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Nano-scale hardness and elastic modulus of WC-Co composites and their relationship to the tools life during particleboard milling

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Abstract: *Nano-scale hardness and elastic modulus of WC-Co composites and their relationship to the tool life during particleboards milling.* The paper summarizes the results of the technique of hardness and elastic modulus determination using a load and displacement sensing indentation experiments. During the tests these properties were measured in nano-scale for different types of WC-Co composites using the Anton Paar TriTec Ultra Nano Hardness Tester (UNHT). In addition, durability examination of WC-Co tools during milling of particleboard was carried out. In the final stage, the correlation of the studied properties with the lifetime of tools was analyzed. The studies have revealed a relationship between micro-hardness and the total cutting length of the WC-Co tools.

Keywords: WC-Co composites, hardness, elastic modulus, nano-scale mechanical behavior, tool life, particleboard, milling

INTRODUCTION

Cemented tungsten carbide offers excellent wear resistance due to the combination of hard WC particles in a soft binder matrix making tungsten carbide one of the oldest and most successful powder metallurgy products (Sarin 1981). These hard metals are therefore used in a wide range of applications, including wood cutting tools.

The relations between hardness and modulus of elasticity and friction and wear can be investigated on the microstructural scale (Ndlovu 2009). The scratch resistance is not directly related to the hardness or other mechanical properties. However, a deeper understanding of the relation between hardness and scratch resistance is of interest (Staedler and Schiffmann 2001). The nanotribological properties can be studied in detail and could lead to a better understanding of the microstructure properties and their relationship to wear resistance.

The cutting tools used in composite wood machining contain approx. 2.5 – 4% Co (cobalt) and are the most resistant to wear. These tools are recommended for processing wood-based materials with homogeneous structure, where abrasive wear is important (Kowaluk et al. 2009).

Wilkowski et al. determined that the wear of the cutting edge is the most intensive in the initial wear stage and is followed by monotonic wear later (Wilkowski et al. 2018).

The mechanism of wear is very complicated and its theoretical treatment usually splits the processes that take place into four categories. These are abrasion, adhesion, erosion and sliding, which may act individually or in combination (Ndlovu 2009).

The aim of the work was to evaluate the nano-scale properties of selected composites and to determine their relationship to the tools life during particleboard milling.

MATERIAL AND METHODS

WC-Co indexable knives with dimensions of $29.5\times12.0\times1.5$ mm^3 in size, produced by Ceratizit company (Reutte, Austria) and Tigra company (Oberndorf am Lech, Germany) were used for tests. Selected properties of the tested WC-Co composites are shown in Table 1.

Table 1. Properties of the tested WC-Co composites [www.ceratizit.com; www.tigra.com].

Material symbol	WC grain size [µm]	Binder content Co [%]	Density [g/cm^3]	Hardness	Bending strength [MPa]
UMG04	<0,2	2,0	15,30	2450 (HV30)	3200
SMG02	0,2-0,5	2,4	15,25	2200 (HV30)	3500
KCR08	0,5-0,8	3,2	15,20	1790 (HV30)	2300
T04F	1,0-1,4	4,0	-	1750 (HV10)	2350
T10MG	0,7-1,0	10,0	-	1650 (HV10)	3600

Hardness and modulus are calculated from the load-displacement data for each indentation by the Oliver and Pharr method. The method was introduced in 1992. Mechanical properties can be determined directly from indentation load and displacement measurements without the need to image the hardness impression. The indenter is driven into the material surface causing both elastic and plastic deformation taking place and resulting in a hardness impression in the shape of the indenter. As the indenter is withdrawn, only the elastic portion of the displacement is recovered. This allows one to distinguish between the elastic and plastic properties of the material. A schematic of indentation-load versus displacement data during one cycle of loading and unloading is shown in Figure 1. The most important features are the peak load (P_{max}), the maximum depth (h_{max}), the final or residual depth after unloading (h_f) and the elastic unloading stiffness (S), defined as the slope of the upper portion of the unloading curve during the initial stages of unloading (also called the contact stiffness) (Oliver and Pharr 2003, Ndlovu 2009).

The local properties were measured using an Anton Paar TriTec Ultra Nano Hardness Tester (UNHT) (Fig. 2). The Berkovich indenter was used (Fig.3). The measurement parameters were as follows: maximum load - 1 mN, loading / unloading speed - 2 mN/min, pause - 5 s (Fig. 4). The measurement on each sample was repeated five times.

