Effect of Thermal Treatment on Surface Quality of Beech Wood after Plane Milling

Monika Kvietková, Miroslav Gašparík*, and Milan Gaff

This paper deals with the determination of the surface quality of both thermally treated and thermally untreated wood after the plane milling process. The milled surface quality was evaluated on the basis of the arithmetical mean deviation of the assessed profile, R_a. Surface quality measurements were carried out for various milling process parameters, such as tool clearance angles of 15º, 20º, and 25º, cutting speeds of 20, 30, and 40 m/s, and feed speeds of 4, 8, and 11 m/min. A splinter with a uniform thickness of 1 mm was removed from the wood through milling. Based on the results, it can be stated that thermal treatment of wood has no statistically significant impact on roughness. The most significant impact of the monitored factors were associated with feed speed, clearance angle, and cutting speed. The lowest average roughness values were found at 20º clearance angles, a feed speed of 4 m/min, and a cutting speed of 40 m/s. Increases in cutting speed led to a decrease in average roughness, while an increase in feed speed had the opposite effect.

Keywords: Roughness; Cutting speed; Feed speed; Surface quality; Beech wood; Thermowood; Milling

*Contact information: Department of Wood Processing, Czech University of Life Sciences in Prague, Kamýcká 1176, Praha 6 - Suchdol, 16521 Czech Republic; *Corresponding author: gathiss@gmail.com*

INTRODUCTION

Wood was one of the first materials ever utilized by humans in ancient times. Because of its easy accessibility, workability, and excellent properties, it became one of the most utilized materials. As time passed and wood consumption advanced, the demands for its utilization increased, along with concerns about its durability. Wood is a material naturally exposed to deterioration caused by both biotic and abiotic factors, thus limiting its useful lifetime (Mburu *et al*. 2008; Esteves and Pereira 2009). To extend its lifetime, the wood should be protected against the action of adverse factors. Both physical and chemical methods are used for wood protection. One of the ways for improvement of wood properties and protection is through thermal treatment.

Wood thermal treatment is a modern treatment method for wood and products thereof. A material called Thermowood® is produced in an air atmosphere. The Thermowood® production process was developed on the basis of research conducted at the VTT research center in Finland (Mayes and Oksanen 2003; Yildiz *et al*. 2006). The Thermowood® production process consists of three main phases: temperature increase plus drying, thermal treatment, and cooling plus moisture adjustment (Kačíková and Kačík 2011). During the first phase, the temperature increases quickly to 100 °C in a steam environment inside the drier. Afterwards, the temperature is increased gradually to 130 °C. In this way the material is dried to almost zero moisture. The second phase includes the thermal treatment. After drying, the temperature is increased to between 185 and 215 °C. Once the required temperature is achieved, this temperature is held for between 2 and 3 h, depending on the product's final use. During the third phase, cooling and moisture adjustment take place. Then, the temperature is decreased. When the temperature reaches between 80 and 90 °C, the wood is moistened to between 4% and 7% (Mayes and Oksanen 2002).

After any machining process, certain surface irregularities appear on the machined area, regardless of whether they are on natural materials or thermally treated ones. Therefore, attention should be paid to the surface quality, taking into account the various combinations of technical and process parameters.

The product quality can be defined as the sum of features specified by the producer and price regulation authorities according to different criteria. From among these criteria, the surface quality and dimensional accuracy relate to the machining processes (Lisičan 1996). The machined surface area can be identified by the whole series of its features, as the surface roughness parameters are decisive in practice (arithmetical mean deviation of the assessed profile and corrugation profiles). Each machining method leaves typical configurations of irregularities on the surface (the appearance of surfaces machined by saw will be different to those machined by milling machine or by another process), even if the piece dimensions are identical (Prokeš 1982).

The wood surface roughness, corrugation, and deviation from the ideal overall geometric shape are the surface geometry deviations. The surface geometry is defined based on the irregularities resulting from macroscopic, microscopic, and submicroscopic features. The wood surface roughness is dependent on its inherent morphology and on the machining method employed (Aydin and Colakoglu 2003, 2005; Dornyak 2003; Temiz *et al*. 2005).

The machined surface's resulting roughness depends on many process factors, such as cutting conditions, tool geometry (shape), processed material properties, cutting process stability, *etc.* (Wasielewski and Orlowski 2002; Magoss 2008). The overall surface assessment options are widened in the standard ISO 4287 (1997) in a manner that all parameters defined therein can be applied to the primary profile, roughness profile, and corrugation profile (Fig. 1).

