Influence of Cutting Wedge Treatment on Cutting Power, Machined Surface Quality, and Cutting Edge Wear When Plane Milling Oak Wood

Peter Koleda,* Štefan Barcík, Ján Svoreň, Ľubomír Naščák, and Andrej Dobrík

The cutting power value, the surface quality of the machined surfaces, and the cutting edge wear were determined in the planar milling of oak wood (*Quercus robur* L.). The experimental tool was a milling head with two interchangeable blades. The basic material of the three milling cutters was HS 18-0-2-5 high-speed steel (ISO 4957 2018). Two milling blades were treated with different coatings: a multilayer AlTiCrN coating of thickness 1 μm to 4 μm (knife B) and a multilayer MoC coating of thickness 1 μm (knife C). Parameters for the experiment were as follows: tool angular geometry: α = 30°, β = 45°, γ = 15°, and δ = 75°; spindle speed: 3000 min^{-1}, 4000 min^{-1}, and 5000 min^{-1}; feed rate: 6 m/min, 8 m/min, 10 m/min, 12 m/min, and 14 m/min; cutting depth: 1 mm and 2 mm. The results showed that the cutting power for face milling increased with milling length for all three blades. The greatest power was measured at milling using the knife C (mean value of 209.3 W). The wedge wear parameter WB_W increased with milling length; knife C reached the greatest value (WB_W = 54.0 μm at length of 270 m). The surface quality parameter (R_a) of the machined surfaces was almost unchanged with increasing milling length beyond 90 m for all knives.

Keywords: Cutting edge wear; Cutting power; Plane milling; Surface roughness

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INTRODUCTION

Many products are produced in the woodworking industry, and one of the main production processes is plane milling. This process is considered in terms of the cutting capacity, the quality of the machined surface, the wear of the cutter blade, safety, and ambient noise. The first four criteria, which form a considerable part of the financial costs, are of economic interest to every company. Cost reduction is possible only with a deeper knowledge of the process. The wear of the cutting edge may be affected by modification of the cutting edge. In practice, several methods of cutting edge treatment are known. One of them is the coating method. Unfortunately, only a limited number of research papers are focused on the energy consumption of woodworking (Mandić *et al*. 2010; de Moura *et al*. 2011; Barcík and Gašparík 2014; Tu *et al*. 2014; Ispas *et al*. 2016; Krauss *et al*. 2016; Kubš *et al*. 2016, 2017; Koleda *et al*. 2018).

Mandić *et al*. (2010) examined the effects of beech samples on cutting power during plane milling. Cutting power significantly increased at the feed rate v_f > 8 m/min. Kubš *et al*. (2016, 2017), from their research of beech and pine wood machining, have shown that the most important factors affecting the cutting power during plane milling are the cutting speed, the kinematic angle of the milling cutter face, and the feed rate. Greater differences in power have been demonstrated at different face angles of the milling cutter.

Ispas *et al*. (2016) examined the impact of cutting depth (1 mm, 2 mm, and 3 mm) of beechwood samples on cutting power during plane milling. Their results showed that the cutting power increased with increasing cutting depths, rotation speeds (3300 min^{-1} and 4818 min^{-1}), and feed rates (4.5 m/min, 9 m/min, 13.5 m/min, 18 m/min, and 22.5 m/min).

Krauss *et al*. (2016) analysed the impact of cutting depth (0.5 mm, 1.0 mm, and 2.0 mm) of pine samples on cutting power during plane milling. Their results showed that cutting power in plane milling of wood increases with increasing cutting depth.

Both in scientific work and in practice, it is important to determine the roughness of the surface during woodworking and after each technological operation. The surface quality in processing is one of the most important properties affecting other technologies such as bonding, gluing, and surface treatments. However, the determination of surface roughness in flat milling is a complex process with many considerations. These include the anatomical structure of the wood and particularly its basic elements, such as fibers, pores, tracheids, rays, variations of annual circles, cell structure, wood density, and the ratio of summer to spring wood. Other considerations are the machine quality, such as machine stiffness and precision, and the manufacturer of the milling cutter (with factors including angular geometry of the cutting blade and materials, such as high-speed steel or sintered carbide). Lastly, machining conditions should also be considered, including the method of obtaining the machined surface, the cutting speed, the feed rate, and possibly the feed on the cutting edge of the milling cutter (Kilic *et al*. 2006; Tiryaki *et al*. 2014).

The surface quality can be assessed by roughness measurement. Roughness can be measured by contactless and contact methods. Non-contact methods include vision and optical techniques, lasers, ultrasound, pneumatic techniques, photography, and 3-D surface topography (Hernández and Cool 2008; Novák *et al.* 2011; Hernández *et al*. 2014; Korčok *et al*. 2018). Contact methods include the electric method with a touching diamond point with a radius of 2 μm to 5 μm (Škalić *et al*. 2009; Sogutlu 2010; Gaff *et al*. 2015; Kvietková *et al*. 2015a, 2015b; Bendikiene and Keturakis 2016; Ispas *et al*. 2016; Keturakis *et al*. 2017; Sogutlu 2017).

Škalić *et al*. 2009 examined the impact of different types of wood (beech, heat-treated beech, oak, and fir) on the surface quality at different machining conditions (rotation speed of 6000 min^{-1}; feed rates of 6 m/min, 12 m/min, 18 m/min, and 24 m/min; cutting depth of 2 mm). The results showed that the lowest values of the roughness parameter ($R_a \approx 4$ μm) were for the oak wood.

