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Analysis of the surface roughness of native wood species depending on angular parameters of the cutting tool during milling in different conditions

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Abstract: *Analysis of the surface roughness of native wood species depending on angular parameters of the cutting tool during milling in different conditions.* The presented study concerned the effect of technological parameters such as feeding speed and sharpness angle on the surface roughness of three native wood species: beech, pine and black locust. The sharpness angle was investigated in range of 40-55° during milling with various values of feeding speeds. Milling process was carried out with the use of bottom spindle milling machine and roughness measurements were completed using stylus profilometer. In order to analyze the results simple linear regression analysis was done. It has been stated that in milling process linear upward trend of the surface roughness occurs with an increase in the feeding speed. However, the characteristic of this feature depends on the sharpness angle and wood species. In case of the sharpness angle, the best results were obtained for an angle in range of 40-45°. Designated linear regression lines were characterized by high coefficient of determination.

Keywords: surface roughness, milling process, surface quality, pine, beech, black locust, feeding speed, sharpness angle, simple regression analysis

INTRODUCTION

Milling process is one of the most frequently used operations in manufacturing of wood products such as furniture, floors, construction elements etc. Its effects often determine quality of a final products. The quality can be described by various parameters, among others by surface roughness. Surface roughness of wood depends on numerous factors occurring in the milling process, such as feeding speed, cutting speed, cutting depth, angular parameters of tool etc. (Hernández *et al.* 2001; Kilic *et al.* 2006; Malkoçoğlu 2007). These factors play an important role in machining process also in the aspect of tool wear (Kazlauskas *et al.* 2017; Keturakis *et al*. 2017), power consumption (Barcik *et al.* 2008), cutting forces (Marchal *et al.* 2009) and sound emission (Iskra and Tanaka 2005). Machined material and its properties, such as density and anatomical structure, have also a considerable effect on the surface quality (Magoss and Sitkei 1999; Thoma *et al.* 2015).

In case of angular parameters of tool, most of the previous research concerned effects of rake angle on the surface roughness of different wood species (Hernández *et al*. 2001; Malkoçoğlu 2007; Azemović *et al*. 2014). Authors stated, that in terms of surface quality the best results were obtained when the rake angle was the lowest. The sharpness angle was the object of investigations mainly in terms of tool wear during milling of various materials (Kowaluk *et al.* 2009; Keturakis and Lisauskas 2010). Authors found, that the higher is sharpness angle, the lower in tool wear. Pinkowski *et al.* (2018) investigated the effect of sharpness angle on the surface roughness during milling of four wood species and found, that optimal value of the angle in the aspect of surface quality is 40°. Authors noticed that research on this subject should be narrowed to the range close to this value because of the best obtained results.

Considering above, the aim of this study was to analyze the effect of feeding speed on the surface roughness of three native wood species during milling with the use of knives with different sharpness angle in the range of 40-55°.

MATERIALS

Three native wood species: beech (*Fagus sylvatica* L.), pine (*Pinus sylvestris* L.) and black locust (*Robinia pseudoacacia* L.) were machined with the use of Felder F900z bottom-spindle milling machine and Felder F-38 feeding equipment. Engine power of the machine was 5,5 kW. Parameters such as rotational speed of spindle, depth of cut (working engagement) and rake angle were constant and amounted 6000 min^{-1}, 1 mm and 25°, respectively. Three cutting knives were used, with three values of the sharpness angle: 40°, 45° and 55°. Dimensions of the knifes were 50 mm x 30 mm x 3 mm. Knives were fixed in four-edge cutterhead, and in each operation one properly set knife was used. Four values of the feeding speed were used: 3.2, 8.3, 12.5, and 16.7 m/min. Mean densities of the samples were 450 kg/m^3 for pine, 700 kg/m^3 for beech and 800 kg/m^3 for black locust.