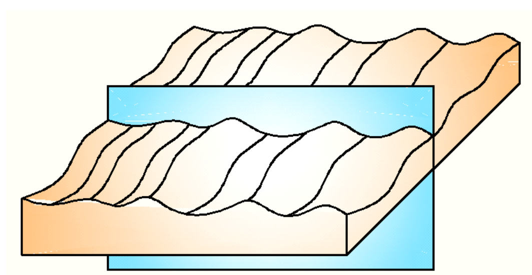

Fig. 1. Surface profile

Milling is a widely utilized method in chip machining of both wood and wood-based materials. The purpose of milling is to machine the wood (by a chip-generating process) into the required dimension, shape, and surface quality (Magoss 2008). The milled surface of the wood is considered as one of the best in terms of quality (Costes and Larricq 2002; Karagoz *et al*. 2011). The main movement in milling is rotation, carried out by the tool (the milling machine).

The workpiece carries out the ancillary movement of feeding (Fig. 2). Feeding is a circle rolling alongside a straight line so that the point at the tool cutting edge depicts a cycloid (cut curve) on the workpiece (Mikolášik 1981; Keturakis and Juodeikienė 2007).

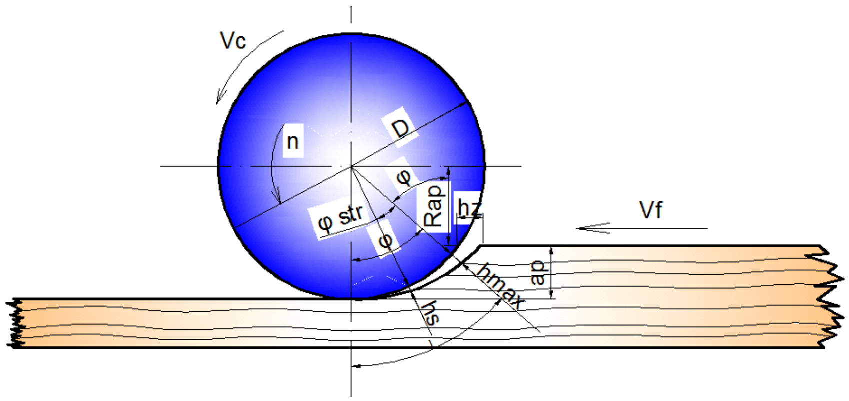

Fig. 2. Theoretical calculation of thickness and length for the milled chip from roll milling; v_f is feed speed (m/min), v_c is cutting speed (m/s), h_{max} is maximum thickness (mm), h_s is cut splinter thickness (mm), a_p is cut depth (m), f_z is feed per tooth (mm), n is tool rotation frequency (cutter rotating speed) (min^{-1}), D is tool (cutter) diameter (m), R – a_p is cut depth *vs*. tool radius ratio, φ is tooth cutting angle (°), and $φ_{str}$ is central angle (°).

This work included the comparison of surface roughness for native and thermally modified beech wood after plane milling. The plane milling was carried out with various factors, such as tool clearance angles of 15º, 20º, and 25º, cutting speeds of 20, 30, and 40 m/s, and feed speeds of 4, 8, and 11 m/min.

EXPERIMENTAL

Materials

The European beech trees (*Fagus sylvatica* L.) used in this study grew in the central region of the Czech Republic, near Kostelec nad Černými lesy, east of Prague. The zones suitable for samples were cut from the trunk at a height of 2 m from the stump. The zones, which were in the middle distance between the pith and bark, were chosen for sample preparation. From these parts, 100-cm-long sections were cut that contained 1.5-mm-wide annual rings. For the experiments, beech samples with dimensions of 40 × 100 × 500 mm were used. All the samples were air-conditioned in the conditioning room (ϕ = 65 ± 3% and t = 20 ± 2 ºC) for more than six months to achieve an equilibrium moisture content (EMC) of 12%. The actual EMC of each sample was measured using a weighing method after conditioning.

A special group of beech samples was prepared for the identification of the physical and mechanical properties of native and thermally modified wood. These samples were prepared according to relevant standards and were only used for identification and verification of these properties.

All of the air-conditioned samples were divided into two groups, samples of native beech wood and samples for thermal treatment. The whole investigation contained 270 samples.

Procedure

Thermal treatment

Beech samples chosen for thermal modification were put on a metal grate and subsequently placed inside a thermal chamber S400/03 (LAC Ltd., Czech Republic) and modified. Table 1 lists the times of all thermal treatment stages, as well as technical parameters. Thermally modified samples were then conditioned at a temperature of 20 °C and relative air humidity of 65%. All samples were then machined to a final thickness of 25 mm using a thickness planer, DHM 630P (Holzmann, Germany). Thus, planed native and thermal modified materials (final dimensions 25 × 100 × 500 mm) were prepared for milling.