The literature in basic woodcutting theory states that the roughness of the machined surface, expressed by one of the roughness parameters (R_a, R_z, *etc.*), increases with increasing tool wear (Magoss 2008). Research has shown that the main cause of wear of the milling cutter blade is friction (abrasive component of wear). The cutting wedge of the milling cutter and, particularly, its face interact with the machined wood (Beer *et al*. 2003). Some studies have shown that changes in the shape of the milling cutter blade depend mainly on the angular and micro-geometric parameters (Porankiewicz *et al*. 2005; Kowaluk *et al*. 2009), as well as the technical properties of the milling cutters (Bendikiene and Keturakis 2016, 2017; Keturakis *et al*. 2017). The tools were coated by various methods, and their effects on cutting power, cutting edge wear, and machined surface quality were examined in this article.

EXPERIMENTAL

Materials and Methods

The experiment utilised samples from cuttings of *Quercus robur* L. with an average age of 95 years. The lumber was cut on thickness of 30 mm at the Technical University in Zvolen, Slovakia, using a trunk band saw. This lumber was further dried in an oven at a moisture content of 8%. After drying, the lumber was cut into 100 mm width lateral tangential timbers. The cuts were processed on the grinder and thicknessing planer to reach a thickness of 25 mm and cut to a length of 750 mm on the circular saw. The final sample sizes were 25 mm in thickness, 100 mm in width, and 750 mm in length. Thirty samples were prepared, but for the measurements of cutting power and surface roughness, six pieces were selected. These samples were used as a standard. The selected samples for individual feed rates are shown in Fig. 1.

Fig. 1. Selected samples for measurement of cutting power and surface roughness

Experimental measurements of cutting power and surface roughness were performed on devices located in the development laboratories of the Technical University in Zvolen, Slovakia. Experimental measurements of cutting blade wear were performed at Ironal, Banská Bystrica, Slovakia. Surface milling of the samples was performed by a combined woodworking machine (ZDS-2, Liptovské Strojárne, Liptovský Mikuláš, Slovakia), a vertical milling machine using a mechanized feeder (MW 102, TOS Svitavy, Svitavy, Czech Republic). The samples were milled longitudinally when the directions of the cutting speed vector and feed rate vector were counter-rotating.

Fig. 2. Overall view of milling equipment

The machine was connected to a mobile suction system. An overall view of the device is shown in Fig. 2

In the experimental measurements, a milling head with diameter of 125 mm for two knives (Staton, Turany, Slovakia) was used as a tool for wood machining. One knife was clamped only to dynamically balance the tool. Against this was fastened the examined blade, so the 125-mm cutting diameter of the milling head was reached. Three milling blades were used (Fig. 3, Table 1), having the same base material: high-speed tool steel HS 18-0-2-5 (ISO 4957 2018) with chemical composition as shown in Table 2.

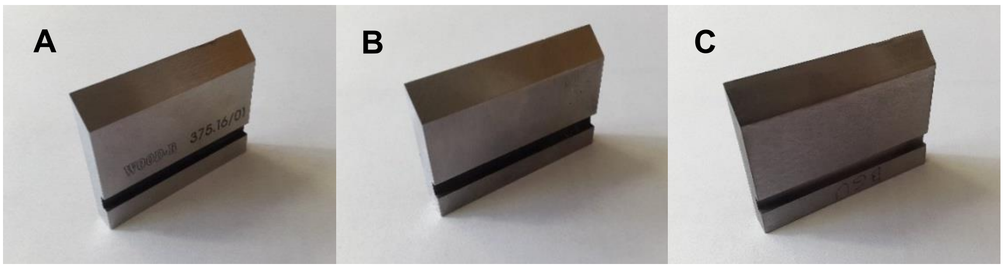

Fig. 3. Removable milling knives

Table 1. Parameters of Removable Milling Knives

Steel	HS 18-0-2-5 (HSS 55 – 19 855)
Hardness	64 HRC
Dimensions of Milling Knife (mm)	50 × 30 × 5
Sharpness Angle	45°

Table 2. Chemical Composition of HS 18-0-2-5 Steel (ISO 4957 2018)

Element	Co	4.7%
	V	1.5%
	W	18%
	Cr	4.2%
	C	0.7%
	Si	≤ 0.45%

Milling knives B and C were coated by the physical vapor deposition (PVD), while knife A had no additional surface treatment. Knife B was coated at the company Staton (Turany, Slovakia); knife C was coated at the laboratory of the Department of Solid State Physics, Faculty of Physics, Belarusian State University, Minsk, Belarus. The hardness values of the milling knives after coating were measured at the Technical University in Zvolen, Slovakia, by a Skoda RB1 hardness meter (diamond cone 120°, measuring range 20 HRC to 67 HRC – Škoda, Plzeň, Czech Republic). Three injection sites were selected along the cutting edge on the face. The coating specifications are given in Table 3. Technological conditions of the machining are listed in Table 4.

Table 3. Coatings of Removable Milling Knives B and C

Coating	Knife B	Knife C
Type of Coating	Multilayer AlTiCrN	Multilayer MoC
Coating Thickness	1 μm to 4 μm	1 μm
Deposition Temperature	450 °C to 500 °C	750 °C
Mean Hardness for Coating	62 HRC	57 HRC

Table 4. Technological Conditions of Machining

Parameter		Value
Tool geometry	Rake angle	15°
	Sharpness angle	45°
	Clearance angle	30°
	Cutting angle	75°
Rotation speed		3000 min^{-1} (0 – 22.5 m)
		4000 min^{-1} (0 – 22.5 m)
		5000 min^{-1} (0 – 270 m)
Feed rate		6 m/min
		8 m/min
		10 m/min
		12 m/min
		14 m/min
Cutting depth		1 mm (0 – 11.25 m)
		2 mm (11.25 – 22.5 m)
		1 mm (22.5 – 270 m)

Measurement of cutting power was performed using the apparatus shown in Fig. 4, which was assembled at the Department of Manufacturing and Automation Technology of the Technical University in Zvolen, Slovakia. The device consisted of a frequency converter that controlled the speed of a three-phase asynchronous motor. Another part of the device was a sinusoidal filter that smoothed the impulse voltage from the inverter in such a way as to approximate the ideal sinusoidal phase with a phase shift of 120°. The frequency converter measured the active motor input without losses and evaluated engine power from the current, voltage and efficiency of the motor.

