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INVESTIGATION OF WEAR RESISTANCE OF ROUTER CUTTERS COATED DIFFERENT ANTIWEAR COATINGS

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Abstract. The article presents the investigational results, which show resistance of solid tungsten carbide (WC) router cutters not coated and coated by titanium carbonitride (TiCN), chromium nitride (CrN) and diamond-like carbon (DLC) coatings, to wear. The tests were carried out using the oak wood samples, which were down milled in the CNC machining center by two different milling tests. The resistance of cutters to wear was assessed optically through measurement of the helical cutting edge width. The cutting edge width was measured in the set intervals of cutting path. The received results revealed that the router cutters coated with CrN are the most resistant to wear. The router cutters coated by TiCN and DLC are less durable. The WC router cutters, which are not coated at all, are the least resistant to wear.

Key words: router cutter, helical cutting edge wear, tungsten carbide, anti-wear coatings, oak wood.

Introduction

When the wood is milled, the tools get worn under the impact of abrasive wear, temperature, electrical and chemical factors [1–3]. These factors become more intensive when the plywood or wood composites are milled [4]. The durability of the tool's cutting edge is also affected by vibrations, which appear during the cutting process [5]. The presence of all these factors leads to decreasing weight of the tool and changes in its microgeometrical parameters. When the tool gets blunt, its effectiveness decreases and with time it becomes unsuitable for usage [1]. When the tool's cutting edge gets worn, the roughness of the milled surface increases [6].

The tests revealed that the wear of the cutting edge of the tool depends on the cutting path or work time, tool's material, cutting mode and characteristics of the wood or its composites [7]. The wear of the tool's cutting edge is divided into three stages depending on the wear's intensity: initial, monotonic and emergency [8].

In order to increase the resistance of the tools to wear, the tungsten carbide (WC) tools are treated in low temperature or coated by coatings harder than tool material [9, 10].

The main function of the tool's coating is to reduce the contact between the tool and material. This causes smaller abrasive wear, adhesion and corrosion. High hardness and chemical stability of certain coatings provide them with high resistance to crumbling of surface layers and cutting edge when high and low speed of cutting is used [10].

The coatings are put on the tool materials by physical (PVD) and chemical (CVD) vapor deposition methods [11]. The tungsten carbide-based alloys are used as the base for such coatings as titanium carbonitride (Ti(C, N)), aluminum chromium nitride (Al-Cr-N), diamond (crystalline carbon), chromium nitride (CrN) or multilayered chromium nitride/chromium carbonitride (CrN/CrCN) coatings [12–15].

The main objective of this research is to compare the resistance of router cutters, which are not coated and which are coated by titanium carbonitride (TiCN), chromium nitride (CrN) and diamond-like carbon (DLC) coatings to wear while down milling the oak wood.

Testing Procedures

The tests were done using the spiral router cutters of finish processing made from solid tungsten carbide-based with a cobalt binder alloy of K01–K20 grade (Table 1), which are not coated and which are coated by TiCN, CrN and DLC coatings (Table 2).

Table 1. Specifications of milling tool [16]

Carbide grade (ISO–Code)	K01–K20	Diameter *D*	Ø12 mm
Binder	6 % Co	Cutting edge length *l*	54 mm
Hardness	1800 (HV 10)	Cutter length *L*	101 mm
Bending 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. Specifications of coatings

Coating	Colour	Deposition method	Thickness, µm	Hardness HV	Deposition temperature, °C	Operating temperature, °C	Coefficient of friction
TiCN	Reddish brown	PVD	3	3000	450	600	0.3
CrN	Silver gray	PVD	3	1800	450	700	0.5
DLC	Gray	PE - CVD	3	10000	550	700	0.1

The resistance to wear of router cutters was tested while milling the solid wood panel (900×900×20 mm), which were made when the oaken scantlings (900×67×20 mm) were glued using polyvinyl acetate dispersion (Danafix 437 D3). The scantlings were made from solid oak wood, the average moisture content was $\omega = 8$ %, average number of annual rings at 1 cm was 4.6 unit, and density was $\rho = 737.8$ kg/m^3. The average temperature in the testing room was $t = 19 \pm 2$°C, and relative air humidity was $\varphi = 60 \pm 5$ %.

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 one milling test. The characteristics of the tests were presented in the Table 3.