Table 1. Conditions and Procedures for Thermal Treatment – Thermo Wood Preparation

Input technical parameters		**Thermal treatment procedure**	
Moisture content of wood	11.5 %	Heating	5.5 h
Filling capacity of TW furnace	0.38 m^3	Drying	6 h
Electricity consumption	6 kWh	Heating	6 h
Maximum reached temperature	190 °C	Thermal (TW) treatment	1 h
		Cooling	9 h
		Total time	27.5 h

Plane milling

The plane milling was carried out using a one-spindle cutter FVS with a STEFF 2034 feeding system (Maggi Technology, Italy). Cutter parameters are listed in Table 2. These parameters were chosen according to the most frequently used equipment for plane milling. A splinter with a uniform thickness of 1 mm was removed from the wood through plane milling.

Table 2. Cutting Conditions for Plane Milling

One-spindle cutter FVS (Ø 130 mm) with feed system STEFF 2034		**Cutter head**	
Input power (kW)	4	Clearance angle α	15, 20, and 25°
RPM	3000, 4500, and 6000	Cutting angle of wedge β	45°
Cutting speed (m/s)	20, 30, and 40	Rake angle γ	30, 25, and 20°
Feed speed (m/min.)	4, 8, and 11	Cutting angle δ	60, 65, and 70°

Roughness measurement

The surface roughness was measured using a roughness meter, Form Talysurf Intra (Taylor-Hobson, Great Britain). The roughness measurements were realized according to ISO 4287 (1997) as well as ISO 4288 (1996). A measurement was carried out in three tracing lengths with a track length of 50 mm, and the track oriented along the feed direction of the sample, *i.e.*, in the direction parallel to the wood fiber and length of the sample. The surface roughness was evaluated using the arithmetical mean deviation of the assessed profile, R_a (Fig. 3). R_a, the roughness mean value, is the average distance from the profile to the mean line over the length of assessment (Mummery 1992; Karagoz *et al*. 2011).

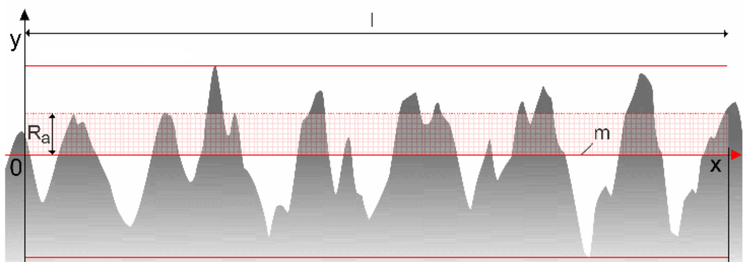

Fig. 3. Parameter R_a in roughness profile; R_a is arithmetical mean deviation of the assessed profile (μm), *m* is the middle line, and *l* is the sampling length (mm)

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

Evaluation and Calculation

The density was determined as an auxiliary indicator. Density was calculated according to Eq. 1 from ISO 13061-2 (2014),

$$\rho_w = \frac{m_w}{a_w * b_w * l_w} = \frac{m_w}{V_w} \tag{1}$$

where ρ_w is the density of the test sample at certain moisture content w (kg/m^3), m_w is the mass (weight) of the test sample at certain moisture w (kg), a_w, b_w, and l_w are dimensions of the test sample at certain moisture w (m), and V_w is the volume of the test sample at a certain moisture w (m^3).

The density of wood after treatment was calculated according to Eq. 2 from ISO 13061-2 (2014),

$$\rho_{tw} = \frac{m_{tw}}{a_{tw} * b_{tw} * l_{tw}} = \frac{m_{tw}}{V_{tw}} \tag{2}$$

where ρ_{tw} is the density of the test sample after treatment (kg/m^3), m_{tw} is the mass (weight) of the test sample after treatment (kg), a_{tw}, b_{tw}, and l_{tw} are dimensions of the test sample after treatment (m), and V_{tw} is the volume of the test sample after treatment (m^3).

The moisture content of samples was determined and verified before and after thermal treatment. These calculations were carried out according to ISO 13061-1 (2014) and Eq. 3,

$$w = \frac{m_w - m_0}{m_0} * 100 \qquad (3)$$

where w is the moisture content of the samples (%), m_w is the mass (weight) of the test sample at certain moisture w (kg), and m_0 is the mass (weight) of the oven-dry test sample (kg).

Drying to the oven-dry state was also carried out according to ISO 13061-1 (2014) using the following procedure. The samples were placed in the drying oven at a temperature of 103 ± 2 °C until a constant mass was reached. Constant mass was considered reached if the loss between two successive weighing measurements, carried out at an interval of 6 h, was equal to or less than 0.5% of the mass of the test sample. After cooling the test samples to approximately room temperature in a desiccator, the sample was weighed rapidly enough to avoid an increase in moisture content of more than 0.1%. The accuracy at weighing should be at least 0.5% of the mass of the test sample.

