of modification it was even higher by 5.35 % (Tab. 3).

Tab. 3. Roughness and waviness values for thermally treated and untreated beech wood (n=45).

	Modification	R_a Average [µm]	R_a Standard deviation [µm]	R_a -95,00 %	R_a +95,00 %	W_a Average [µm]	W_a Standard deviation [µm]	W_a -95,00 %	W_a +95,00 %
1	0	7.874	0.172	7.534	8.215	71.98	1.854	68.32	75.65
2	I	7.097	0.172	6.756	7.438	40.94	1.854	37.27	44.60
3	II	6.079	0.172	5.738	6.420	51.22	1.854	47.56	54.89
4	III	6.662	0.172	6.322	7.003	75.83	1.854	72.16	79.49

Tab. 4. Roughness and waviness values for different values of clearance and feed rate (n=20).

	Depth of cut [mm]	Feed rate [$m \cdot min^{-1}$]	R_a Average [µm]	R_a Standard deviation [µm]	R_a -95,00 %	R_a +95,00 %	W_a Average [µm]	W_a Standard deviation [µm]	W_a -95,00 %	W_a +95,00 %
1	1	2	7.024	0.259	6.513	7.535	49.9	2.782	44.4	55.4
2	1	4	6.320	0.259	5.809	6.831	88.7	2.782	83.2	94.2
3	1	6	5.732	0.259	5.221	6.243	31.2	2.782	25.7	36.7
4	3	2	6.604	0.259	6.093	7.115	38.9	2.782	33.4	44.4
5	3	4	7.491	0.259	6.980	8.002	44.3	2.782	38.8	49.8
6	3	6	5.176	0.259	4.665	5.687	53.5	2.782	48.0	59.0
7	5	2	8.189	0.259	7.678	8.700	62.7	2.782	57.2	68.2
8	5	4	8.440	0.259	7.929	8.951	105.6	2.782	100.1	111.1
9	5	6	7.377	0.259	6.866	7.888	65.2	2.782	59.7	70.7

The process of thermal modification influenced the values of the arithmetical mean deviation of the roughness profile R_a. We measured its decrease up to the wood steaming temperature of 125 °C (Fig. 3). As the wood undergoes a reduction in density during the steaming process (DUDIAK and DZURENDA 2021), the wood becomes more brittle and the output may chip after milling during the cycloidal movement of the tool in the machining process, which may cause less roughness. When wood is thermally modified, its chemical structure changes, and thus it can be concluded that wood becomes more fragile not only as a whole, but also at the level of anatomical elements. Given that, in general, we can define the process of cutting wood as a process of breaking connections between material particles (disruption of the mutual bond of wood fibers), the fibrous structure should also be assumed to be more fragile and to decrease to a smaller depth below the dividing plane ("fibers are less torn out") as well as for better separation of the grade from the workpiece. VANČO *et al.* (2017) that the roughness of wood R_a at 160 °C is lower than in the case of native untreated wood and subsequently increases again from 160 °C. KORČOK *et al.* (2019) also observed the effect of a decrease in roughness up to 160 degrees, while above this temperature the roughness started to increase again. At a temperature of 210 °C and above, the roughness is even higher than with non-thermally treated wood. At the same time, these results are modified by the fact that the average surface roughness of beech wood decreased by 22.80 % during the second mode of wood steaming and then starts to increase again at a temperature of 135 °C, but it is still lower than the roughness of untreated native wood. While the roughness can be explained by the brittleness of the wood due to the loss of amorphous shrinkage (ISPAS *et al.* 2016), the increase in roughness at higher carbohydrates of the term modification can be justified by the degradation of the wood associated with the increase in its porosity (VANČO *et al.* 2017). From the mentioned publications and the values measured by us, it can be concluded that although at low temperatures of thermal treatment up to 160 °C the roughness decreases, paradoxically it increases again at higher temperatures.

