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Wear of cemented tungsten carbide (WC) router cutters during oak wood milling

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1. Introduction

The WC-based (WC-Co) hard alloys were patented in 1923 in England and in the USA. They were started to be used for manufacture of blades of various cutting tools [1]. Different tests of wear of cutting tools revealed that the cutting edges made of WC are more resistant to wear, while compared with blades made from stellites, high-speed steel, high-alloyed or alloyed tool steel [2]. The diamond cutting edge in average four times harder than the cutting edge made of WC, but four times weaker in case of bending strenght, moreover, it is characterized by low toughness [3]. The hardmetal is the alloy of various metal carbides – tungsten (W), titanium (Ti) and/or vanadium (V) bonded with elastic binder. WC was used in wood processing industry for the first time in 1929 [3]. Usually the hardmetal used in wood industry consists of 80 – 90% W and 20 – 10 % cobalt (Co) [3]. The cutting edge of tools used in composite wood processing contains approx. 2.5 – 4% Co and are the most resistant to wear. These tools are recommended for processing of wood based materials with homogeneous structure, which induce abrasive wear [4]. When the wood composite materials are processed, the cutting edge of tools is working more intensively than in case of processing solid wood [1-4]. More intensive wear of tools' cutting edge appear when tools are used to process wet wood or wood based materials [3, 4]. During cutting thermal, electric, and chemical factors affects the wear of WC tools' blades [5-11]. The wear of cutting edge (change in the micro-geometry of the cutting edge) is the main factor that restricts the efficiency of tools [4, 6, 12]. According to the tests, the wear of the tool's cutting edge depends on the cutting length or processing duration, tool's material, cutting mode, and main characteristics of the processed solid wood or wood composites [3, 4, 13, 14]. The wear of the tool's cutting edge might be divided into three stages: initial, monotonic and emergency [5, 6, 13]. The wear of the cutting edge leads to continuous decreasing of quality of the processed surfaces [15-17]. The surface unevenness is formed due to the peculiarities of mechanical processing. The size of unevenness depends on the processing mode, microgeometry of the tool blade cutting edge (nose), cutting direction, and of the cutting and feed speeds [18-20].

The main objective of this research is to identify the influence of milling mode on wear of handled router cutters and on the quality of milled surfaces.

2. Testing procedures

The tests were accomplished using the spiral router cutters for final finishing made of tungsten carbide-based hardmetal with a cobalt binder alloy of grade T06MG (Table 1). The steadiness of router cutters was tested by milling the solid wood panel (900 × 900 × 20 mm), which was made of the glued, using polyvinyl acetate dispersion (Danafix 437 D3), oaken scantlings (900 × 67 × 20 mm). The scantlings were made of solid oak (*Quercus*) wood, the average moisture content was ω = 8 %, average number of annual rings at 1 cm was 4.6 units, and density was ρ = 737.8 kg/m^3. The average temperature in the testing laboratory was t = 19 ± 2°C, and relative air humidity was φ = 60 ± 5%.

The milling tests were carried out in the CNC machining center (Holzher Pro Master 7123). The length of the cutters installed in the HSK 63F tool holder was 60 mm. The samples were down milled in three different milling modes. The characteristics of the milling modes were presented in Table 2.

Table 1

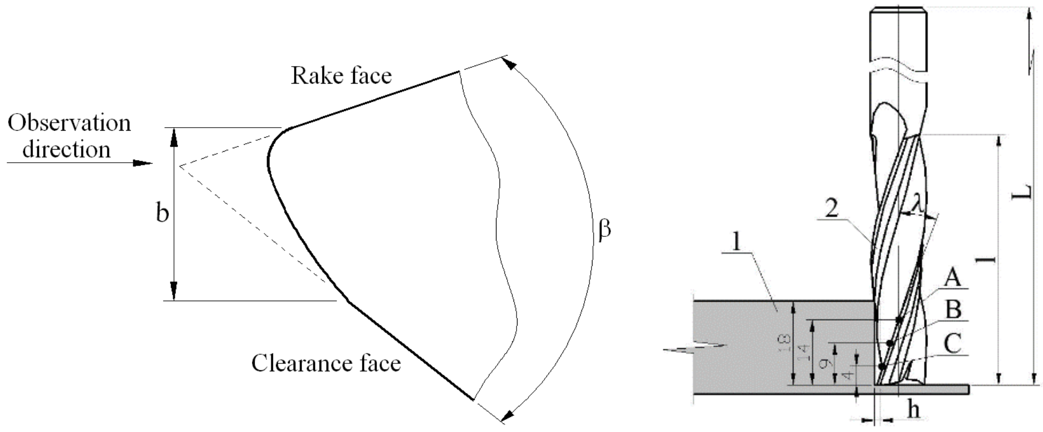
Characteristics of routers cutter tools [22]