RESULTS AND DISCUSSION

Physical and Mechanical Properties

The average moisture of native beech wood was 11.5%, which corresponds to equilibrium wood moisture under conditions φ = 65 ± 3% and t = 20 ± 2 °C (Table 1). The average moisture content of thermally modified beech was 3.7%. Maulis (2009) reported 4% moisture content for thermally modified beech wood, under comparable conditions.

Table 3. Moisture Content of Native and Thermally Modified Beech Wood

Native beech wood			Beech wood with thermal treatment	
Minimum value	10.7%		Minimum value	2.9%
Maximum value	13.6%		Maximum value	4.5%
Average value	11.5%		Average value	3.7%
Standard deviation	0.199		Standard deviation	0.495
Coefficient of variation	2.4		Coefficient of variation	12.3

The average density of native beech was 709 kg/m^3. This value is slightly lower than the 720 kg/m^3 value indicated by Wagenführ (2000). The average density of thermally modified beech, after 1 h of thermal treatment at 190 °C, was 675 kg/m^3. Hence, the density of thermally modified beech wood was lower by 34 kg/m^3, *i.e.*, a 5.04% density decrease. Maulis (2009) indicated a 10% decrease in density of thermally modified beech wood at a temperature of 210 °C. However, Yildiz (2002) found a slight density increase for beech wood (2.25%) for treatments at 130 °C for 2 h.

Surface Roughness

Based on the significance level "P" values given in Table 4, the effect of the clearance angle of the tool, cutting speed, and feed speed can be deemed statistically significant. The impact of thermal treatment was shown to be a non-significant factor. The interaction of the four monitored factors combined was statistically insignificant.

Based on the resulting effect of the clearance angle of the tool shown in Fig. 4, it is possible to conclude that for the use of a tool with a clearance angle of 20°, there was a statistically significant decrease in roughness value when compared with tools with clearance angles of 15° and 25°. The average roughness achieved for a clearance angle around 15° was 12.5% higher compared to a clearance angle of 20°, but only approximately 4.6% higher than that of a clearance angle around 25°.

Table 4. Effect of Individual Factors on Roughness

Monitored factor	Sum of squares	Degrees of freedom	Variance	Fisher's F - Test	Significance level P
Overall diameter	4012.22	1	4012.22	4845.29	0.001
Clearance angle	10.136	2	5.068	6.120	0.003
Cutting speed	8.839	2	4.419	5.337	0.006
Feed speed	39.949	2	19.974	24.122	0.001
Treatment	0.789	1	0.789	0.953	0.331
Clearance angle × Cutting speed × Feed speed × Treatment	9.306	8	1.163	1.405	0.198
Error	10.136	2	5.068	6.120	0.003

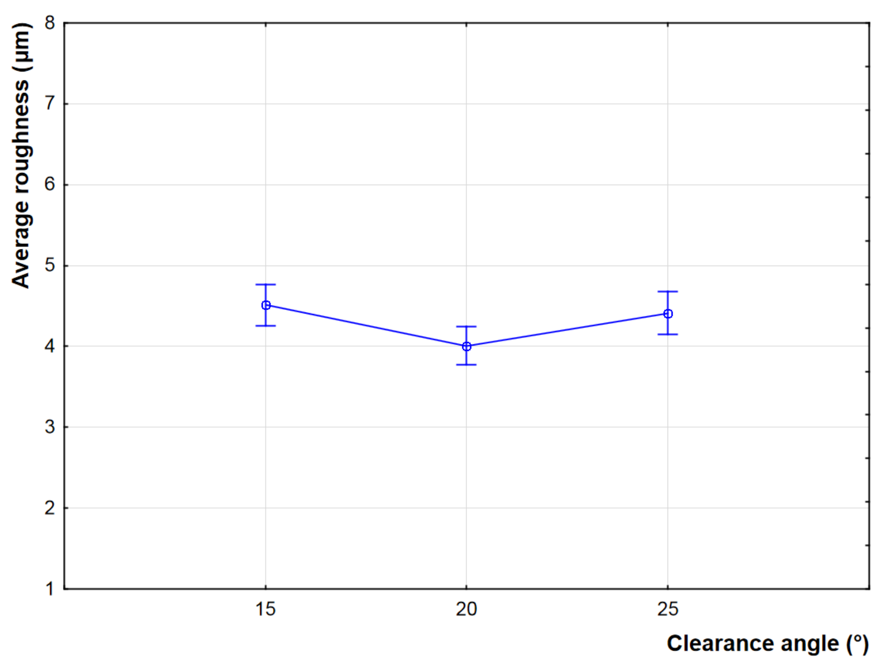

Fig. 4. A 95% confidence interval shows the influence of clearance angle on average roughness