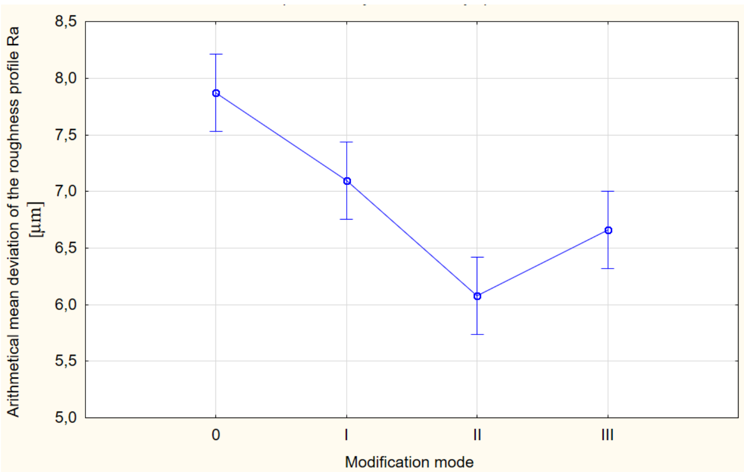

Fig. 3. Effect of thermal modification modes on roughness.

Thermal modification has a significant effect on the waviness of beech wood. Its value after the first regime of thermal modification was lower by up to 43.12 % (Fig. 4) and thus we can conclude that the quality of the wood surface has improved. In part, this phenomenon can be explained by the decrease in the density of beech wood in the process of thermal modification. Changes in mechanical properties are taking place in wood, which will ultimately affect the machining processes in the tool-workpiece system. By changing the mechanical properties in the process of thermal treatment, the wood becomes more brittle, which enables a better separation of the chips from the processed material. However, because of higher temperatures in the second and third mode of thermal modification, the waviness values increased again. A re-increase in waviness may have been due to evaporation of the lignin at higher temperatures and opening of macrostructures of the wood (KORČOK *et al.* 2019). Thus, the measured results did not confirm the claims that thermal treatment improves surface quality in our case (Korkut a Guller 2008). We then compared the change in surface quality from temperatures of heat treatment with heat treatment regimes above 135°C. Dependencies partially supporting the measured results were found. KVIETKOVÁ *et al.* (2015a), in turn, reports an improvement in surface quality (lower waviness values) up to a thermal modification temperature of 210 °C. Above this temperature, the quality continues to deteriorate. Similar results were also measured by KUČERKA *et al.* (2022), where at a temperature of 160 °C there was a decrease in waviness, but subsequently, in the temperature range of 160-200 °C, it gradually increased, and above the level of 210 °C, a sharp increase in waviness occurred. KAPLAN *et al.* (2018b) also provided an insight into the issue, who in the results reports an increase in the waviness values at a temperature of 160 °C compared to thermally untreated wood and a subsequent increase and thus a deterioration of the surface quality in the temperature range of 160-210 °C. The team of authors measured these results using a laser profilometer. In the case of measuring waviness with a contact profilometer, KAPLAN *et al.* (2018a) at a temperature of 160 °C, a reduction in waviness compared to non-thermally treated wood and a subsequent linear growth in the range of 160 – 210 °C. From the mentioned scientific publications, it can be concluded that the waviness of thermally treated wood above 200 to 210 °C is higher than that untreated native wood and, in most cases, increases from the level of 160 °C. At a temperature of 160 °C, in most cases, the waviness was smaller than with non-thermally treated wood. The article, on the other hand, examines the effects of wood steaming modes on waviness values below temperatures of 160 °C, thereby supplementing the often-missing information on thermal modification processes at lower temperatures. Therefore, if we were to take into account only the waviness values of thermally treated wood in our case, the increase in waviness as a result of increasing temperatures is almost linear, and at a temperature of 135 °C the waviness is even higher than in non-thermally treated wood.

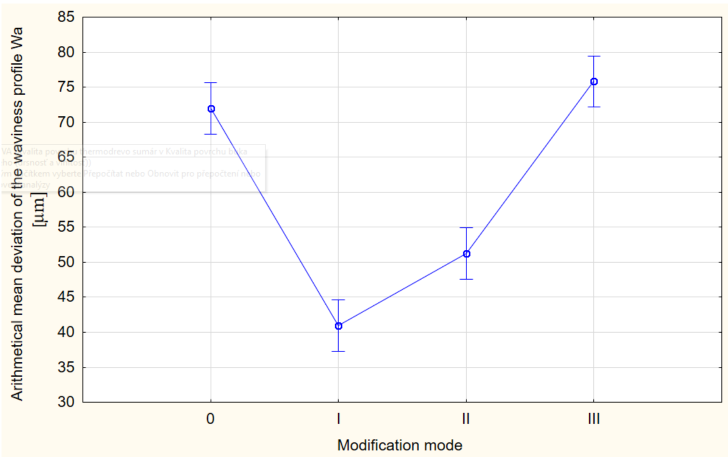

Fig. 4. Effect of thermal modification modes on waviness.

