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Analysis of sliding friction of WC-Co composite on particleboard

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Abstract: *Analysis of sliding friction of WC-Co composite on particleboard.* The paper presents the analysis of the coefficient of friction at the contact area between WC-Co composite and particleboard. The four types of WC-Co composite in the form of milling indexable knives for wood materials machining were tested. The tests were carried out on a linear reciprocating tribotester (pin-on-flat), where the sample was the clearance surface of WC-Co indexable knives and the counter-sample was made of three-layer particleboard. Before and after tribological tests, the surface roughness of tested knives was measured. The highest values of friction coefficient were obtained for the type UMG04 of cemented carbide - with nano size of WC grains and the lowest content of cobalt. The average coefficient of friction for selected types of WC-Co correlated with the average increase in surface roughness (the roughness parameter R_y).

Keywords: WC-Co composites, particleboard, sliding friction, surface roughness

INTRODUCTION

The wear of cutting tools during machining of wood materials is a complex process. It consists of many physical (mechanical) and chemical mechanisms that change over time with varying intensity and interact with each other (Porankiewicz et al. 2005).

The mechanical wear is caused by mechanical interaction of surfaces (Klamecki 1976). The chemical wear is caused by oxidation and tribochemical reactions. The mechanical wear is divided into abrasive wear, erosive wear, adhesive wear and fatigue wear (Kazlauskas and Jankauskas 2017).

The wear of the tool's surface layers is also increased by the fact that wood starts decomposing under high pressure and temperature present in the friction area. At the beginning of the process, when the temperature is 100-150°C, moisture evaporates from wood. When the temperature reaches 275-300°C, hemicellulose starts decomposing. Moreover, at 400°C the cellular tissue starts to decompose and generates acids, alcohol and pitches (Pamfilov et al. 2014).

However, due to high wear speeds and heavy damages to blades, the abrasive wear is the least desirable. Moreover, the other wear types are also activated in the course of this wear. The abrasive wear is usually caused by the blade's contact with material harder than the tool. However, strong abrasive wear can also be observed in the wood cutting process (Kazlauskas and Jankauskas 2017, Krakhmalev et al. 2007, Wilkowski et al. 2018a, 2018b).

The abrasive wear of the tool is caused by the sliding of hard particles between two contacting surfaces of tool and workpiece (Wilkowski et al. 2019b). The abrasive wear is proportionate to the cutting length and directly related to cutting speed (Klamecki 1976, Csanady and Magoss 2013, Wilkowski and Barlak 2018).

The aim of this work was to investigate the sliding friction coefficient at the contact area between milling WC-Co blades and the three-layer particleboard.

MATERIAL AND METHODS

The four types of WC-Co knives with dimensions of 29.5×12.0×1.5 mm^3 produced by Ceratizit company (Reutte, Austria) were used for the tests (Fig. 1, upper). The selected properties of the tested WC-Co composites are compared in Table 1. The composites varied as regards the content of binder (cobalt) and the size of tungsten carbide grains. These differences affected the basic physical and mechanical properties of the composites. UMG04 material had the highest density and hardness due to the WC grain size (nano-size) and low cobalt content (2 wt.%).

Table 1. Properties of the tested WC-Co composites (www.ceratizit.com)

Material symbol	WC grain size (µm)	Co binder content (wt.%)	Density (g/cm^3)	Hardness HV30	Bending strength (MPa)
UMG04	<0.2	2.0	15.30	2450	3200
SMG02	0.2-0.5	2.4	15.25	2200	3500
KCR08	0.5-0.8	3.2	15.20	1790	2300
HC05	0.5-0.8	4.0	15.15	1730	2100

The scope of work involved a series of tribological studies. Twenty-four tests for dry sliding friction were performed. The dry sliding friction of four types of WC-Co knives was investigated using a pin-on-flat tribotester (Fig. 2) in which pins were rubbed in reciprocating motion against samples (flat). The samples were milled from the cross-section of the Pfleiderer chipboard (Grajewo, Poland) with the thickness of 18 mm and the density of 648 kg/m^3. Moreover, it had a shape of a longitudinally cut cylinder with different bottom and top diameters (bottom: 9 mm, top: 7 mm, height: 13 mm) - see Fig. 1, lower. Because of the fact that each knife was tested on individual counter-sample, all 24 samples had to be manufactured precisely and identically. Therefore, they were made using CNC plotter Kimla 1015 (Częstochowa, Poland).