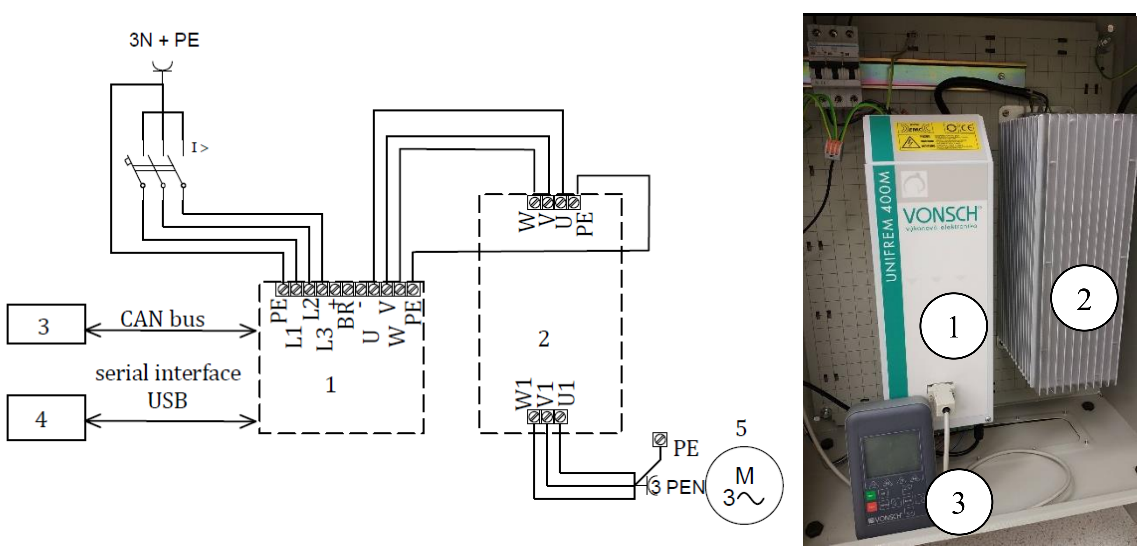

Fig. 4. Connection of devices for power measurement: (1) frequency converter (UNIFREM 400 007 M, VONSCH, Brezno, Slovakia), (2) sinusoidal filter (SKY3FSM25, VONSCH, Brezno, Slovakia), (3) operating panel, (4) laptop, (5) 3-phase asynchronous motor (2.2 kW, 2880 min^{-1})

Cutting power could be calculated from Eq. 1,

$$P = P_C - P_{C0} \tag{1}$$

where P_C is total power (W), and P_{C0} is idle power (W). The total power (P_C) consumed by the electric motor during milling was calculated from the relationship in Eq. 2,

$$P_C = U_C \cdot I_{C0} \cdot \cos\varphi \tag{2}$$

where U_C is voltage (V), I_C is current (A), and cos φ is the power factor. The idle power P_{C0} could be obtained from Eq. 3,

$$P_{C0} = U_{C0} \cdot I_{C0} \cdot \cos\varphi \tag{3}$$

where U_{C0} is voltage (V), I_{C0} is current (A), and cos φ is the power factor when idling.

To determine the surface roughness, a non-contact laser profilometer (LPM-4, KVANT Ltd., Bratislava, Slovakia) was used, which works on the optical principle (light cut method). With this method, laser light (from a laser diode) is projected at a 45°-angle on the measured surface and then scanned by an LCD camera (Marlin F-131B, Allied Vision Technologies, Stadtroda, Germany) with a 2/3" Cypress IBIS5 CMOS chip (Cypress Semiconductor Corp., San Jose, CA, USA). The laser beam produces a light track on the surface, which is evaluated by LPMView 1.2 measuring software (KVANT Ltd., Bratislava, Slovakia) after image capture by the LCD camera and image binarisation. The profilometer was calibrated based on the roughness pattern. The non-contact laser profilometer setup is illustrated in Fig. 5.

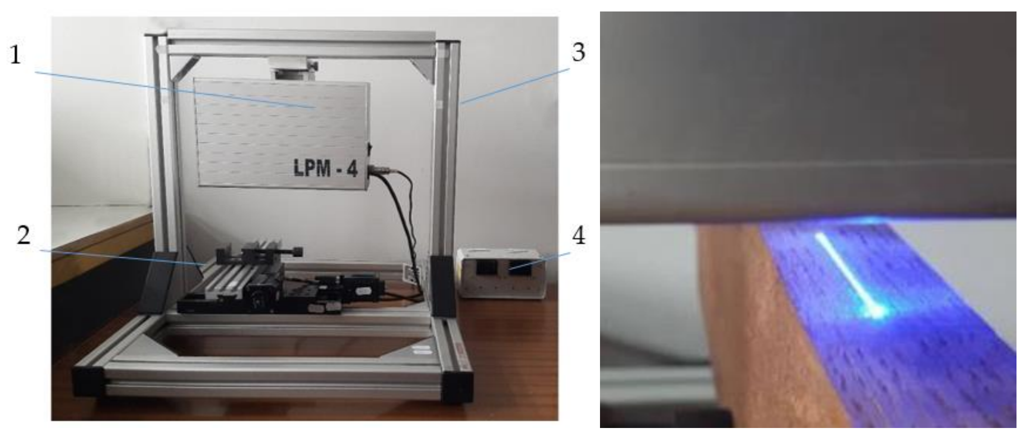

Fig. 5. Assembly of laser profilometer: (1) profilometer head, (2) shift system for X-Z plane, (3) framework, (4) shift control unit