Surface roughness was measured with the use of a stylus profilometer ME10 (Carl Zeiss, Jena, Germany). A tip radius of the measuring gauge was 10 µm and an apex angle was 90°. Length of the measuring section was 50 mm and the cut-off length was 2,5 mm. Roughness parameters were calculated in accordance with ISO 4287 (1997). To describe the surface roughness two parameters were used: the arithmetic mean surface roughness (R_a) and the maximum height of the profile (R_z). Roughness parameters were calculated using ProGraf software. For each sample five measurements were completed.

Results analysis was done in Excel software (Microsoft, Redmond, WA, USA).

RESULTS AND DISCUSSION

Figures 1-3 present graphs with the results of R_a and R_z parameters with a trend (regression) lines for all tested samples of studied wood species. It can be seen that in all cases the surface roughness is characterized by linear upward trend during increasing the feeding speed. This feature has been noted previously (Škaljić *et al.* 2009; Azemović *et al.* 2014; Pinkowski *et al.* 2018) and it has been caused by larger load of the knife. However, increase in the results of roughness parameters was different for different sharpness angles. In case of beech wood (Fig. 1) for R_a parameter this trend was similar for all tested knifes, but for the R_z it is visible that obtained dependences are slightly different.

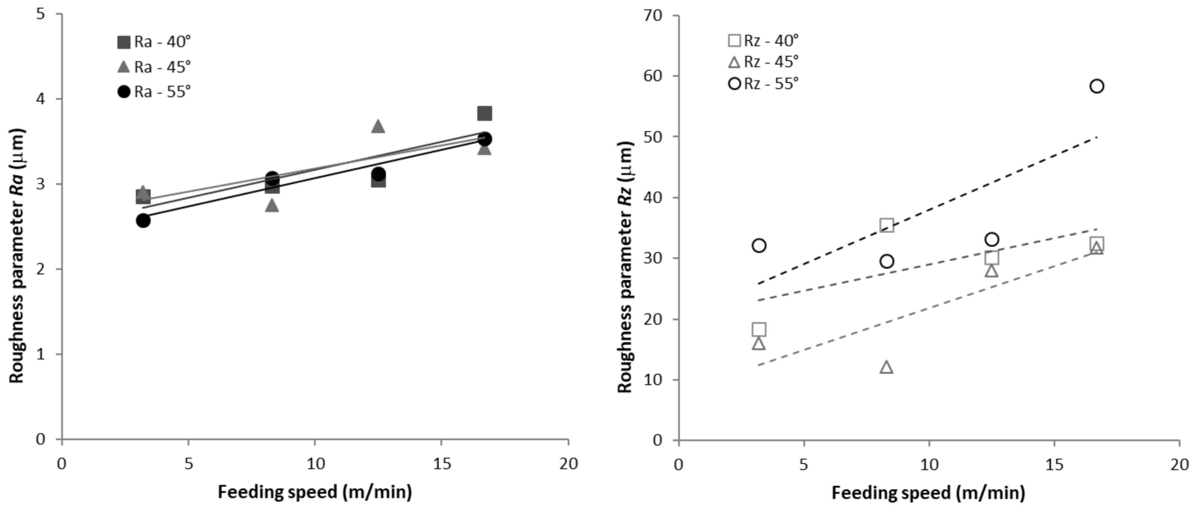

Figure 1. Surface roughness of beech depending on the sharpness angle and the feeding speed

Pine wood was characterized by high differentiation of the results for different knifes, especially in case of the R_a parameter. As it's shown in Fig. 2, the lowest increase of R_a and R_z parameters was observed for knifes with the sharpness angle of 40°, but in case of the R_z the lowest values of the results was noted for the knife with the sharpness angle of 45°.