Three-layers particleboard produced by Pfleiderer (Grajewo, Poland) with a thickness of 18 mm and density 648 kg/m^3 was subjected to machining tests. Workpieces with dimensions 1000x400x18 mm^3 were milled on CNC tool machine Busellato Jet 130 (Thiene, Italy) equipped with one edge milling head Faba FTS.07 (Baboszewo, Poland) with diameter 40 mm. There were made grooves (with a width equal to the tool diameter – 40 mm) in particleboard panels on a depth of 6 mm. During machining, constant cutting parameters (feed speed 2,7 m/s, spindle speed 18 000 rpm, feed per tooth 0,15 mm) were maintained. On each work piece 10 repetitions were done. After each passage (1 m of feed distance), measurement of tool wear with workshop microscope was carried out. The clearance surface of edge was taken into account. The maximum width of wear (direct indicator VB_{max}) was estimated. Machining was stopped as soon as wear width was equal or higher than 0,2 mm. Thus, this value was assumed as tool wear criterion. Cutting length covered to achieve tool wear criterion (VB_{max} = 0,2 mm) was assumed as the tool life indicator (Barlak et al. 2018). The cutting tests for each group of WC-Co composites were repeated six times.

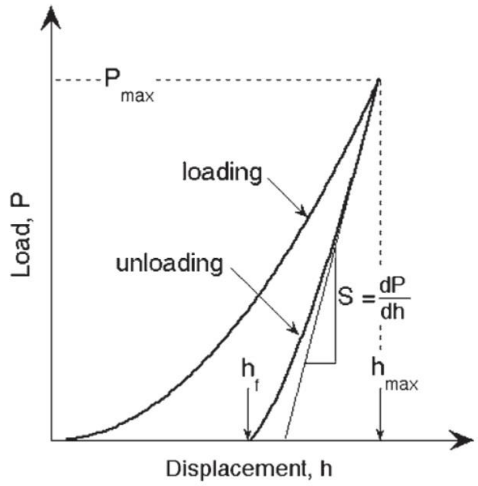

Figure 1. Schematic illustration of indentation load–displacement data showing important measured parameters (Oliver and Pharr 2003).

Figure 2. Anton Paar TriTec Ultra Nano Hardness Tester (UNHT).

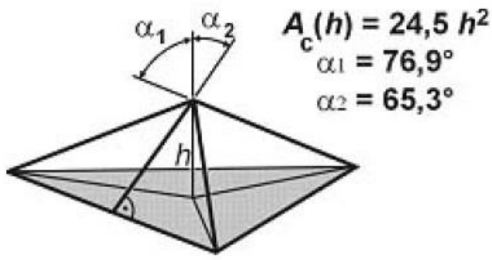

Figure 3. Berkovich indenter geometry (Kempf 2002).

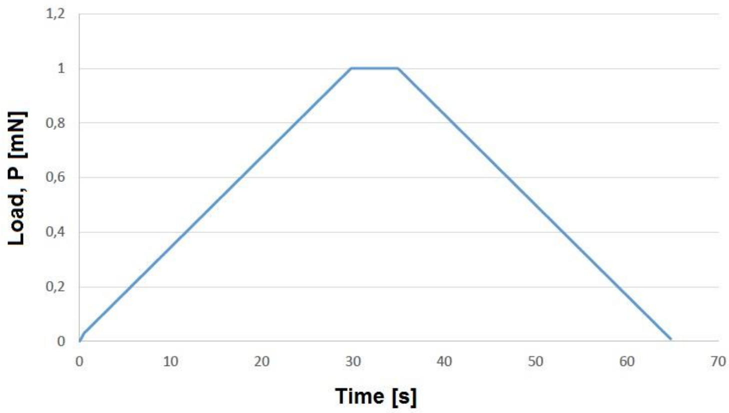

Figure 4. Change of load with time.

RESULTS AND DISCUSSION

Fig. 5 and 6 show the measured properties of the examined WC-Co composites. The ranges in the charts show +/- standard deviation of the tested property. The highest nano-hardness was obtained for UMG04, i.e. a material with the smallest WC (<0,2 μm) grains and the lowest contribution of cobalt (2,0 wt% Co). However, the lowest nano-hardness was found for T10MG – with the large WC size (0,7 - 1,0 μm) and moreover with the highest contribution of cobalt (10 wt% Co) (Fig.5). The effect of cobalt content on nano-hardness is confirmed by Ndlovu (2009).

The highest nano-elastic modulus was noticed for WC-Co with symbol UMG04 and the lowest for SMG02 and T04F (Fig. 6). The obtained tendencies in the results were not analogous to those obtained for nano-hardness. This observation is confirmed by the low correlation between the studied properties in the nano-scale (Fig. 7). According to Ndlovu, the Young's modulus was found to increase with decreasing cobalt content, i.e. Young's modulus is inversely proportional to the Co content. The indenter size is comparable to the WC grain size and therefore the material response is strongly influenced by the local mechanical properties of the composite (Ndlovu 2009).

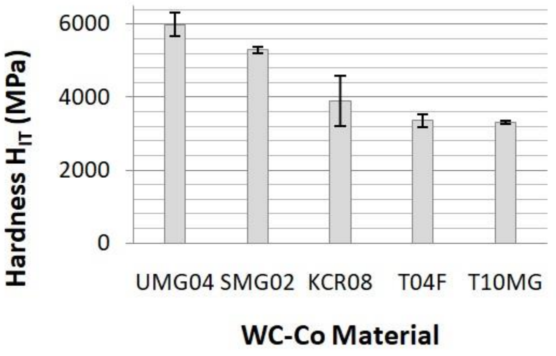

Figure 5. Nano-hardness of the tested WC-Co tools.