The measurement procedure using the profilometer and measurement software was simple, with several steps. According to STN EN ISO 4287 (1999), which defines the procedure for surface assessment by the profile method, an estimate of the monitored parameter is performed on one basic length. The wavelengths of the individual profile characteristics are an important parameter in the evaluation. When assessing the quality of the wood and the wood surface, it is advisable to pay attention to the setting of boundary conditions that will filter out unwanted measurement errors (Robust Gaussian Regression Filter). The program allows data to be stored in the X-Y graph for further processing or exporting of the profile characteristic table data to the computer (Šustek and Siklienka 2018). Research into the distribution of temperature fields in milling can explain the influence of the emerging temperature on the surface quality (Cernecky *et al*. 2017).

Tool wear was determined by measuring the fractional particle size (Koleda and Hrčková 2018). The wear of the cutting wedge of the milling cutter was measured using a Hommel-Etamic C8000 contour measuring system (Jenoptik, Jena, Germany). Evovis software (Jenoptik) was included (as standard) for evaluating the measured parameters.

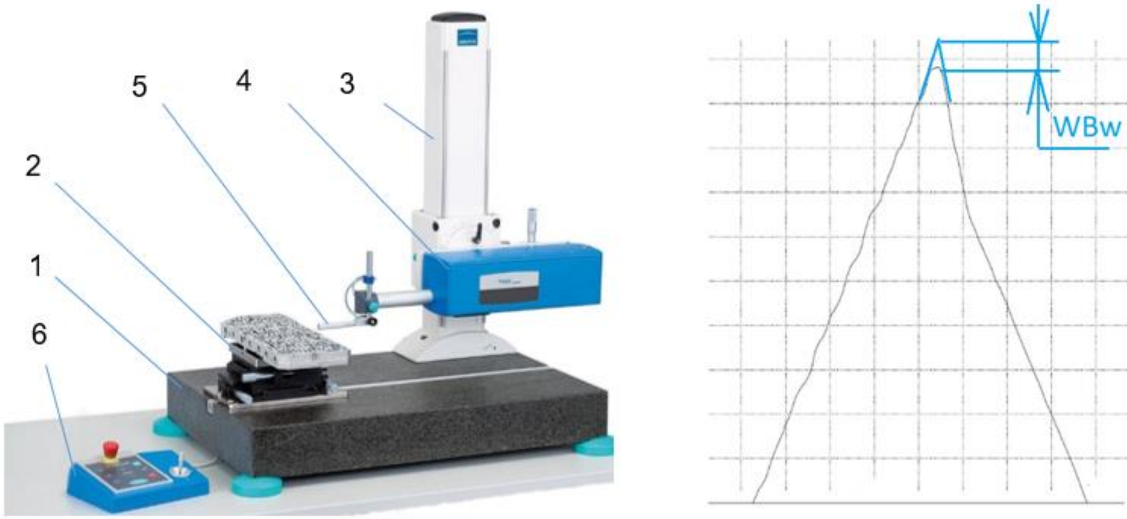

Fig. 6. Contour measuring system: WB_W – displacement of cutting edge along the axis of cutting wedge angle β (Porankiewicz *et al*. 2005), (1) granite foundation slab, (2) table, (3) console, (4) arm, (5) contact head, (6) controlling desk

Several different parameters related to the plane milling process were recorded. Parameter values were obtained mainly in numerical form. However, when determining the values of the wedge wear, the measurement results were in the form of contour graphs, which were analysed and evaluated. The programs Microsoft Excel (Microsoft Corporation, Redmond, WA, USA) and Statistica 12 (StatSoft Inc., Tulsa, OK, USA) were used for data processing.

RESULTS AND DISCUSSION

Table 5 shows the descriptive statistics of the measured values of cutting power. The greatest values were measured while milling with the MoC-coated knife. The cutting power increased with increasing milled length. This result was due to blunting of the cutting edge. Changing the feed rate did not cause a statistically significant change in the cutting power.

Table 6 shows the effects of the individual factors (parameter F) on the cutting power. The greatest effect on the power was from the type of tool, while the smallest effect was from the feed rate.

Table 5. Descriptive Statistics of Measured Cutting Power

		N	Mean (W)	SD (W)	SE (W)	-95% (W)	+95% (W)
Knife	A	1050	149.42	41.59	1.28	146.90	151.93
	B	1050	145.08	38.28	1.18	142.76	147.40
	C	1050	209.29	44.13	1.36	206.61	211.96
Length (m)	11.25	450	134.93	35.45	1.67	131.65	138.22
	45	450	157.93	43.67	2.06	153.89	161.98
	90	450	158.91	45.89	2.16	154.66	163.16
	135	450	164.71	62.90	2.97	158.88	170.54
	180	450	158.74	35.32	1.67	155.47	162.01
	225	450	206.96	42.70	2.01	203.00	210.92
	270	450	193.31	46.88	2.21	188.96	197.65
Feed rate (m/min)	6	630	155.56	50.73	2.02	151.59	159.53
	8	630	175.66	43.89	1.75	172.23	179.10
	10	630	171.37	49.33	1.97	167.51	175.23
	12	630	167.25	55.37	2.21	162.91	171.58
	14	630	169.80	51.44	2.05	165.78	173.83

SD – standard deviation; SE – standard error; ±95 % - the bounds of the confidence interval

Table 6. Univariate Tests of Significance

	SS	Degrees of Freedom	MS	F	p
Knife	2704006	2	1352003	5886.0	0.00
Length	1589466	6	264911	1153.3	0.00
Feed	144005	4	36001	156.7	0.00

SS – sum of squares; MS – mean of squares

Duncan's test of statistical similarity of the milling blades' measured power values showed a statistically significant difference between the individual datasets. This result indicates that the use of different cutting wedge adjustments affected the cutting power. The test results are shown in Table 7.