During the tests, the contact load of 50 N was imposed perpendicularly to the clearance surface of the WC-Co blade with the counter-sample (normal force). The stroke length of the reciprocating motion was 7 mm (1 test cycle) and the sliding velocity 0.012 m/s. The friction force was registered with a 10 kHz signal recording frequency on the National Instruments USB-6001 measurement card (Austin, USA). The kinetic friction coefficient was analyzed. The graphical user interface of the program for recording measurement signals is outlined in Fig. 3. The full tribological test of one knife consisted of 10 000 cycles what gave 700 m of sliding distance.

Surface roughness at the contact area was measured by a portable surface tester called the Mitutoyo Surftest SJ-201 (Kawasaki, Japan) that is presented in Fig. 4. Furthermore, it was measured before and after the tribological test. The total length of the measured section was 2.4 mm and consisted of three elementary subsections with the length of 0.8 mm. The basic roughness parameters R_a, R_z and R_y were determined according to ISO 4287:1997. For each contact area, six roughness profiles were recorded. The average increase in roughness was calculated as a difference between the average values of the roughness parameter before and after the tribological test.

Additionally, the knives wear surfaces were analyzed by scanning electron microscopy (SEM) Zeiss EVO MA10 (Carl Zeiss, Jena, Germany) for the magnification of 20 000×.

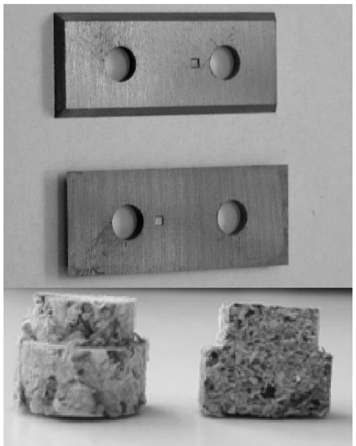

Figure 1. WC-Co indexable knives (upper) and the counter-sample of particleboard (lower)