According to results shown in Fig. 5, the cutting speed can be deemed a statistically significant factor as far as the arithmetical mean deviation of the assessed profile R_a. As evident from the values specified in the graph, if the cutting speed increases, the roughness values decrease in a statistically significant manner. The average roughness of the milled wood with the lowest cutting speed of 20 m/s was about 7% higher than a cutting speed of 30 m/s, and 12.2% higher than a cutting speed of 40 m/s.

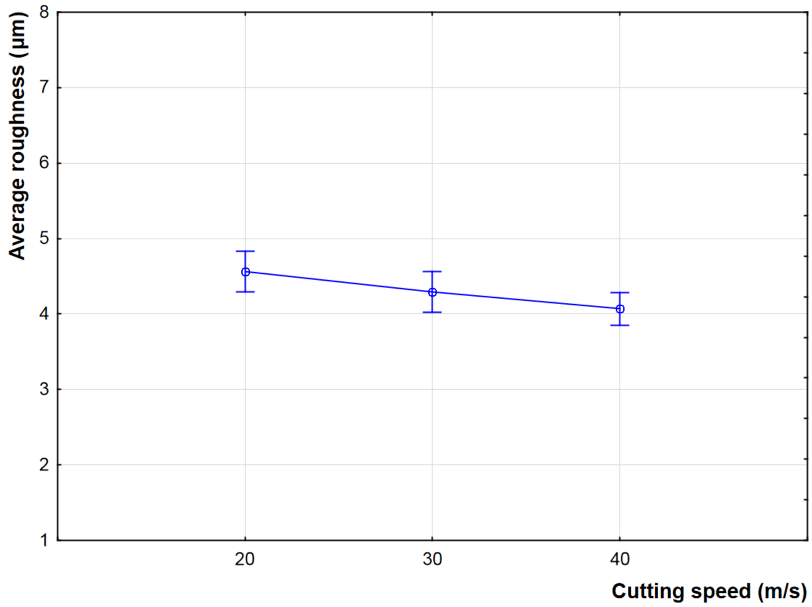

Fig. 5. A 95% confidence interval shows the influence of cutting speed on average roughness

The feed speed increase during milling had a statistically significant impact on the increase of average roughness values (Fig. 6). Effect of feed speed on average roughness had contrary characteristics, as was found for cutting speed. The increase of average roughness between the lowest feed speed of 4 m/min and the highest of 11 m/min is approximately 26.3%. However, the difference found between a feed speed of 8 m/min and 11 m/min was only 11.6%.

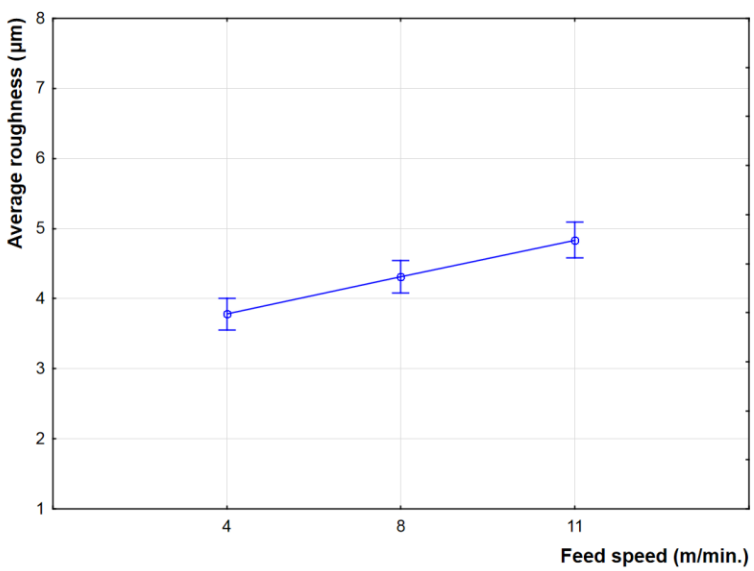

Fig. 6. A 95% confidence interval shows the influence of feed speed on average roughness

The effect of the thermal treatment (Table 2) had no statistically significant effect on average roughness values (Fig. 7). The difference in the values of the average surface roughness between untreated and thermally treated wood was only 2.8%. Higher values were measured for the native (untreated) wood.