Table 7. Duncan's Test of Probability of Similarity between Knives' Power Values

Knife	A	B	C
A		0.000009	0.000011
B	0.000009		0.000009
C	0.000011	0.000009	

From the analysis of variance of the blades' cutting power, depending on the feed rate (Fig. 7), it is evident that knife A and knife B had similar cutting power values. Meanwhile, the cutting power value of knife C was higher, indicating increased energy consumption.

Ispas *et al*. (2016) investigated plane milling of beech wood (*Fagus sylvatica* L.) with a conventional milling cutter head diameter *ØD* = 125 mm; carbide-tipped removable plates; rotation speed n = 4818 min^{-1}; cutting depth a_e = 1 mm; feed rate v_f = 4.5 m/min, 9.0 m/min, 13.5 m/min, 18.0 m/min, and 22.5 m/min; and sample thickness h = 28 mm. They achieved similar cutting power values.

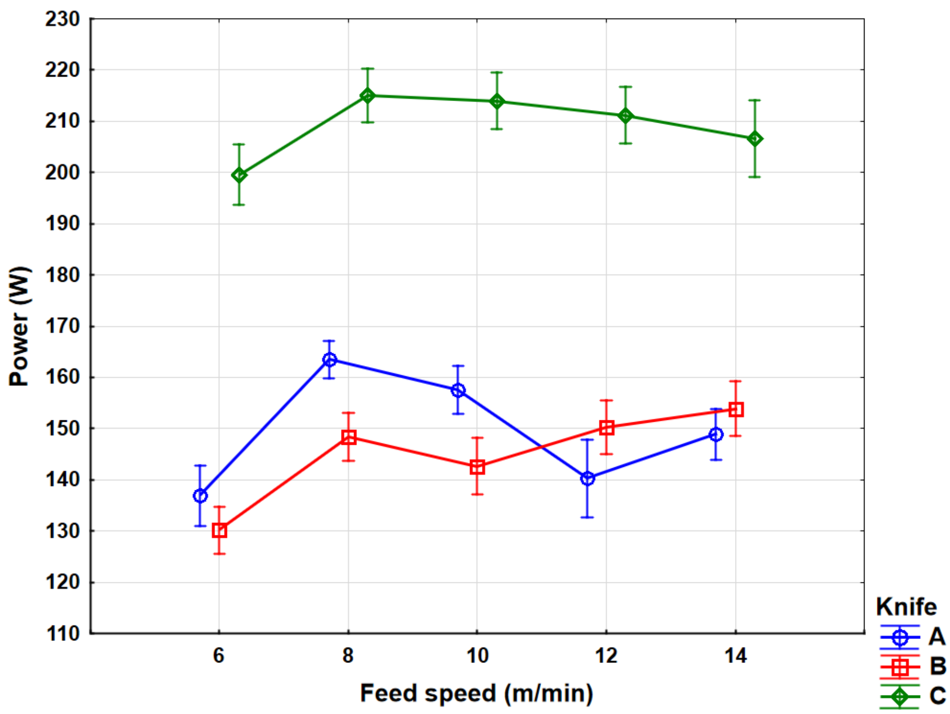

Fig. 7. Weighted means of cutting power for all knives; 5000 min^{-1}; cutting depth a_e = 1 mm; milling length L = 11.25 m to 270 m

Another observed factor in the experimental measurements was the influence of the feed rate on the cutting power. Duncan's test showed statistical similarity of data between the feed rates of 10 m/min and 14 m/min. The test results are shown in Table 8.

Table 8. Duncan's Test of Probability of Similarity between Feed Rates

Feed Rate (m/min)	6	8	10	12	14
6		0.000004	0.000003	0.000009	0.000011
8	0.000004		0.000009	0.000003	0.000011
10	0.000003	0.000009		0.000013	0.066821
12	0.000009	0.000003	0.000013		0.002758
14	0.000011	0.000011	0.066821	0.002758	

As shown in Fig. 8, the cutting power values, dependent on the milling length (L = 11.25 m to 270 m), were largely similar across feed rates and generally increased with increasing milling length L.

The cutting depth (a_e) and the feed rate (v_f) affected the cutting power values during the experiment. The mean values of measured cutting power are graphed in Fig. 9.