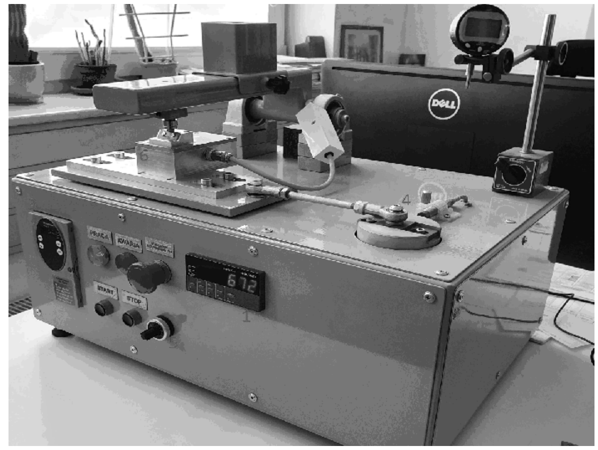

Figure 2. The pin-on-flat tribotester used in testing the friction coefficient

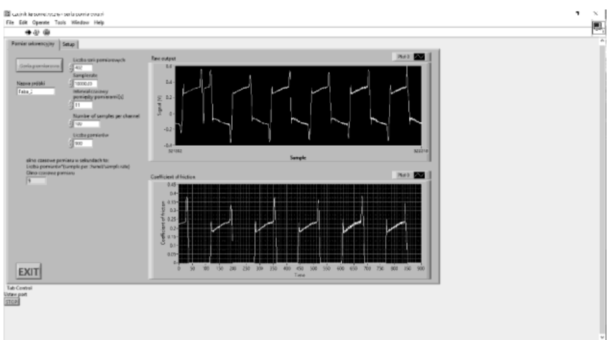

Figure 3. The graphical user interface for registering friction forces

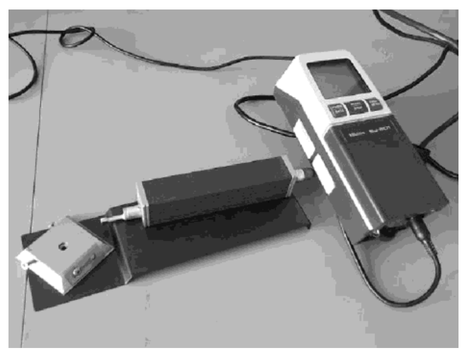

Figure 4. The surface roughness tester Mitutoyo Surftest SJ-201

RESULTS AND DISCUSSION

Fig. 5 shows the progression of the coefficients of friction for individual types of the knives during the tribological tests. A relatively slight increase in the friction coefficient as a function of the number of cycles can be noticed. This may indicate that surface of the knives has not undergone major wear changes due to sliding friction. The selected progressions of the coefficient of friction for UMG04 (2 passes) and KCR08 (1 pass) are considerably higher. Moreover, they significantly differ from the others. The formation mechanism of these progressions is unknown; however, it is not associated with the state of the roughness of the tested surfaces. These distinctive waveforms significantly affect the friction coefficient variability in groups, as illustrated in Fig. 6. The intervals plotted on the graph show the value of the standard deviation which was the highest for UMG04 and KCR08 knives. It also introduced insignificant differences in the coefficient of friction between the tested types of WC-Co composites. The highest average coefficient of friction (0.4) was recorded for UMG04 and the lowest (0.27) for HC05 (Fig. 6). Generally, three groups of knives (SMG02, KCR08 and HC05) demonstrated the same level of sliding friction at the contact surface with the three-layer particleboard.