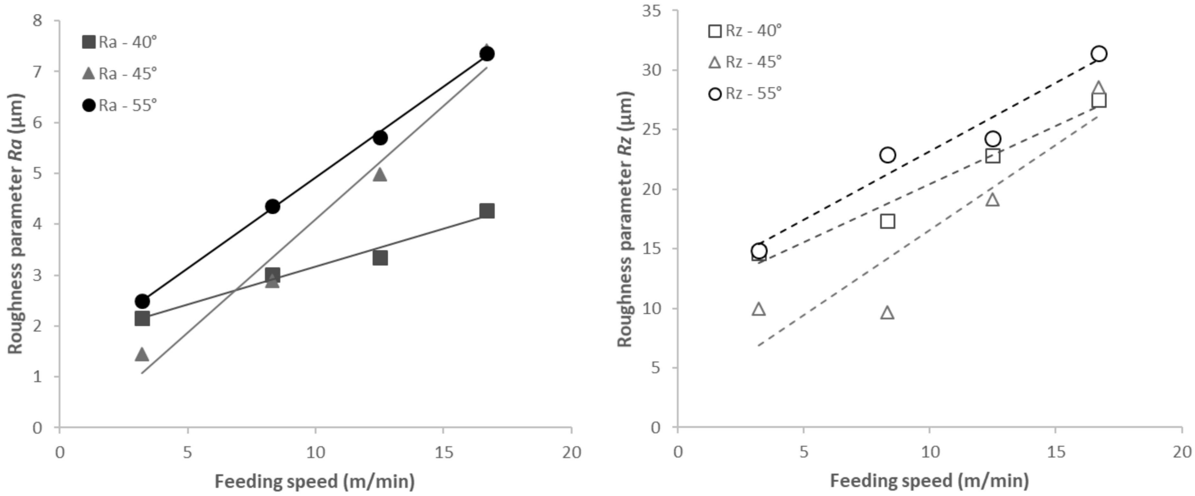

Figure 2. Surface roughness of pine depending on the sharpness angle and the feeding speed

Black locust is the highest dense wood from the analyzed species, but on the other hand it contains cavities with large dimensions. It has been previously stated that the denser is wood the lower is surface roughness (Csanády *et al.* 2015; Pinkowski *et al*. 2018), but heterogeneity may cause dispersion of results and thus lower determination of designated trend lines. The largest increase in values of roughness parameters during increasing the feeding speed was noted for the knife with the sharpness angle of 40°.

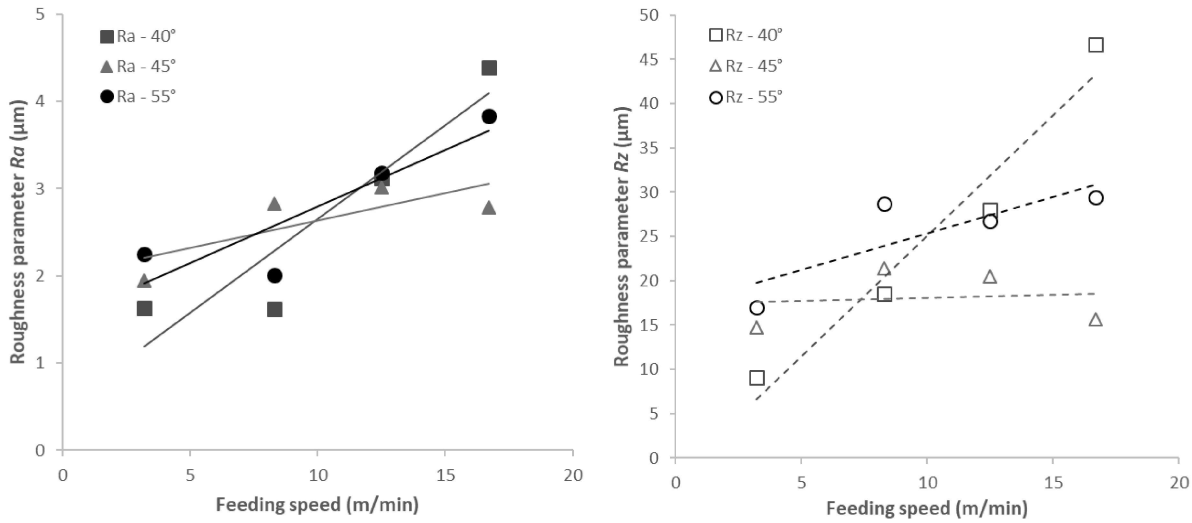

Figure 3. Surface roughness of black locust depending on the sharpness angle and the feeding speed

Table 1. Simple linear regression equations of *Ra* parameter depending on the feeding speed and the sharpness angle