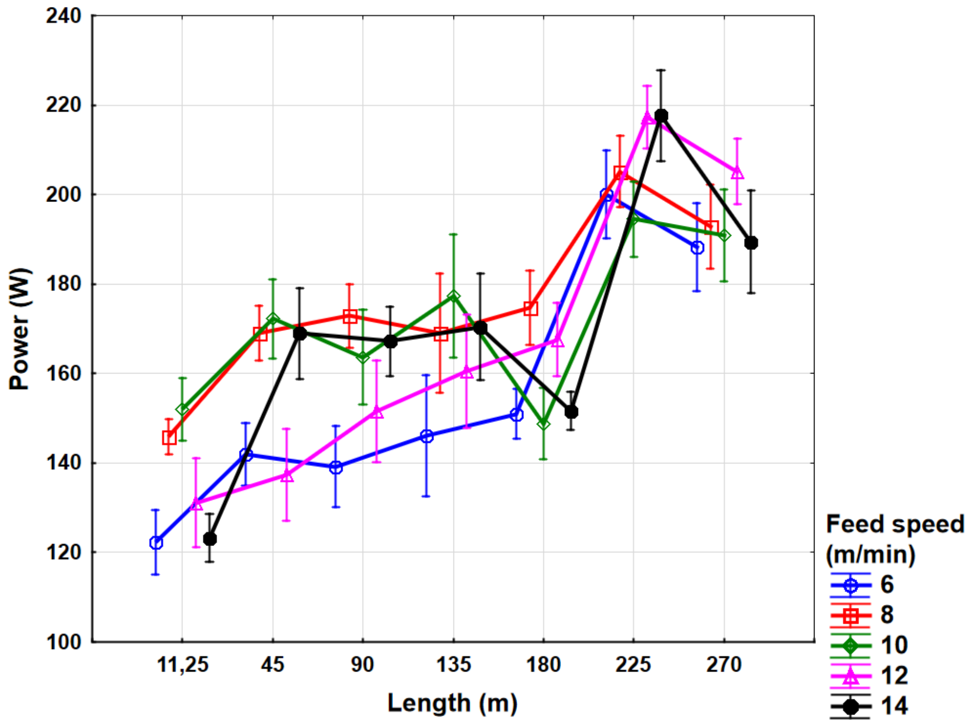

Fig. 8. Weighted means of power depending on milled length at different feed rates for all knives; 5000 min^{-1}; a_e = 1 mm

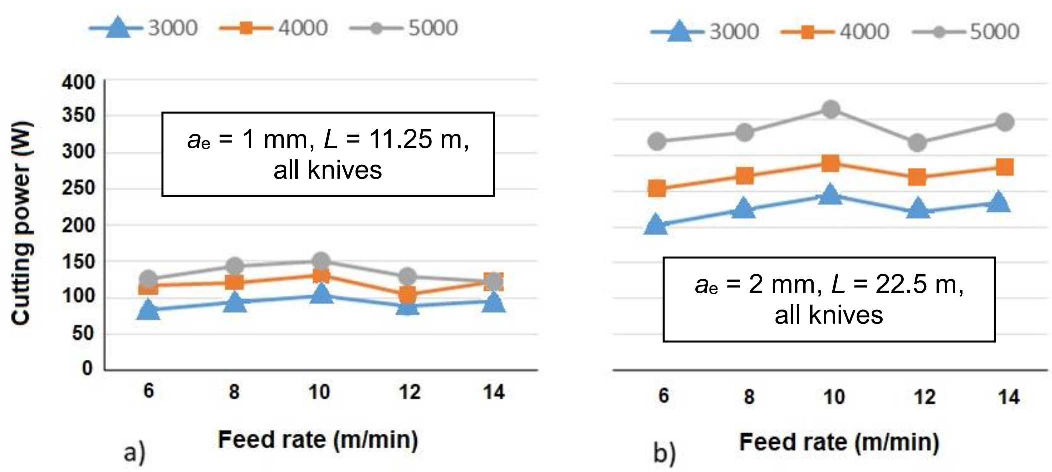

Fig. 9. Effect of cutting depth and feed rate on cutting power: (a) a_e = 1 mm, L = 11.25 m, all knives; (b) a_e = 2 mm, L = 22.5 m, all knives

Figure 9 shows that the cutting speed (v_c) also affected the cutting power. In general, the cutting power increased as the spindle speed increased. The cutting power at the cutting depth a_e = 2 mm was approximately double the power at the cutting depth a_e = 1 mm, for all cutting speeds. Kubš *et al*. (2017) also reported an increase in cutting power depending on the cutting speed (v_c = 20 m/s, 30 m/s, and 40 m/s) in plane milling of beech wood samples (*Fagus sylvatica* L.). The results of Krauss *et al*. (2016), in planar milling of pine forest samples (*Pinus sylvestris* L.), verify the increase in cutting power depending on the cutting depth (a_e = 0.5 mm, 1 mm, and 2 mm).

The surface quality of the machined area is assessed by the parameters of surface roughness (R_a, R_z, and R_{max}). The selected R_a parameter determines or imposes additional requirements on the surface machining to achieve the desired surface roughness value. Figure 10 shows the arithmetic mean values of the surface roughness parameter R_a of the machined surfaces of the milled samples as a function of the feed rate for all examined knives.

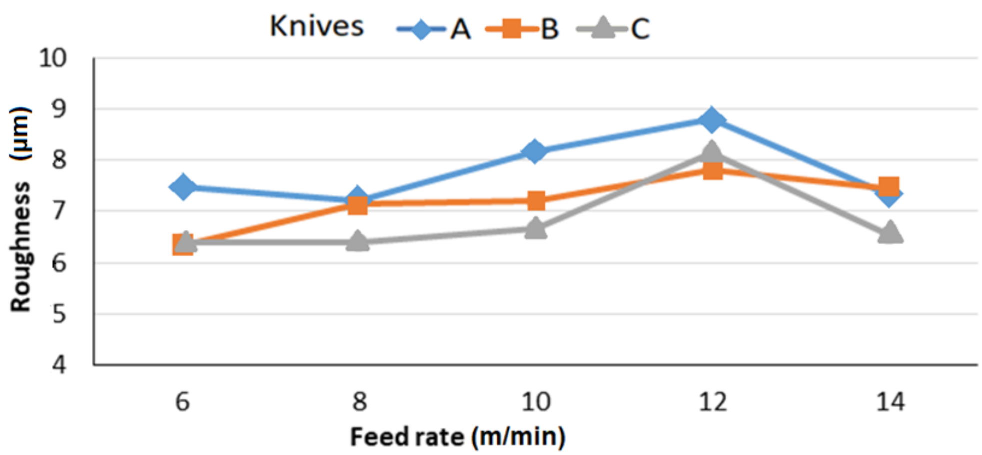

Fig. 10. Effect of feed rate on the surface roughness; 5000 min^{-1}; a_e = 1 mm; milling length L = 11.25 m to 270 m

