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The influence of WC grain size on the durability of WCCo cutting edges in the machining of wood-based materials

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Abstract: WCCo cemented carbides are one of the basic materials used for tools. They consist of tungsten carbide in 70–96% and a binding warp – cobalt. High hardness of these materials determines their high resistance to abrasive wear. These properties predispose them to be used as a material for cutting tools.
This study presents the results of tests on the durability of cutting edges made of WCCo composite of different WC grain in the machining of wood-based materials. The tests showed a several-fold increase of the durability of edges made of WCCo composite of grain size of 0.2÷0.5 μm compared to WCCo blades of WC grain size of 0.5÷0.8 μm and 0.8÷1.3 μm.

Keywords: WC; tungsten carbide; WCCo composite; cutting tools

INTRODUCTION

The furniture industry is an important branch of Polish economy system, and furniture is one of the main products exported from Poland. Growing production of furniture, coupled with the technological progress in machining equipment which provides higher and higher machining parameters, generate a demand for new tool materials what will meet higher and higher requirements [1, 2].

90% of the materials used in furniture industry are wood-based, including: MDF, HDF, particleboard and fibreboard. The multilayer wood-based materials are made of wood particles of different sizes, compressed at a high temperature and pressure using resin, especially urea-formaldehyde, melamine and phenol [3].

Wood-based materials are difficult to machine. They have a heterogeneous structure, a complex chemical composition and structure anisotropy, so, compared to metals, they require different machining techniques [4]. Furthermore, they show low thermal conductivity, which results in significant tool wear. However, accelerated wearing process occurs frequently, especially at high cutting speeds during machining of chipboards containing increased fraction of mineral contaminations in comparison to MDF. Tool wear mechanism consists of two effects, namely: a continuous abrasive wear with superimposed cyclic spalling of edge zone caused by direct contact with hard mineral particles (sand) [5].

WCCo cemented carbides are commonly used tool materials for the machining of wood-based materials. The main component of cemented carbides is WC tungsten carbide. It is characterised by high melting point, increased hardness, high thermal and electrical conductivity and chemical stability at increased temperatures. Thanks to its high bending strength and good wettability with carbides, cobalt is the most common material used as a binder [6, 7]. The size of a WC grain and cobalt content have a crucial impact on edge properties, especially bending strength and hardness [8].

Although carbides have been known for ages, researchers are still trying to improve their cutting properties and durability through, e.g. hard coatings, laser modifications of the outer surface, etc. [9, 10]. Another way of improving tool materials is to develop materials of a submicron and nanometric grain size [11, 12].

MATERIALS

Commercial WCCo indexable knives, with dimensions as shown in Figure 1, and WC grain sizes were used to conduct the tests: ultrafine (0.2 <0.5 μm), submicron (0.5 <0.8 μm), fine (0.8 <1, 3 μm). The basic properties of the edge material (given by the manufacturer) are listed in Table 1.

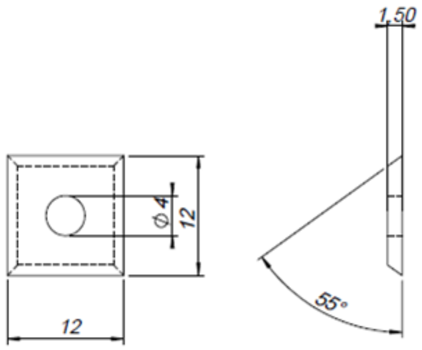


Figure 1. An indexable knife

Table 1. Basic properties of WCCo edges used for the tests

Name	Co content % wt.	Density g/cm³	Hardness		
			HV10	HV30	HRA
Ultra Grade	2.4	15.25	2,300	2,200	95.2
Submicron Grade	4.2	15.20	1,920	1,885	93.4
Fine Grade	4.0	14.90	1,790	1,700	92.5

The tool durability was tested using 1000 x 400 x 18 mm particleboard. The basic properties of the board are listed in Table 2.

Table 2. Selected properties of the particleboard used for the tests

Material	Density [kg/m³]	Tensile strength [MPa]	Bending strength [MPa]	Module of elasticity [MPa]
Particleboard, thickness 18 mm	648	0.41	8.68	2,212

The particleboard milling processes were executed using the BUSELLATO JET 100 machine tool. The tools were tested using a double-edge head. The image of the head and the technical drawing are shown in Figure 2. The spindle rotational speed was 15,000 rpm, feed per tooth: 0.15 mm, feed speed: 4.5 m/min. The wear of the edges was measured each time the board length of 1 m have been milled. The depth of wear was measured using a workshop microscope. The measurement had been taken until the wear value, i.e. the maximum loss of contact surface VB_{max} was 0.2 mm. The micro-structure of tool fractures was tested using the SEM FEI QUANTA 200 Scanning Electron Microscope.