Wood species	**Sharpness angle (°)**		
	40	45	55
Beech	$Ra = 0{,}0661 * f + 2{,}5066$ $R^2 = 0{,}7432$	$Ra = 0{,}0542 * f + 2{,}6377$ $R^2 = 0{,}5248$	$Ra = 0{,}0664 * f + 2{,}4017$ $R^2 = 0{,}9443$
Pine	$Ra = 0{,}1489 * f + 1{,}6791$ $R^2 = 0{,}9744$	$Ra = 0{,}445 * f - 0{,}3472$ $R^2 = 0{,}9749$	$Ra = 0{,}3566 * f + 1{,}3556$ $R^2 = 0{,}9986$
Black locust	$Ra = 0{,}2145 * f + 0{,}5077$ $R^2 = 0{,}8648$	$Ra = 0{,}063 * f + 2{,}0002$ $R^2 = 0{,}5842$	$Ra = 0{,}1296 * f + 1{,}4974$ $R^2 = 0{,}7846$

Tables 1 and 2 contain simple regression equations and coefficients of determination R^2 of R_a and R_z parameters of all tested samples. It can be seen, that coefficient of determination is very diverse depending on the sample and it is in a range of 0,1-0,99. However, in most cases the coefficient amount over 0,7.

As shown in the tables, pine wood was characterized by the highest coefficients of determination R^2, which in most cases amounted over 0,9.

Table 2. Simple linear regression equations of the *Rz* parameter depending on the feeding speed and the sharpness angle

Wood species	**Sharpness angle (°)**		
	40	45	55
Beech	$Rz = 0{,}8703 * f + 20{,}255$ $R^2 = 0{,}4532$	$Rz = 1{,}3783 * f + 7{,}9739$ $R^2 = 0{,}7198$	$Rz = 1{,}779 * f + 20{,}21$ $R^2 = 0{,}5833$
Pine	$Rz = 0{,}9744 * f + 10{,}672$ $R^2 = 0{,}9688$	$Rz = 1{,}4298 * f + 2{,}2839$ $R^2 = 0{,}849$	$Rz = 1{,}1478 * f + 11{,}693$ $R^2 = 0{,}9525$
Black locust	$Rz = 2{,}7124 * f - 2{,}0296$ $R^2 = 0{,}9536$	$Rz = 0{,}0701 * f + 17{,}364$ $R^2 = 0{,}0146$	$Rz = 0{,}819 * f + 17{,}145$ $R^2 = 0{,}6699$

CONCLUSION

The study showed that both the sharpness angle and the feeding speed have an effect on the surface roughness of wood. Moreover, dependences between these parameters and surface quality were different for different wood species, what was given by different properties and anatomical structure of species. It has been found, that the surface roughness increase with an increase in the feeding speed, and it can be described as a linear upward trend. In most analyzed cases the surface roughness was the highest for the sharpness angle of 55°.

Developed regression equations, which describe dependences between analyzed factors and surface quality, were characterized by high coefficients of determination, which in most cases amounted over 0,7. The best fit of the equations was found for pine wood where the coefficient in most cases amounted over 0,95.

REFERENCES

1. AZEMOVIĆ E., HORMAN I., AND BUSULADŽIĆ I., 2014: Impact of planing treatment regime on solid fir wood surface, Procedia Engineering nr. 69; 1490-1498
2. BARCÍK Š., PIVOLUSKOVÁ E., & KMINIAK R., 2008: Effect of technological parameters and wood properties on cutting power in plane milling of juvenile poplar wood, Drvna industrija nr. 59; 107-112
3. CSANÁDY E., MAGOSS E., AND TOLVAJ L., 2015: Quality of Machined Wood Surfaces, Springer International Publishing, Cham, Switzerland.
4. HERNÁNDEZ R. E., BUSTOS C., FORTIN Y., AND BEAULIEU J., 2001: Wood machining properties of white spruce from plantation forests, Forest Products Journal 5 nr. 1; 82
5. ISKRA P., AND TANAKA C., 2005: The influence of wood fiber direction, feed rate, and cutting width on sound intensity during routing, Holz als Roh-und Werkstoff nr. 63; 167-172.
6. ISO 4287, 1997: Geometrical product specifications (GPS) - Surface texture: Profile method - Terms, definitions, and surface texture parameters, International Organization for Standardization, Geneva, Switzerland.
7. KAZLAUSKAS D., JANKAUSKAS V., BENDIKIENĖ R., KETURAKIS G., & MAČĖNAITĖ L., 2017: Wear of cemented tungsten carbide (WC) router cutters during oak wood milling, Mechanics nr. 23; 469-472
8. KETURAKIS G., BENDIKIENE R., AND BALTRUSAITIS A., 2017: Tool Wear Evolution and Surface Formation in Milling Various Wood Species, BioResources nr. 12; 7943-7954