In addition to thermal modification, the arithmetical mean deviation of the roughness and waviness profile was also influenced by the cutting conditions – feed rate and depth of cut. For a deeper analysis of the issue of the presented article, we have always analyzed the most significant factors that affect roughness and waviness. The most significant factor affecting waviness is the feed rate (Fig. 5). While at a depth of cut of 3 mm, the increase in waviness with increasing feed rate is in accordance with the literature (KAPLAN *et al.* 2018a,b). In the case of depth of cut of 1 mm and 5 mm, the highest waviness value was reached at a feed rate of 4 m·min^{-1}, which does not confirm the claims of the literature. As the feed rate increases, the feed per tooth should also increase, which will cause an increase in the thickness of the cut layer (chip). The greater the thickness of the cut chip, the worse the strength ratios in the cutting zone, which results in greater damage below the parting plane (SMAJIC *et al.* 2020).

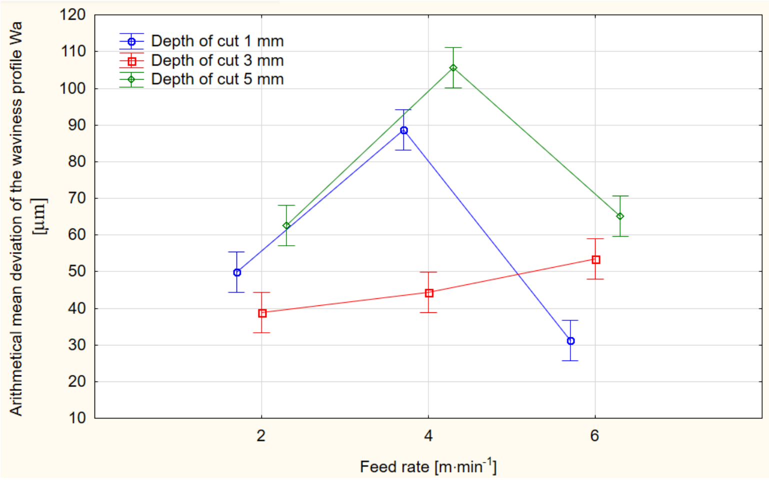

Fig. 5 Effect of cutting conditions on waviness

For roughness, the most significant influencing factor was depth of cut (Fig. 6). The measured values confirm the literature, according to which increasing the depth of cut has a negative effect on the surface roughness. During the formation of the cut layer, its dimensions and shape are affected by the cutting speed, the feed rate, and the depth of cut. The larger the cut chip, the lower the quality of the wood surface. This phenomenon is explained by the transformation of the chip formation process. When increasing the depth of cut value, the thickness of the cut layer gradually increases. Within the transition plane (the plane between the old and new surface), there is a significant change in the cutting angle of the fibers φ_2. At the beginning, the resultant vector of the cutting speed is similar to the inclination of the wood fibers, but at the end it is up to 90°. The larger this angle is, the more the wood structure is broken below the parting plane (the fibers are "pulled out"). A larger depth of cut also means a larger path of the tool in the cut. The longer this path is, the greater the force ratios are in the section. Measurements by ZHU *et al.* (2022), however, showed that the amount of depth of cut can also reduce the roughness. The feed rate also affected the roughness R_a, but again the measured results do not confirm the literature. In most cases, they deal with tools with a larger diameter and slower revolutions, while in our case it was a small diameter tool with significantly higher revolutions.

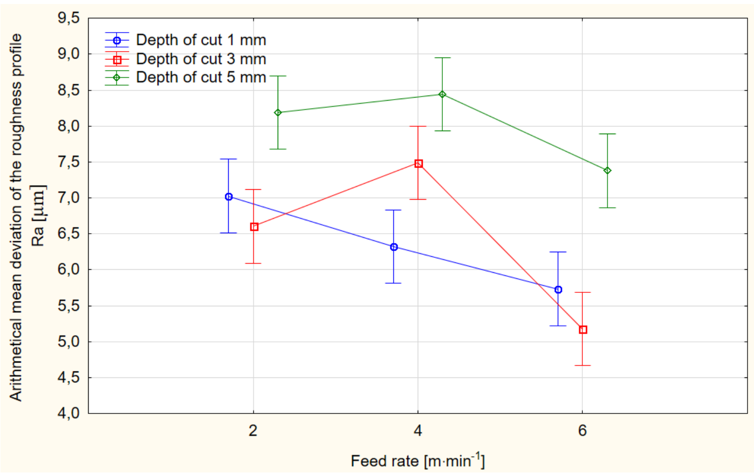

Fig. 6. Effect of cutting conditions on roughness.