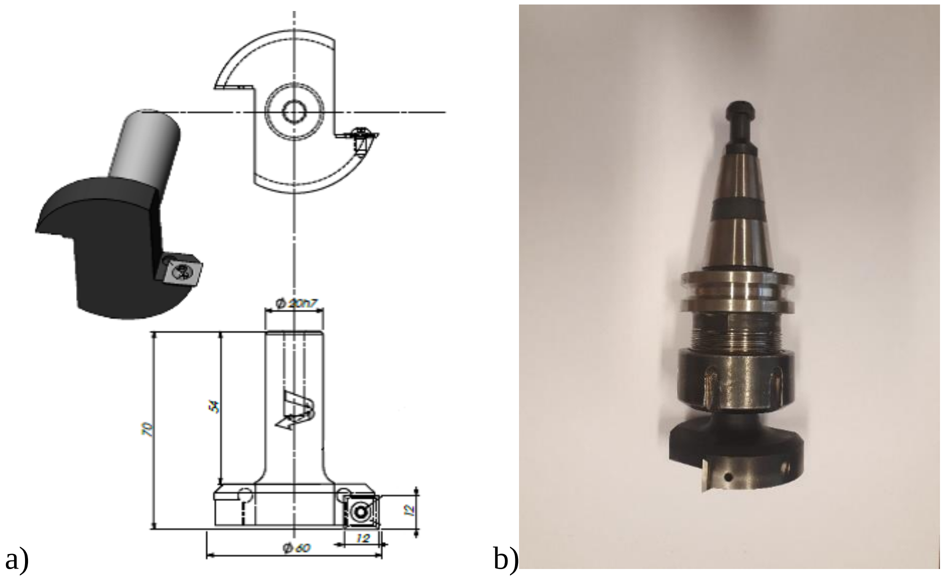


Figure 2. Milling head a) — technical drawing, b) image

RESULTS

Figure 3 shows a graph of the relation between the VB_{max} wear value and the cutting length. The edge of carbides of the lower WC grain size (Ultrafine) had the highest durability. The length of cutting route until the edge was blunt (VB_{max} > 0.2 mm) was 8478 m (27 running metres of the board). The durability of Submicron and Fine edges was twice as small.

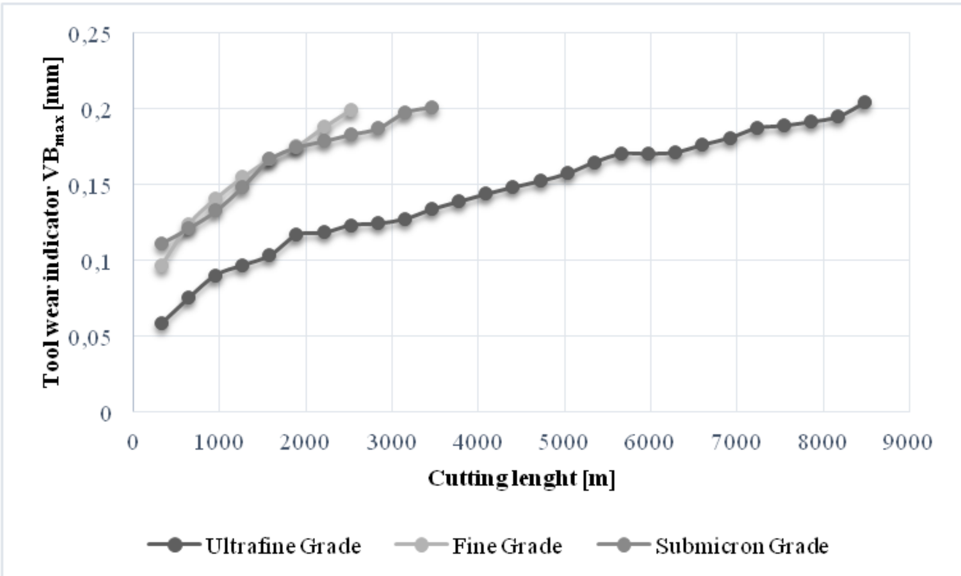


Figure 3. A graph of the relation between the wear indicator [mm] and the cutting length [m]

As shown on Figure 3 – the larger the WC grain, the less durable the edges. Edges of 0.2–0.5μm WC grain size were the most durable. Test results show that WCCo edges are worn due to the removal of the cobalt binder in the first place due to the following processes: plastic deformation, micro-abrasion. The removal of the cobalt binder results in the WC grain being crushed and torn off the tool material. Therefore, the smaller the WC grain size and the lower the content of cobalt evenly spread over the borders of WC grains, the higher the wear resistance of the tool. It is also worth noticing that the edges of the smallest grain size also had lower cobalt content.