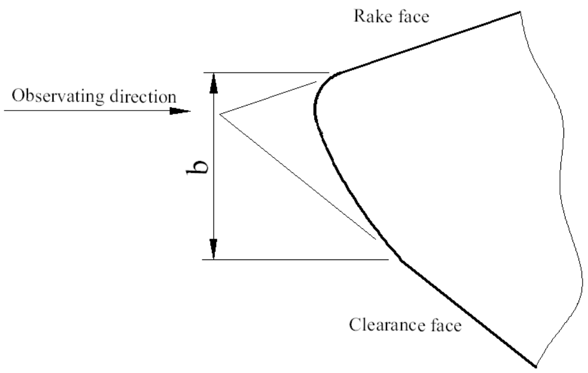
Table 3.Milling test conditions

Number of test	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 milling h, mm
1	18000	11.3	0.01	5.00	1

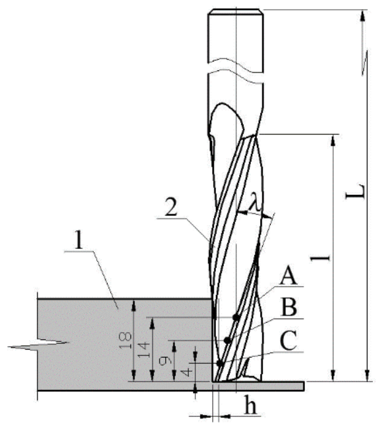
The wear of the cutters was evaluated by measuring the helical cutting edge width b (Fig. 1a) [17]. The values of the cutting edge width b were measured optically, using the optical microscope (Nicon Eclipse E 200) with digital video camera (Lumenera Infinity 1) [18]. The cutting edge width b was measured in the set intervals of cutting path L (Table 4). The measurements in each interval of cutting path L were done in three places (A, B and C) (Fig. 1b). The received images were processed and measured using the personal computer and software (Infinity Analyze Release 5.0.2).

Table 4. Intervals of cutting path

Router cutters	Milling test	Cutting path L, m
WC	1	130, 1190, 2248, 3267, 4332, 5403, 6547, 7585, 11024, 14953, 19980, 26130
WC + TiCN WC + CrN WC + DLC	1	130, 1130, 2130, 3130, 4130, 5130, 6130, 7130, 11130, 15130, 20130, 26130



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

Results and discussions

The researches helped to determine the resistance of router cutters made from WC and coated by TiCN, CrN and DLC to wear while down milling the oak wood samples.

One of the factors affecting the durability of tools was the cutting path. Its influence was investigated in down milling test.

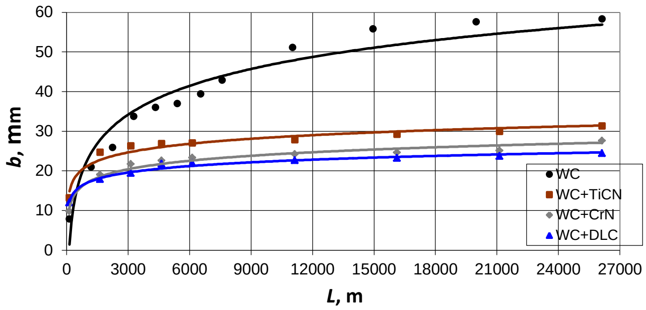
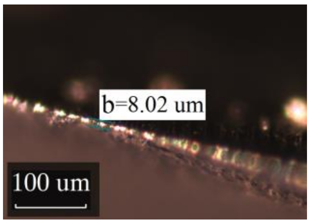


Fig. 2. Influence of the cutting path L on the cutting edge width b.

The testing results revealed (Fig. 2) that the wear mechanism of all the cutters is similar in the section of cutting path up to 3132 m. The initial wear is intensive in this stage. The numeric values of the cutting edge width *b* of all the cutters grow rapidly there. It was noticed in this section of milling path that the uncoated WC cutter gets worn more intensively if compared to the coated cutters.

The wear of all the cutters in the section of cutting path up to 9130 m gets less intensive. However, an evident difference between the durability indexes of uncoated and coated cutters is noticed already.

In the further section up to 26132 m the wear of all the cutters slows down. However, the durability difference between the WC cutter not coated by any coating and coated cutters increases.