CONCLUSIONS

The article proved the effects of thermal modification and cutting conditions on the values of arithmetical mean deviation of roughness R_a and waviness W_a. The following can be concluded from the results:

1. The thermal treatment of beech wood by steaming caused a significant decrease in the roughness values R_a from the original average value of untreated beech wood R_a = 7.874 µm to the value R_a = 6.079 µm (in II. mode of wood steaming with the temperature of saturated steam 125 °C) and a subsequent slight increase in roughness to R_a = 6.662 µm (in III. mode of wood steaming with the temperature of saturated steam 135 °C). It can be concluded that the roughness decreased due to the loss of amorphous polysaccharides, which ultimately affects the mechanical properties of the wood. The process of thermal modification of wood by steaming actually caused an increase in the quality of the surface of the material, but only up to a temperature of 135 °C. Above this temperature, the roughness begins to increase again.
2. The arithmetical mean deviation of waviness W_a was also significantly affected. From the original average waviness value of untreated beech wood, W_a = 71.98 µm, after the 1st mode of wood steaming, the waviness decreased to an average value of W_a = 40.94 µm. Subsequently after II. and III. steaming mode, the average waviness increased again, up to the value of W_a = 75.83 µm, which is higher than in the case of non-thermally treated wood. It can be concluded that the process of thermal modification of wood by steaming improved the quality of the surface, but only up to a temperature of 105 °C. At higher temperatures, the quality deteriorated again.
3. Both parameters evaluating surface quality were significantly influenced by cutting conditions. In the case of waviness, the most significant factor was the feed rate. When depth of cut of 3 mm, we also measured an increase in the waviness value with increasing feed rate, which is in line with the works of other authors. In the case of depth of cut of 1 mm and 5 mm, the highest value of waviness was measured at the feed rate of 4 $m \cdot min^{-1}$, which does not confirm the theory according to which the waviness increases with increasing feed rate and thus the quality of the surface decreases.
4. When measuring the roughness R_a, the most important factor was the depth of cut. The measured data really confirmed the theory from the literature that with increasing depth of cut, there is also an increase in the roughness values and thus also a deterioration of the surface quality. We measured the lowest roughness values at the depth of cut of 1 mm, namely R_a = 5.732 µm, while we measured the highest roughness value at a depth of cut of 5 mm, namely R_a = 8.44 µm.

The article is a contribution to the field of research on thermal modification of wood. It evaluates the lower temperatures of wood modification by steaming already at temperatures of 105 °C, 125 °C and 135 °C, thereby contributing to knowledge about the quality of the wood surface created due to thermal treatment even below the temperature range of 160-210 °C, which are commonly studied. At the same time, it discusses the two most measured parameters, namely roughness R_a and waviness W_a.

REFERENCES

AHO, A., ALVEAR, M., AHOLA, J., KANGAS, J., TANSKANEN, J., SIMAKOVA, I., SANTOS,L.,J., ERÄNEN, K., SALMI, T., MURZIN, D., GRÉNMAN, H. 2022. Aqueous phase reforming of birch and pine hemicellulose hydrolysates. In BioResource Technology, 348 (2022), 126809. DOI: 10.1016/j.biortech.2022.126809

DUDIAK, M. and DZURENDA, L. 2021. Changes in the Physical and Chemical Properties of Alder Wood in the Process of Thermal Treatment with Saturated Water Steam. In Coatings, 11, 898-910. DOI: 10.3390/coatings11080898

DZURENDA, L. 2022. Mode for hot air drying of steamed beech blanks while keeping the colours acquired in the steaming process. In Acta Facultatis Xylologiae Zvolen. Zvolen, 64(1), 81-88. DOI: 10.17423/afx.2022.64.1.07

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.

ISPAS, M. 2016. Milling of Heat-Treated Beech Wood (*Fagus sylvatica* L.) and Analysis of Surface Quality. In BioResources. 11(4), 9095-9111. DOI: 10.15376/biores.11.4.9095-9111

Forestry and wood technology, 130–136. ISSN 1898-5912.

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. In BioResources. 13 (1), 1591-1604. DOI: 10.15376/biores.13.1.1591-1604

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. In Wood Research. 63 (1), 127-140. ISSN 2729-8906.