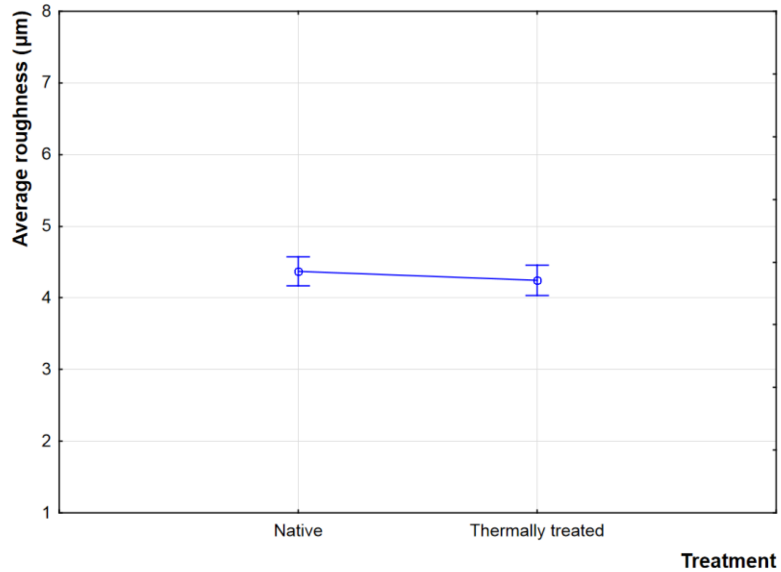

Fig. 7. A 95% confidence interval shows the influence of treatment on average roughness

Figure 8 describes the impact of all factors on the average roughness of thermally treated wood. As can be seen in the individual curves, it is difficult to determine the definite character of the average roughness, depending on examined factors. Feed speed exhibited a clear effect, as with its increase the average roughness also slowly grew. The effect of cutting speed was not generally clear. Although the highest average roughness was found at a cutting speed of 20 m/s, further gradual reduction was not uniform. Differences between the various curves were not clear and not too high. As such, the combination of all factors was deemed statistically insignificant.

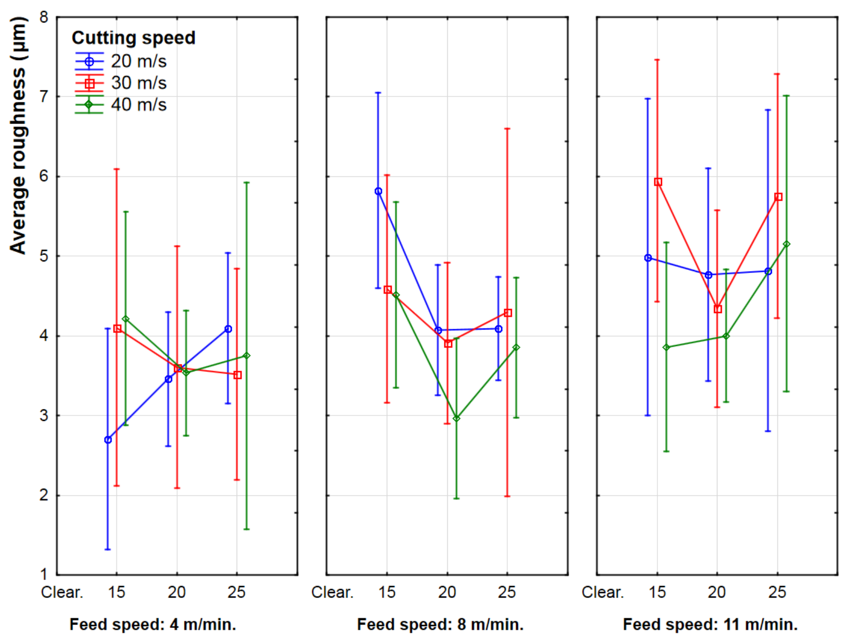

Fig. 8. A 95% confidence interval shows the influence of cutting speed, feed speed, clearance angle, and treatment on average roughness of thermally treated wood

Figure 9 shows the simultaneous effect of all factors on average roughness, but for native wood. Here again, there was a gradual slight increase in the average roughness values influenced by an increase in feed speed. The influence of individual factors had very similar characteristics to the previous case.