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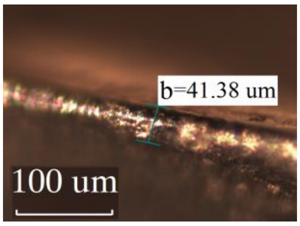

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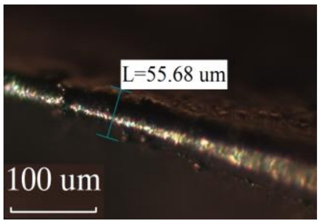
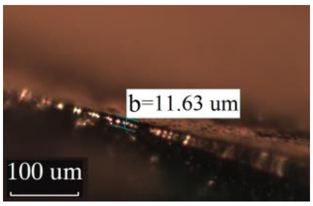


c

3 pic. Optical images of the cutting edge width b of uncoated WC cutter: a - L = 130 m; b - L = 11024 m; c - L = 26130 . (150 x).



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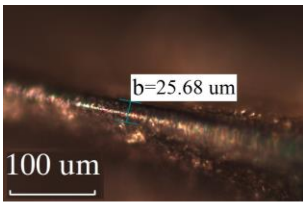

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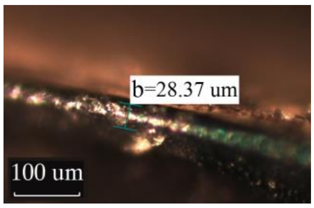

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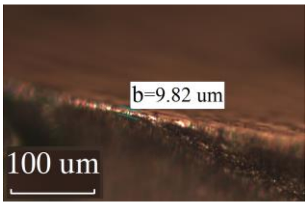
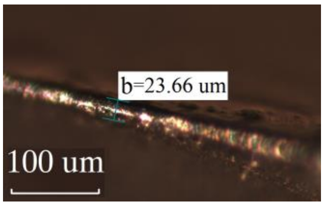
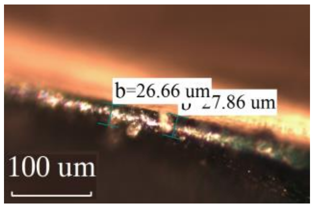
4 pic. Optical images of the cutting edge width b of WC+TiCN cutter: a - L = 130 m; b - L = 11130 m; c - L = 26130 . (150 x).

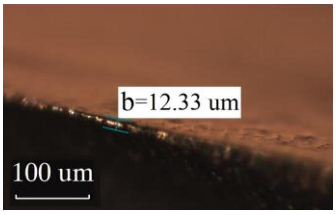


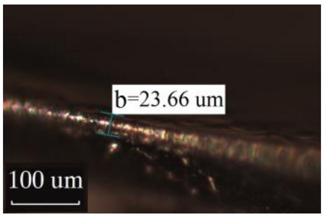


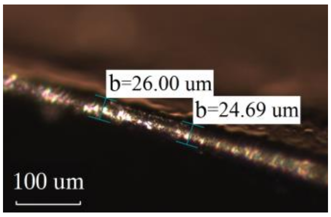


a b c

5 pic. Optical images of the cutting edge width b of WC+CrN cutter: a - L = 130 m; b - L = 11130 m; c - L = 26130 . (150 x).







a b c

6 pic. Optical images of the cutting edge width b of WC+DLC cutter: a - L = 130 m; b - L = 11130 m; c - L = 26130 . (150 x).

Conclusions

1. The cutting path had the biggest influence on the wear of cutters. The most intensive wear of the cutters was in the section from 0 to 3132 m of the cutting path. The wear of the uncoated cutters and cutters coated by TiCN, CrN and DLC gets stabilized in the section from 3132 to 26132 m and passes to the monotonic wear gradually.
2. When the milling tests were done under the conditions of two tests, it was determined in the section of cutting path up to 26132 m that the cutting edge of the cutter coated by TiCN get worn less by 1.6 times on average if compared to the uncoated cutters. The wearing intensity of the cutter coated by DLC was smaller by 1.9 times on average. The cutter coated by CrN coating was the most resistant to wear. Its wearing intensity was smaller twice on average.
3. It is recommended to continue the durability tests of the cutters coated by TiCN, CrN and DLC through the analysis of influence of various biological sorts of wood and wood's humidity on the dynamics of tools' wear.

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