Hardmental grade (ISO – Code)	T06MG (K01 – K20)	Diameter *D*	Ø12 mm
Binder	6% Co	Cutting edge length *l*	54 mm
Hardness	1800 (HV 10)	Cutter length *L*	101 mm
Tensile strength	2700 N/mm^2	Rake angle γ	21°
Toughness	8.2 K_1C/MPa m$^{-1/2}$	Sharpness angle β	59°
Operating temperature	800 – 1000°C	Clearance angle α	10°
Coefficient of friction	0.4 – 0.6 μ_s	Inclination angle λ	20°

Table 2

Characteristics of milling modes

Milling mode	Rotational speed of spindle n, min^{-1}	Cutting speed v, m/s	Feeding per cutter u_z, mm	Feed speed u, m/min	Depth of milled layer h, mm
1	18000	11.3		5.00	
2	21000	13.2	0.01	5.86	1
3	24000	15.1		6.69	



a b

Fig. 1 Measurement schemes of the helical cutting edge width *b*: a - cross-section of the cutting edge; b - scheme of measurement points of the cutting edge width *b*; *1* – sample; *2* – router cutter; A, B and C – measurement points; *h* – depth of milling; *λ* – inclination angle

The wear of the cutters was detected by measuring the helical cutting edge width *b* (Fig. 1, a) [21]. The values of the cutting edge width b were registered optically, using the optical microscope (Nicon Eclipse E 200) with digital video camera (Lumenera Infinity 1). The cutting edge width b was measured in the set intervals of cutting length *L* (Table 4). The measurements in each interval of cutting length *L* were done in three places (A, B and C) (Fig. 1, b).The cutting edge width *b* was measured in the set intervals of cutting length *L* (Table 3). The measurements in each interval of cutting length *L* were done in three places (A, B and C) (Fig. 1, b). The received images were analysed and measured using the personal computer and software (Infinity Analyze Release 5.0.2).

The parameter of the processed surface roughness Rz was measured by contact stylus tip profilometer (Mahr MarSurf PS1), the radius of diamond tip of which was 2 μm, measurement angle 90º, and measurement length was 17.5 mm. The five sectors have been selected in one sample (17.5 × 17.5 mm), and its roughness was measured along the fiber. In total 180 measurements were done during the testing series. The measurement error of unevenness did not exceed ± 10 %.

Table 3

Intervals of cutting length

Milling mode	Cutting length L, m
1	130, 1190, 2248, 3267, 4332, 5403, 6547, 7585, 11024, 14953, 19980, 26130
2	130, 1630, 3130, 4630, 6130, 7630, 9130, 10630, 12130, 17130, 22130, 26130
3	130, 1011, 1892, 2774, 3655, 4536, 5418, 6299, 7180, 12180, 17180, 22180, 26130

3. Results and discusion

The performed experiments revealed that the cutting speed and cutting length affect wear of router cutters' cutting edge (changes in microgeometry). This research helped to determine, how the wear of cutting edge and different cutting speed affect the quality of milled surfaces. The quality of milled surfaces was evaluated by roughness *Rz*.

One of the factors, which affect the wear of tools, is the cutting length. Its influence was analyzed in case of different milling modes (No. 1, 2 and 3). It was determined that in case of the milling mode No. 1 (Fig. 2) the most intensive initial wear is in the cutting length *L* up to 3270 m – the width of the cutting edge *b* is rapidly increasing. The wear of cutting edge in the cutting path from 3270 m to 7590 m is less intensive because of transition from initial to monotonic stage. The wear is already monotonic in the cutting length *L* from 7590 m to 26100 m – the wear of the cutting edge is slow and constant.

In case of the milling mode No. 2, the intensive initial wear is observed in the cutting length *L* up to 4500 m. There the cutter gets worn the most intensively. The wear becomes slower in the section from 4500 m to 5600 m – the initial wear is getting converted to the monotonic one. The intensity of the cutting edge wear gets even lower in the cutting length L up to 26100 m where monotonic wear takes place.

In case of the milling mode No. 3, the wear of the cutter was the most intensive in the cutting length L up to 3660 m. The wear became slower in the section from 3660 m to 6300 m. It became even slower and got stabilized in the section of the cutting length L from 6300 m to 26100 m. The second factor that affects the wear of tools is the cutting speed; its influence on wear of cutters was determined with the help of analysis of the results received in the course of milling modes No. 1, 2 and 3.