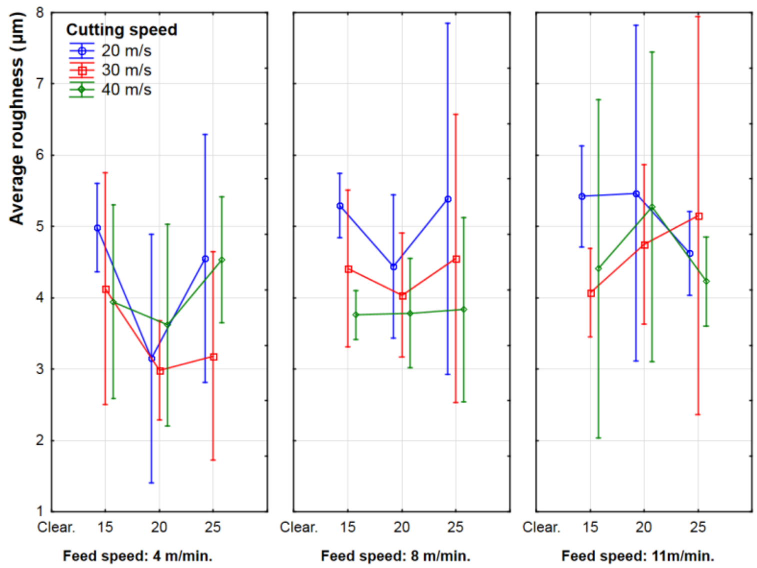

Fig. 9. A 95% confidence interval shows the influence of cutting speed, feed speed, clearance angle, and treatment on average roughness of native wood

The total difference in the values of average roughness between native and thermally treated wood was only 2.8%, a lower value compared to other authors. This difference could have been caused by the short duration of the thermal treatment. In general, as confirmed in several investigations by other authors (Gündüz *et al*. 2008; Korkut and Guller 2008; Korkut *et al*. 2013; Baysal *et al*. 2014), the increase in treatment temperature and its duration reduces the average roughness of wood. Korkut and Budakci (2010), who investigated the influence of thermal treatment on the surface roughness of Rowan (*Sorbus aucuparia*) wood, found decreases in surface roughness up to 12.85% for wood thermally treated at 180 °C for 10 h compared to untreated (control) wood. Similarly, Karagoz *et al*. (2011) found decreases in surface roughness with increasing temperature.

CONCLUSIONS

1. Based on the results, it is possible to conclude that wood thermal treatment has no effect on the average roughness of beech surface after plane milling.
2. The lowest values for surface roughness after plane milling were found with the use of a tool with a clearance angle of 20°. No statistically significant difference was found for tools with clearance angles of 15° and 25°.
3. A decrease in the average roughness values for the surface after plane milling was found when the cutting speed increased.

4. There was a directly proportional increase in average roughness as feed speed increased.

ACKNOWLEDGMENTS

The authors are grateful for the support of the Grant Agency at the Faculty of Forestry and Wood Science, project No. 20124311, "Influence of cutting tools parameters on surface quality for wood-based materials".

REFERENCES CITED

Aydin, I., and Colakoglu, G. (2003). "Roughness on wood surfaces and roughness measurement methods," *Kafkas University Faculty of Forestry Journal* 4(1-2), 92-102.

Aydin, I., and Colakoglu, G. (2005). "Effects of surface inactivation, high temperature drying and preservative treatment on surface roughness and colour of alder and beech wood," *Applied Surface Science* 252(2), 430-440. DOI: 10.1016/j.apsusc.2005.01.022

Baysal, E., Kart, S., Toker, H., and Degirmentepe, S. (2014). "Some physical characteristics of thermally modified Oriental-beech wood," *Maderas. Ciencia y Tecnología* 16(3), 291-298. DOI: 10.1016/j.apsusc.2005.01.022

Costes, J. P., and Larricq, P. (2002). "Towards high cutting speed in wood milling," *Annals of Forest Science* 59(8), 857-865. DOI: 10.1051/forest:2002084

Dornyak, O. R. (2003). "Modeling of the rheological behavior of wood in compression processes," *Journal of Engineering Physics and Thermophysics* 76(3), 648-654. DOI: 10.1023/A:1024741618988

Esteves, B. M., and Pereira, H. M. (2009). "Wood modification by heat treatment: A review," *BioResources* 4(1), 370-404. DOI: 10.15376/biores.4.1.370-404

Gündüz, G., Korkut, S., and Korkut, D. S. (2008). "The effects of heat treatment on physical and technological properties and surface roughness of Camiyani black pine (*Pinus nigra* Arn. subsp. *pallasiana* var. *pallasiana*) wood," *Bioresource Technology* 99(7), 2275-2280. DOI: 10.1016/j.biortech.2007.05.015

ISO 4287 (1997). "Geometrical product specifications (GPS) -- Surface texture: Profile method -- Terms, definitions and surface texture parameters," International Organization for Standardization, Geneva, Switzerland.

ISO 4288 (1996). "Geometrical product specifications (GPS) -- Surface texture: Profile method -- Rules and procedures for the assessment of surface texture," International Organization for Standardization, Geneva, Switzerland.