As shown in Fig. 10, the surface roughness of the milled samples varied only in a small range (≈ 1.5 µm) depending on the feed rate. The influence of the different treatments of the cutting wedges of the milling cutter on the surface roughness was also within a small range (≈ 1.5 µm). Ispas *et al*. (2016) also reported only a very small change in the surface roughness parameter R_a depending on the feed rate (4.5 m/min, 9 m/min, 13.5 m/min, and 18 m/min) at a cutting depth of 1 mm in plane milling of beech wood samples (*Fagus sylvatica* L.). The variation in R_a was approximately 1.5 µm. The results of Korčok *et al*. (2018) showed only a minimal change in the roughness parameter R_a depending on the feed rate (6 m/min, 12 m/min, 18 m/min, and 24 m/min) at a cutting depth of 2 mm in plane milling of wood samples of various types (oak and fir) and heat treatments (steamed beech wood and heat-treated beech wood). Those R_a values were within a range of 1.0 µm. Novák *et al*. (2011), in high-speed conventional planar milling of two types of wood (spruce and beech), showed that the change in the roughness parameter R_a is minimal (within a range of 1.0 µm). Their cutting conditions were feed rates of 18 m/min, 20 m/min, and 22 m/min; a cutting depth of 2 mm; and cutting speeds of 9000 min^{-1} and 10,000 min^{-1}.

Figure 11 shows the arithmetic mean values of the surface roughness parameter R_a of the milled samples as a function of the milling length L for all the examined knives.

Figure 11 shows that the surface roughness parameter R_a generally decreased for the individual milling knives, depending on the milled length. The surface roughness parameter R_a varied within a small range (≈ 3 µm to 5 µm). Bendikiene and Keturakis (2016) reported similar results in their research on the surface quality of birch wood samples (*Betula verrucosa*). The length of milling by individual knives was 3200 m. The observed surface roughness parameters were R_a, R_z, and R_{max}. The dependence of the monitored parameters on the milled length showed very small changes of values (R_a ≈ 2 µm to 3 µm, $R_z \approx 2$ µm to 6 µm, and $R_{max} \approx 2$ µm to 16 µm). The authors reported greater roughness parameter values for roughness measurements perpendicular to the fibre direction.

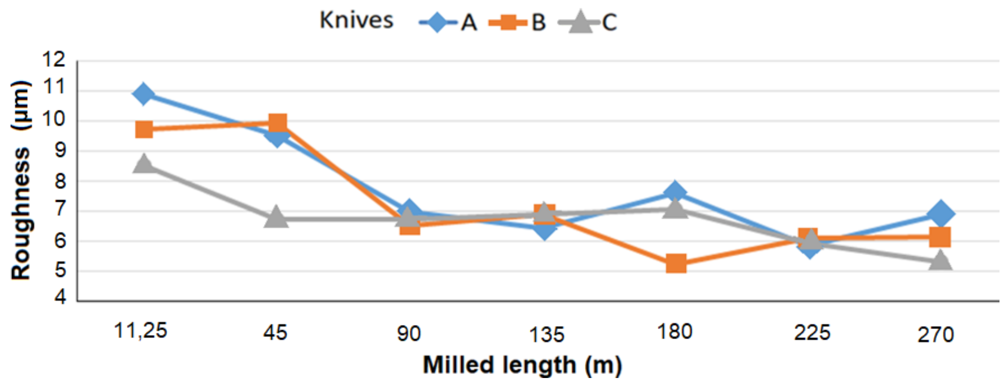

Fig. 11. Effect of milled length on the surface roughness R_a; 5000 min^{-1}; a_e = 1 mm; v_f = 6 m/min, 8 m/min, 10 m/min, 12 m/min, and 14 m/min

Table 9. Numerical Values of WB_W

	WBw (µm)						
Milled length (m)	0	45	90	135	180	225	270
Knife A	42.5	45.0	46.0	47.5	48.5	50.0	51.0
Knife B	17.5	27.5	38.0	40.0	41.5	43.5	46.0
Knife C	17.5	38.0	40.0	42.5	46.5	52.5	54.0

WB_W – displacement of cutting edge along the axis of cutting wedge angle β

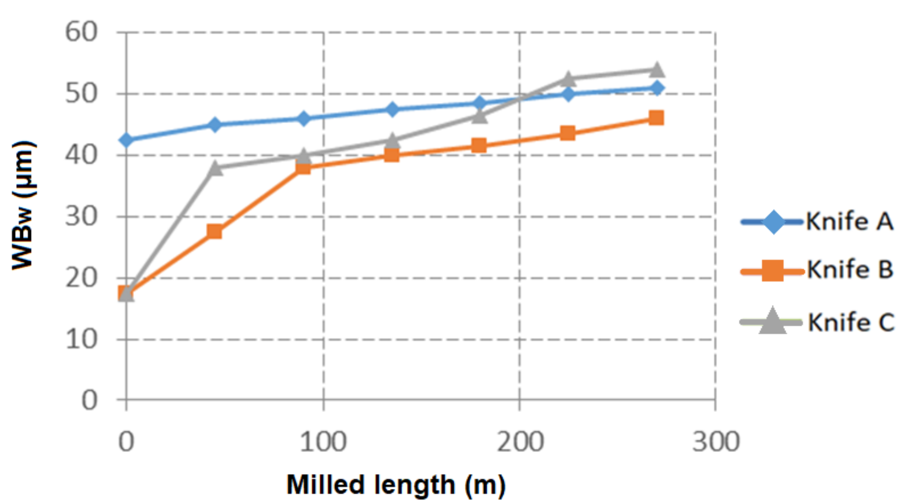

Fig. 12. Dependence of cutting wedge wear on milled length; 5000 min^{-1}; a_e = 1 mm; v_f = 6 m/min, 8 m/min, 10 m/min, 12 m/min, and 14 m/min