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

KORČOK, M., KOLEDA, P., BARCÍK, Š., OČKAJOVÁ, A., and KUČERKA, M. 2019. Effect of technological and material parameters on final surface quality of machining when milling thermally treated spruce wood. In BioResources. 14(4), 10004-10013. DOI: 10.15376/biores.14.4.10004-10013

KORKUT, D. S. and GULLER, B., 2008. The effects of heat treatment on physical properties and surface roughness of red-bud maple (Acer trautvetteri Medw.) wood. In BioResource *Technology*. 99(8), 2846-2851. DOI: 10.1016/j.biortech.2007.06.043

KUBŠ, J., GAFF, M., BARCÍK, Š. 2016. Factors affecting the consumption of energy during the of thermally modified and unmodified beech wood. In BioResources. 11(1), 736-747. DOI: 10.15376/biores.11.1.736-747

KUČERKA, M., KMINIAK, R., KRISTAK, L., ROGOZINSKI, T., PĘDZIK, M. 2022. The influence of thermal modification of oak, spruce and meranti blanks onsurface roughness during sanding. In Innovations in forest industry and engineering design INNO 2022. Sofia: Faculty of Forest Industry- University of Forestry, 113-122. ISBN 978-619-7703-01-6.

Kučerka, M. and Očkajová, A. 2018. Thermowood and granularity of abrasive wood dust. In Acta Facultatis Xylologiae Zvolen, 60 (2), 43-51. DOI: 10.17423/afx.2018.60.2.04

KVIETKOVÁ, M., GAFF, M., GAŠPARÍK, M., KAPLAN, L., BARCÍK, Š. 2015a. Surface quality of milled birch wood after thermal treatment at various temperatures. In BioResources. 10(4), 6512-6521. DOI: 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. In *BioResources*. 10(3), 4226-4238. DOI: 10.15376/biores.10.3.4226-4238

OČKAJOVÁ, A., BARCÍK, Š., KUČERKA, M., KOLEDA, P., KORČOK, M., VYHNÁLIKOVÁ, Z. 2019. Wood dust granular analysis in the sanding process of thermally modified wood versus its density. In BioResources. 14(4), 8559-8572. DOI: 10.15376/biores.14.4.8559-8572

REPELLIN, V. and GUYONNET, R. 2007. Evaluation of heat treated wood swelling by differential scanning calorimetry in Relation with Chemical Composition. In Holzforschung. 59, 28-34. DOI: 10.1515/HF.2004.131

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.
SIKLIENKA, M., ŠUSTEK, J., HAJNÍK, I. 2008. Quantification of surface unevenness using a laser profilometer during sawing on a horizontal band saw. In Chip and chipless woodworking processes. Zvolen: Technická univerzita vo Zvolene, 207-212. ISSN 1339-8350.
SMAJIC, S., LUČIĆ, R., JOVANOVIC, J. 2020. Effect of Different Processing on the Roughness of Oak and Beech Wood. In DAAAM International Scientific Book 2020. 18, 217-226. DOI: 10.2507/daaam.scibook.2020.18
STN EN ISO 4287, 1999. Geometrical Product Specifications (GPS). Surface texture: Profile method - Terms, definitions and surface texture parameters.
ŠUSTEK, J. 2010. LPM laser profilometer with horizontal displacement for tracking surface unevenness. In Chip and chipless woodworking processes. Zvolen: Technical university in Zvolen, 187-192. ISSN 1339-8350.
VANČO, M., MAZÁŇ, A., BARCÍK, Š., RAJKO, Ľ., KOLEDA, P., VYHNÁLIKOVÁ, Z., SAFIN., R. 2017. Impact of Selected Technological, Technical, and Material Factors on the Quality of Machined Surface at Face Milling of Thermally Modified Pine Wood. In BioResources. 12(3), 5140-5154. DOI: 10.15376/biores.12.3.5140-5154
ZHONG, Z.W., HIZIROGLU, S., CHAN, C. 2013. Measurement of the surface roughness of wood based materials used in furniture manufacture. In Measurement. 46, 1482–1487. DOI: 10.1016/j.measurement.2012.11.041
ZHU, Z., JIN, D., WU, Z., XU, W., YU, Y., GUO, X., WANG, A.X. 2022. Assessment of Surface Roughness in Milling of Beech Using a Response Surface Methodology and an Adaptive Network-Based Fuzzy Inference System. In Machines. 10(567), 567. DOI: 10.3390/machines10070567

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