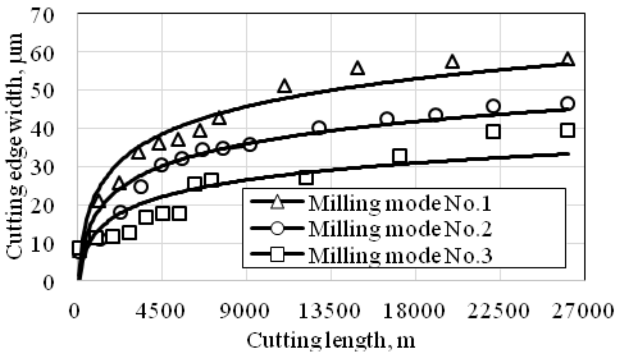


Fig. 2 Influence of the cutting length L on the cutting edge width b

The wear of the cutters was more intensive in case of milling mode No. 1 (v = 11.3 m/s). In the case of the milling mode No. 2 (v = 13.2 m/s) the wear of cutters slows down. When the cutting edge width b reached in the case of the milling mode No. 1 was compared to the width of the milling mode No. 2, the 20.2% difference of was determined. In the case of the milling mode No. 3 (cutting speed 15.1 m/s), even lower wear of cutters was determined – the cutting edge width b was by 32.4% lower when compared to the milling mode No. 1.

The received results are in compliance with the regularities determined by other researchers, as well. According to G. Ramasamy and J. Ratnasingam al., the wear of cutting edge increases with the increasing cutting length [2]. X. Guoa et al. determined in their research that the wear of the cutting edge is the most intensive in the initial wear stage which converts to monotonic wear later [6].

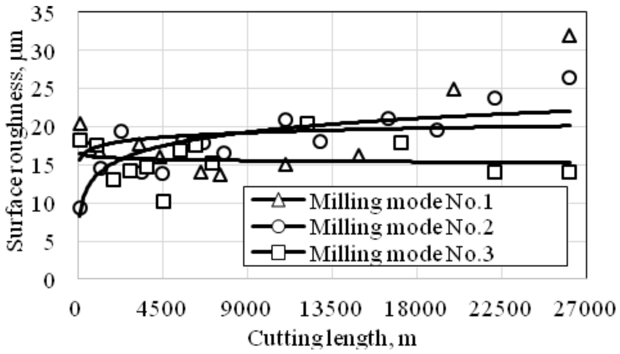


Fig. 3 Surface roughness R_z along the fiber

The analysis of the roughness results of the processed surface (Fig. 3) revealed that the increase of cutting length L and width b of cutting edge cause decreasing of the processed surface quality. This tendency was identified with regard to all the milling mods (No. 1, 2 and 3). The lowest surface roughness is received in the course of milling up to 130 m of the cutting length. The surface roughness is increasing gradually in the section of the cutting length from 130 m to 26100 m. The tool wear increases proportionally to the increase of the cutting length. When the blunt tool is used for wood milling, the wood is ripped and the processed surface is formed through deformation and compression of internal layers of the fibre.

While increasing cutting speed from 11.3 m/s to 15.1 m/s, the processed surface quality increases. The measurements in the cutting length up to 26100 m revealed that in case of the milling mode No. 2 (v = 13.2 m/s) the surface roughness was by 8.96% lower when compared to the milling mode test No. 1 with v = 11.3 m/s. When the milling mode No. 3 and 1 were applied, the difference of the parameter Rz was equal to 51.4%.

4. Conclusions

The cutting length has the highest impact on the wear of router cutters. The wear is the most intensive in the cutting section up to 3130 m. The wear of cutters in the section from 3130 m to 26100 m is stable and low.

The increase of the cutting speed influences the wear of cutting tools. When the cutting speed increases from 11.3 m/s to 13.2 m/s, the intensity of the router cutter's wear gets by 1.25 times lower, and when the cutting speed increases from 11.3 m/s to 15.1 m/s – it gets by 1.48 times lower.

The wear of the router cutter's cutting edge increases with the cutting length. It also causes higher surface roughness. When the cutting speed increases from 11.3 m/s to 13.2 m/s the roughness of the milled surface reduces in 1.1 times. When the cutting speed of 15.1 m/s is used, roughness reduces in 2.1 times, when compared to milling at 11.3 m/s.

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WEAR OF CEMENTED TUNGSTEN CARBIDE (WC) ROUTER CUTTERS DURING OAK WOOD MILLING

S u m m a r y

The paper presents a study on the performance of non-coated solid cemented tungsten carbide (WC) router cutter when milling oak wood. The tests were done with the oak wood samples. The samples were milled in the CNC milling router. The samples were milled at three different milling modes. The measured micro-geometrical parameter was the width of cutting edge. Actual values of cutting edge width were measured by optical method using optical microscope and digital microscopy camera. Width of cutting edge was measured in the established steps of cutting length. The received images were processed and measured using the computer software. The results are presented in the form of summaries and diagrams.

Keywords: router cutter, helical cutting edge wear, tungsten carbide, oak wood.

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