As shown in Fig. 12, the initial wear states of the cutting wedges were different. This was because knife A had a cutting wedge surface created by grinding technology (5-axis CNC grinder, Helitronic Power, Walter, Tübingen, Germany). Knives B and C had cutting wedge surfaces formed by the final coating operation. A rectification or rounding operation of the cutting edges was performed on the knives before the coating operation itself. It was a special treatment of the cutting edges and knife surfaces after grinding before coating. The surfaces of the knives could be polished to a gloss after grinding. Staton (Turany, Slovakia) uses spindle abrasive finishing machine DF 35 with 3 workplace holders (0.75 kW, 230 V) by OTEC (Straubenhardt, Germany) for finishing the cutting edges. Furthermore, the figure shows different and large wear increases for the individual blades for the milled length $L = 0$ m to 90 m. The blade wear value for knife C after milling length $L = 45$ m was approximately the same as for knife B at the milling length $L = 90$ m. This area can be referred to as a running band. For milled length $L = 90$ m to 270 m, the wear increases for the individual blades were small. This area is the normal wear zone. A similar course of wear was also reported by Keturakis *et al*. (2017) for HS 18-0-1. They used the change of cutting edge radius as the parameter of cutting wedge wear.

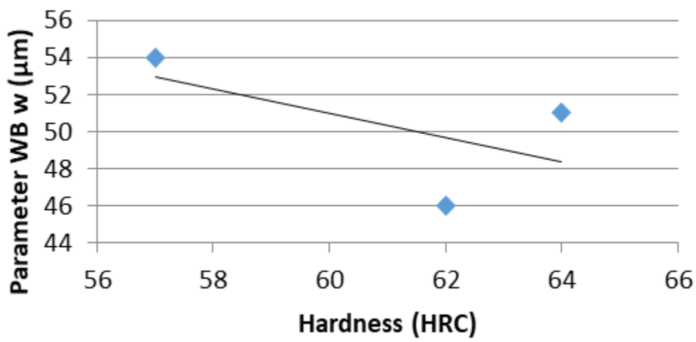

Fig. 13. Relation between the hardness and wear parameter; 5000 min^{-1}; a_e = 1 mm; v_f = 6 m/min, 8 m/min, 10 m/min, 12 m/min, and 14 m/min

Figure 13 shows the relation between the wear parameter WB_W and the average hardness of the base material of the untreated knife A and the coated knives B and C after a milled length $L = 270$ m. The results showed a negative relation between the hardness of the milling cutter material and WB_W, that is, WB_W decreased with increasing hardness. This finding was expected based on the physical properties of metallic materials.

Figure 13 also shows that no method was suitable for coating the steel HS 18-0-2-5. The coating method of knife B reduced the parameter WB_W, while the coating method of knife C increased this parameter with respect to knife A at the milling length $L = 270$ m.

CONCLUSIONS

1. Cutting power during oak milling was greater for knife C (max. value 209.29 W) by approximately 40%, compared with knives A and B. During milling, the cutting power increased with increasing milling length for all selected feed rates. Differences in power were within the range of 40 W to 70 W. The cutting power during milling increased with increasing feed rate, cutting speed, and cutting depth. These dependencies correspond to the knowledge of machining theory.
2. The greatest cutting power difference occurred at all three cutting speeds at a cutting depth of 2 mm. The surface roughness parameter (R_a) of the machined surfaces of the milled samples varied only within a small range (≈ 1.5 µm) for individual knives depending on the feed rate, which might be due to the accuracy or rigidity of the

machine tool. Maximal value of R_a (≈ 8.8 µm) was measured at feed rate of 12 m/min when milling with knife A, minimal value (≈ 6.2 µm) at feed rate of 8 m/min when milling with knife C.

3. The monitored quality parameter of the surface roughness (R_a) of the milled samples decreased for the individual milling cutters, depending on the milled length. The surface roughness parameter R_a decreased within a small range (≈ 3 µm to 5 µm). After a milled length of 90 m, the parameter R_a was almost unchanged for the tested machining conditions. Changes in R_a values can be caused by a change in the chemical composition of the wood due to the heat generated in the machining process. Lignin as a building component of wood is melted and intercellular spaces are filled and surface plasticized. This phenomenon should be the subject of further research.
4. Based on the WB_W wear parameter values, different initial wear states of the cutting wedges were observed. This condition was affected by finishing operations: the grinding operation of knife A and the coating operations of knives B and C. The wear pattern of the blades showed two bands: the running zone at length L = 0 m to 90 m and the normal wear zone at length L = 90 m to 270 m.
5. The experimental measurements showed that no coating method was suitable for coating HS 18-0-2-5. The coating method of knife B reduced the wear parameter WB_W, while the coating method of knife C increased this parameter, compared to knife A at a milling length of 270 m. This result confirms that the greatest value of the WB_W wear parameter resulted in the greatest cutting power for milling knife C.

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