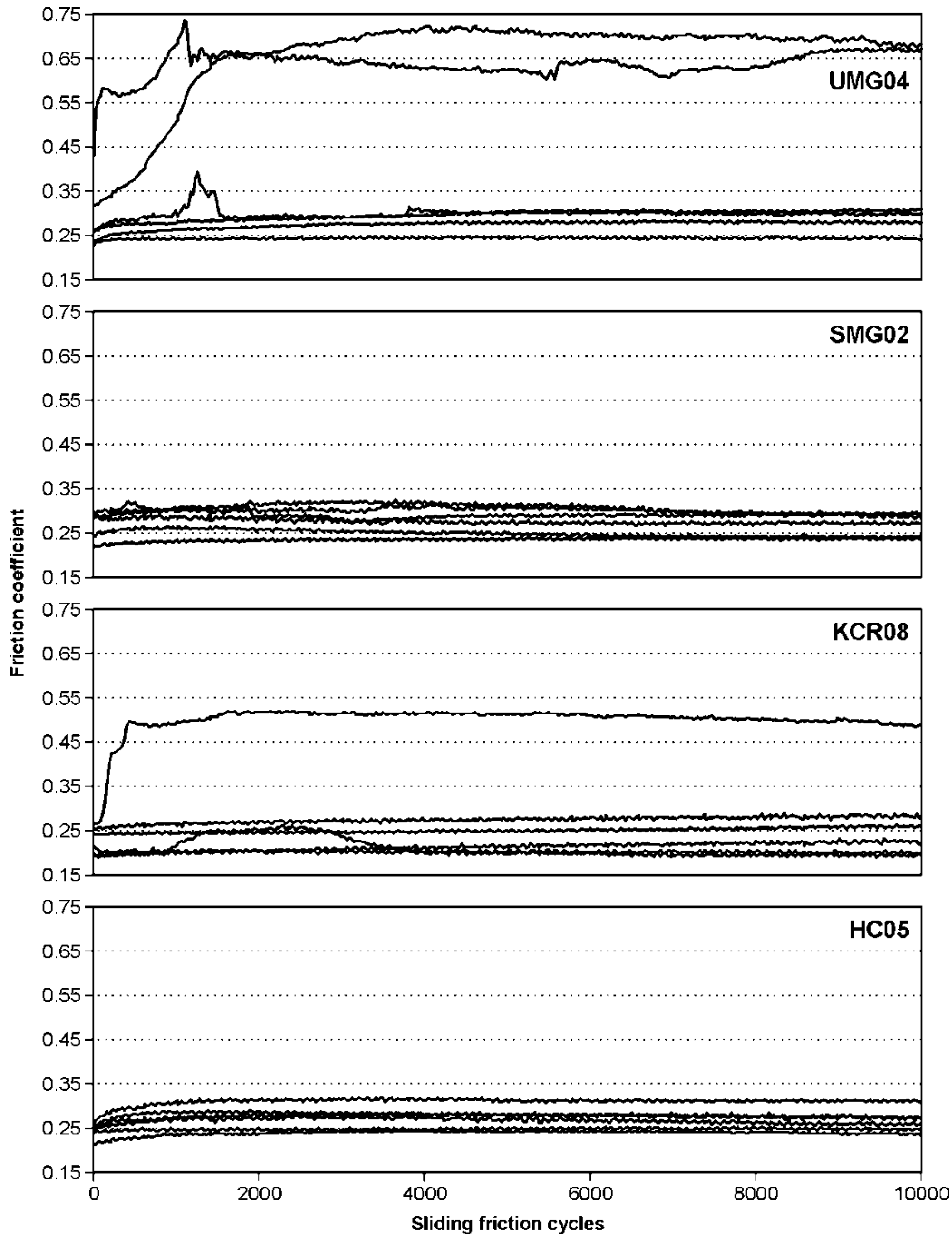

Figure 5. Progrssion of friction coefficient at sliding cycles

The carbide with the smallest WC grains and the lowest content of cobalt binder was found to have the highest friction coefficient. According to Wilkowski et al. (2019b), such material is characterized by the high values of physical and mechanical properties, including hardness and the modulus of elasticity measured at the nano-scale.

Fig. 7 presents the recorded results of the surface roughness measurements for the knives before and after testing. The average values of R_a parameter are shown on the upper graph and R_y parameter representing the maximum deviations on the lower graph. The highest roughness value was obtained for KCR08 knife and the lowest for HC05.

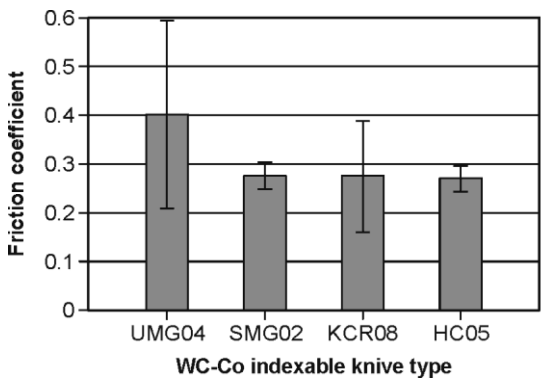

Figure 6. Average friction coefficient for the tested types of knives

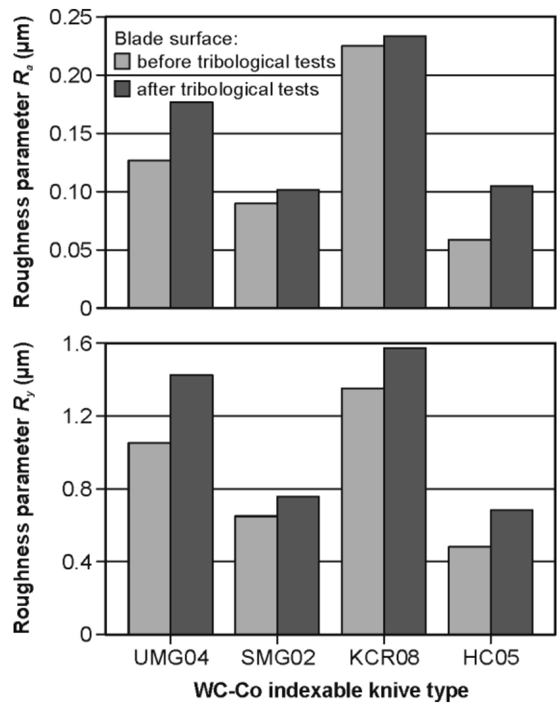

Figure 7. Surface roughness for the tested types of knives

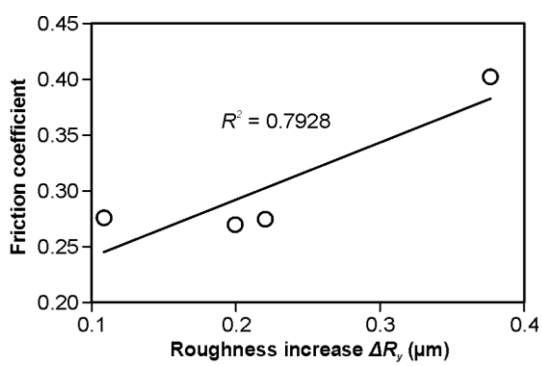

Figure 8. Relationship between roughness increase and friction coefficient

The increase in the roughness of blades surface after testing is noticeable in the case of all types of WC-Co material (Fig. 7). Additionally, ΔR_y is correlated with the average coefficient of friction recorded in the tests (Fig. 8). However, SEM images of carbide surfaces do not clearly indicate an increase in roughness. They would rather suggest surface smoothing as a result of tribological tests (Fig. 9).