9. KETURAKIS G., AND LISAUSKAS V., 2010: Influence of the sharpness angle on the initial wear of the wood milling knives, Materials Science nr. 16; 205-209
10. KILIC M., HIZIROGLU S., AND BURDURLU E., 2006: Effect of machining on surface roughness of wood, Building and Environment nr. 41; 1074-1078
11. KOWALUK G., SZYMANSKI W., PALUBICKI B., AND BEER P., 2009: Examination of tools of different materials edge geometry for MDF milling, European Journal of Wood and Wood Products nr. 67; 173-176.
12. MAGOSS E., AND SITKEI G., 1999: Influence of wood structure on the surface roughness at milling operations, Proceedings of the 4th ICWSF, Missenden Abbey, UK, pp. 290-296.
13. MALKOÇOĞLU A., 2007: Machining properties and surface roughness of various wood species planed in different conditions, Building and Environment nr. 42; 2562-2567
14. MARCHAL R., MOTHE F., DENAUD L. E., THIBAUT B., AND BLERON L., 2009: Cutting forces in wood machining–Basics and applications in industrial processes. A review COST Action E35 2004–2008: Wood machining–micromechanics and fracture, Holzforschung nr. 63; 157-167.
15. PINKOWSKI G., SZYMAŃSKI W., KRAUSS A., AND STEFANOWSKI S., 2018: Effect of Sharpness Angle and Feeding Speed on the Surface Roughness during Milling of Various Wood Species, BioResources nr. 13; 6952-6962.
16. ŠKALJIĆ N., BELJO LUČIĆ R., ČAVLOVIĆ A., AND OBUĆINA M., 2009: Effect of feed speed and wood species on roughness of machined surface, Drvna Industrija nr. 60; 229-234
17. THOMA H., PERI L., AND LATO E., 2015: Evaluation of wood surface roughness depending on species characteristics, Maderas. Ciencia y Tecnología nr. 17; 285-292.

Streszczenie: *Analiza chropowatości powierzchni rodzimych gatunków drewna w zależności parametrów kątowych narzędzia podczas frezowania w różnych warunkach*. Prezentowany artykuł dotyczy wpływu wybranych parametrów technologicznych, takich jak prędkość posuwu oraz kąt ostrza, na chropowatość powierzchni drewna po frezowaniu. W badaniu zostały wykorzystane trzy gatunki drewna: buk, sosna oraz grochodrzew. Kąt ostrza analizowany był w przedziale 40-55° dla wybranych prędkości posuwu. Do frezowania wykorzystana została frezarka dolnowrzecionowa, natomiast do pomiarów chropowatości powierzchni użyto profilometru stykowego. W celu analizy wyników wykorzystana została metoda regresji prostej. Na podstawie uzyskanych danych stwierdzono, że wraz ze wzrostem prędkości posuwu występuje wzrost chropowatości powierzchni drewna. Zależność ta ma charakter liniowy, jednak zależy od gatunku drewna oraz kąta ostrza narzędzia. W przypadku kąta ostrza stwierdzono, że najniższe wartości parametrów chropowatości uzyskane wykorzystując noże z kątem ostrza 40° i 45°. Wyznaczone proste regresji charakteryzowały się relatywnie wysokim współczynnikiem determinacji.

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