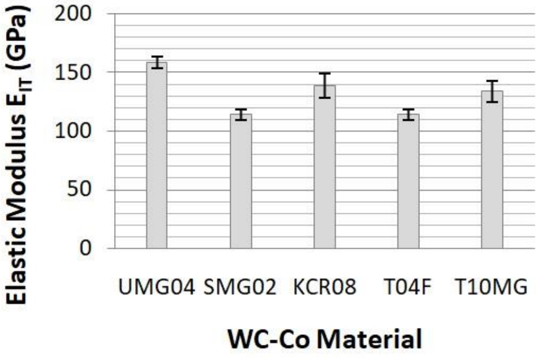

Figure 6. Nano-elastic modulus of the tested WC-Co tools.

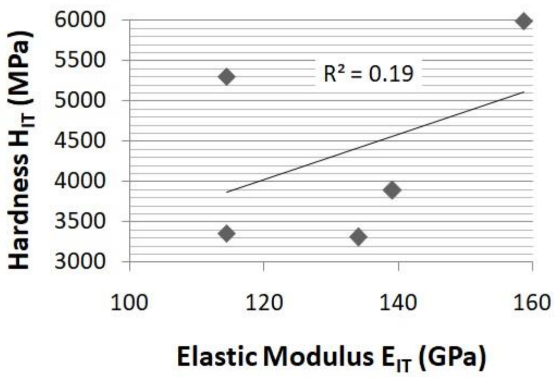

Figure 7. Relationship between nano-hardness and nano-elastic modulus of the tested WC-Co tools.

Fig. 8 and 9 show correlation relationships between the investigated properties and the cutting length as an indicator of tool life time. A relatively high correlation (the coefficient of determination R^2 = 0,72) with the cutting length was observed for nano-hardness (Fig. 8), while the correlation for the nano-elastic modulus is low (Fig.9).

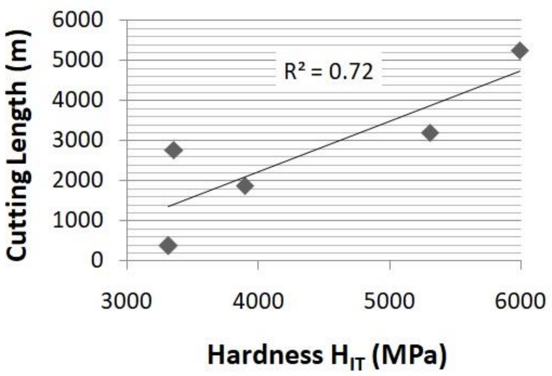

Figure 8. Relationship between total cutting length and nano-hardness of tested WC-Co tools.

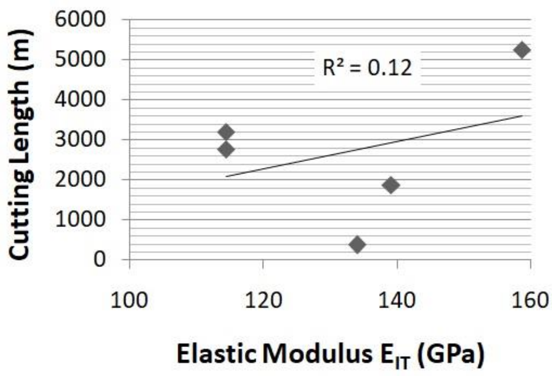

Figure 9. Relationship between total cutting length and nano-elastic modulus of tested WC-Co tools.

CONCLUSION

According to the obtained results, one can formulate the following conclusions:

1. The WC-Co composites with the smallest WC grains and the lowest content of the binder (in the form of cobalt) were characterized by high hardness and elasticity module in the nano-scale.

2. High correlation relationships between the nano-hardness of WC-Co composites and the lifetime of tools during particleboard milling have been demonstrated.

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Streszczenie: *Twardość i moduł sprężystość kompozytów WC-Co w nano-skali i ich związek z trwałością narzędzi podczas frezowania płyt wiórowych.* W artykule przedstawiono zastosowanie metody określania twardości i modułu sprężystości za pomocą techniki wgłębnika z rejestracją obciążenia i przemieszczenia. Mierzono ww. właściwości w nano-skali dla różnych rodzajów kompozytów WC-Co przy użyciu twardościomierza Anton Paar TriTec (UNHT). Ponadto przeprowadzono badania trwałości narzędzi WC-Co podczas frezowania płyty wiórowej. W końcowym etapie przeanalizowano korelację badanych właściwości z okresem trwałości ostrzy. Badania wykazały korelacyjny związek między twardością w nano-skali a całkowitą drogą skrawania ostrzy WC-Co.

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