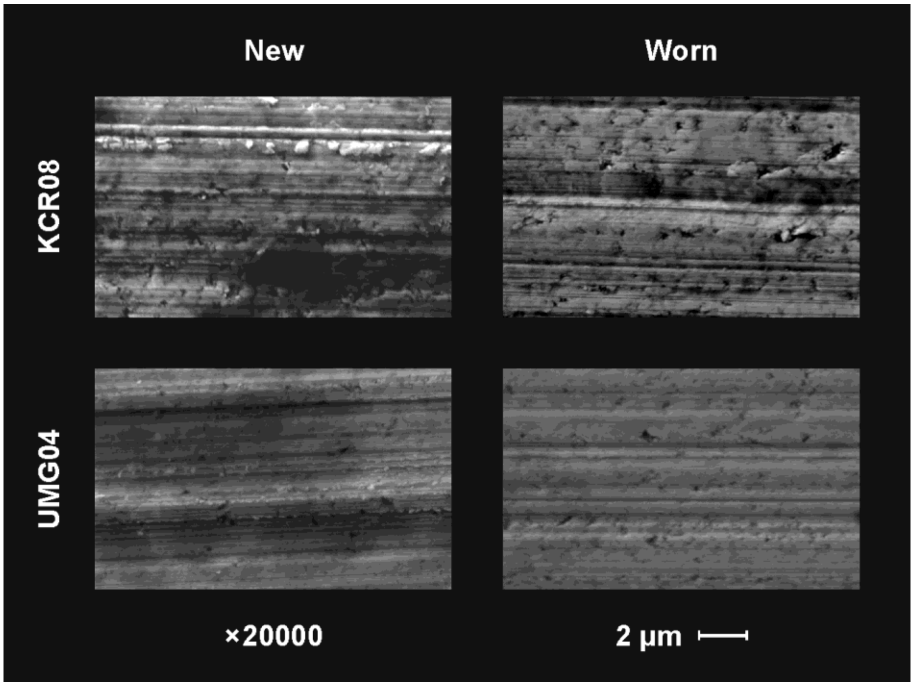

Figure 9. SEM images of new (left) and worn (right) surface for KCR08 (upper) and UMG04 (lower)

The abrasion of WC carbide grains by the particleboard on the sliding distance is excluded due to their significant hardness. It should be assumed that their edges are more exposed as a result of the removal of relatively soft cobalt surface and also, the exposure of the spaces between the WC grains (WC-Co composite porosity). This is a probable reason for the increase in the surface roughness. The suggested phenomenon is more noticeable in SEM images of carbides with a higher cobalt content (dark spots on the SEM image) e.g., KCR08 (3.2 wt.% Co) than for low cobalt carbides such as UMG04 (2.0 wt.% Co).

CONCLUSION

The obtained results lead to the following conclusions:

1. The highest values of friction coefficient were obtained for UMG04 type of cemented carbide with nano grains of WC and the lowest content of cobalt.
2. KCR08 knife was characterized by the highest surface roughness before and after tribological tests. HC05 knife had the lowest average friction coefficient and roughness.
3. The average friction coefficient for individual types of WC-Co correlates with the average increase in roughness expressed by parameter R_y.

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Streszczenie: *Analiza tarcia ślizgowego kompozytu WC-Co w kontakcie z płytą wiórową.* Artykuł przedstawia analizę współczynnika tarcia na styku kompozyt WC-Co i płyt~~a~~y wiórow~~a~~ej. Przebadano cztery rodzaje kompozytu WC-Co w postaci frezarskich noży wymiennych do obróbki materiałów drzewnych. Badania przeprowadzono na tribotesterze typu „trzpień po płaszczyźnie", gdzie próbką była powierzchnia przyłożenia noża wymiennego WC-Co, a przeciwpróbką był trzpień wykonany z trójwarstwowej płyty wiórowej. Przed i po badaniach tribologicznych dokonano pomiaru chropowatości powierzchni badanych noży. Najwyższe wartości współczynnika tarcia uzyskano dla rodzaju węglika UMG04 o najdrobniejszych ziarnach WC i najniższej zawartości kobaltu. Średni współczynnik tarcia dla poszczególnych rodzajów WC-Co korelował ze średnim przyrostem chropowatości wyrażonej parametrem R_y.

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