ISO 13061-1 (2014). "Physical and mechanical properties of wood -- Test methods for small clear wood specimens -- Part 1: Determination of moisture content for physical and mechanical tests," International Organization for Standardization, Geneva, Switzerland.

ISO 13061-2 (2014). "Physical and mechanical properties of wood -- Test methods for small clear wood specimens -- Part 2: Determination of density for physical and mechanical tests," International Organization for Standardization, Geneva, Switzerland.

Kačíková, D., and Kačík, F. (2011). "*Chemické a mechanické zmeny dreva pri termickej uprave* (*Chemical and mechanical changes during thermal treatment of wood)*," Technical University in Zvolen, Slovakia (in Slovak).
Karagoz, U., Akyildiz, M. H., and Isleyen, O. (2011). "Effect of heat treatment on surface roughness of thermal wood machined by CNC," *Pro Ligno* 7(4), 50-58.
Keturakis, G., and Juodeikienė, I. (2007). "Investigation of milled wood surface roughness," *Materials Science (Medžiagotyra)* 13(1), 47-51.
Korkut, S., and Budakci, M. (2010). "The effect of high- temperature heat-treatment on physical properties and surface roughness of Rowan (*Sorbus aucuparia* L.) wood," *Wood Research* 55(1), 67-78.
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," *Bioresource Technology* 99(8), 2846-2851. DOI: 10.1016/j.biortech.2007.06.043
Korkut, S. D., Hiziroglu, S., and Aytin, A. (2013). "Effect of heat treatment on surface characteristics of wild cherry wood," *BioResources* 8(2), 1582-1590. DOI: 10.15376/biores.8.2.1582-1590
Lisičan, J. (1996). "*Teória a Technika Spracovania Dreva* (*Theory and Technique of Wood Processing*)," Matcentrum, Zvolen, Slovakia (in Slovak).
Magoss, E. (2008). "General regularities of wood surface roughness," *Acta Silvatica & Lignaria Hungarica* 4(1), 81-93.
Maulis, V. (2009). *Technologie a Zhodnocení Vybraných Vlastností Dřeva Modifikovaného Teplem (Production Technology and Evaluation of Thermal Modified Wood)*, M.S. thesis, Czech University of Life Sciences, Prague, Czech Republic (in Czech).
Mayes, D., and Oksanen, O. (2003). *ThermoWood® Handbook*, Finnish Thermowood Association, Helsinki, Finland.
Mburu, F., Dumarcay, S., Bocquet, J. F., Petrissans, M., and Gérardin, P. (2008). "Effect of chemical modifications caused by heat treatment on mechanical properties of *Grevillea robusta* wood," *Polymer Degradation and Stability* 93(2), 401-405. DOI: 10.1016/j.polymdegradstab.2007.11.017
Mikolášik, Ľ. (1981). *Drevárske Stroje a Zariadenia l.* (*Woodworking Machinery l.*), Nakladateľstvo Technickej Literatúry, Bratislava, Slovakia (in Slovak).
Mummery, L. (1992). *Surface Texture Analysis: The Handbook*, Hommelwerke GmbH, Germany.
Prokeš, S. (1982). "*Obrábění Dřeva a Nových Hmot ze Dřeva* (*Woodworking and New Materials from Wood*)," SNTL – Nakladatelství Technické Literatury, Prague, Czech Republic (in Czech).
Temiz, A., Yildiz, U. C., Aydin, I., Eikenes, M., Alfredsen, G., and Colakoglu, G. (2005). "Surface roughness and colour characteristics of wood treated with preservatives after accelerated weathering test," *Applied Surface Science* 250(1-4), 35-42. DOI: 10.1016/j.apsusc.2004.12.019
Wagenführ, R. (2000). "*Holzatlas* (*Atlas of Wood*)," 5^{th} Edition, Fachbuchverlag, Leipzig, Germany (in German).
Wasielewski, R., and Orlowski, K. (2002). "Hybrid dynamically balanced saw frame drive," *Holz Als Roh- und Werkstoff* 60(3), 202-206. DOI: 10.1007/s00107-002-0290-4

Yildiz, S. (2002). *Physical, Mechanical, Technological and Chemical Properties of Beech and Spruce Wood Treated by Heating*, Ph.D. thesis, Karadeniz Technical University, Trabzon, Turkey.

Yildiz, S., Gezer, E. D., and Yildiz, U. C. (2006). "Mechanical and chemical behavior of spruce wood modified by heat," *Building and Environment* 41(12), 1762-1766. DOI: 10.1016/j.buildenv.2005.07.017

Article submitted: February 25, 2015; Peer review completed: May 15, 2015; Revised version received and accepted: May 19, 2015; Published: May 26, 2015.
DOI: 10.15376/biores.10.3.4226-4238