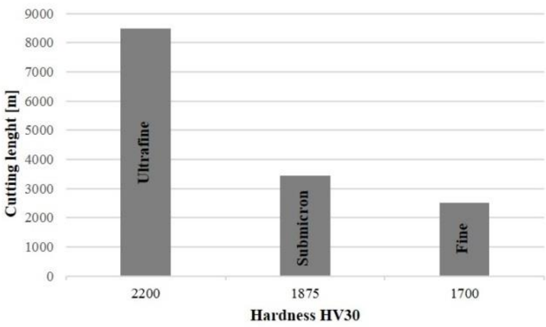


Figure 4. Edge durability depending on hardness

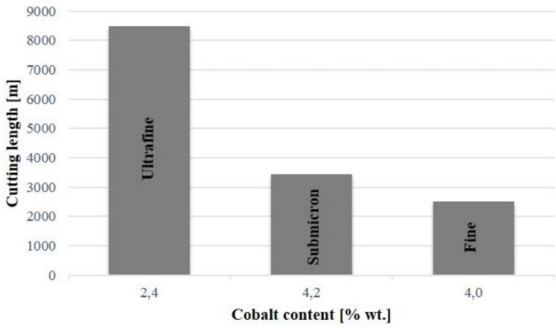


Figure 5. Edge durability depending on cobalt content

Sinters of grain size of 0.2–0.5µm (Ultrafine Grade) has higher hardness and bending strength compared to carbides of grain size of 0.5–0.8 µm (Fine Grade) and 0.8–1.3 µm (Submicron Grade), which results in a higher wear resistance of tools (Figure 4). The smaller the WC grain size, the higher the number of borders between grains, giving higher hardness of edges. Furthermore, the edge hardness increases along with the decrease of the content of soft adhesive binder – cobalt. Figure 5 shows the graph of relation between edge hardness depending on cobalt content.

A sample image of cutting edge is shown on Figure 6. The edges of the smallest WC grain size showed higher resistance to the chipping of the cutting edge.

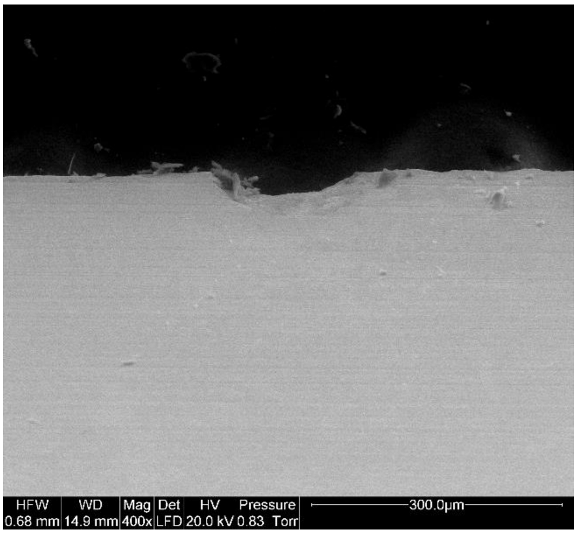
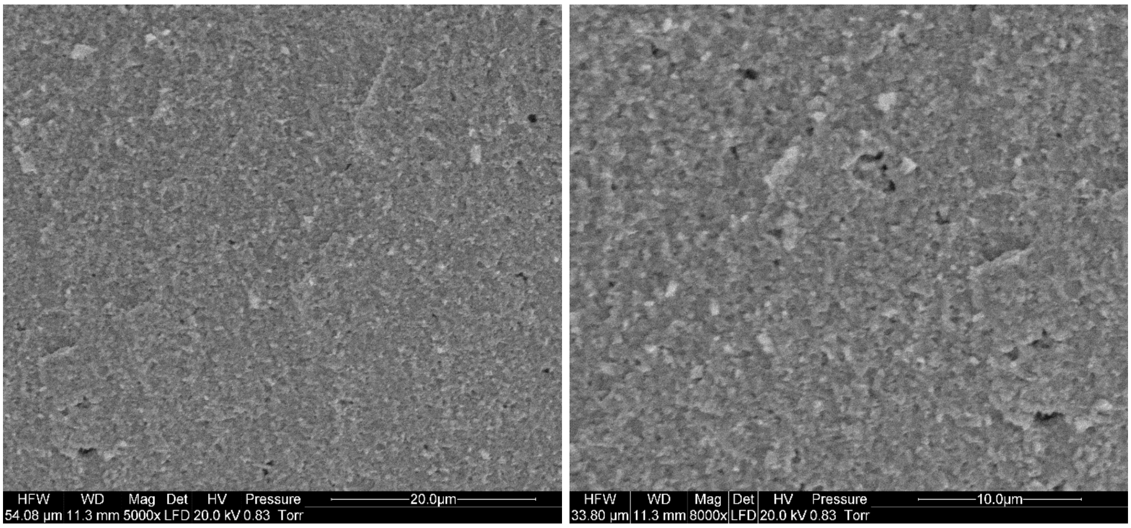


Figure 6. Chipping of WCCo tool material (SEM image)

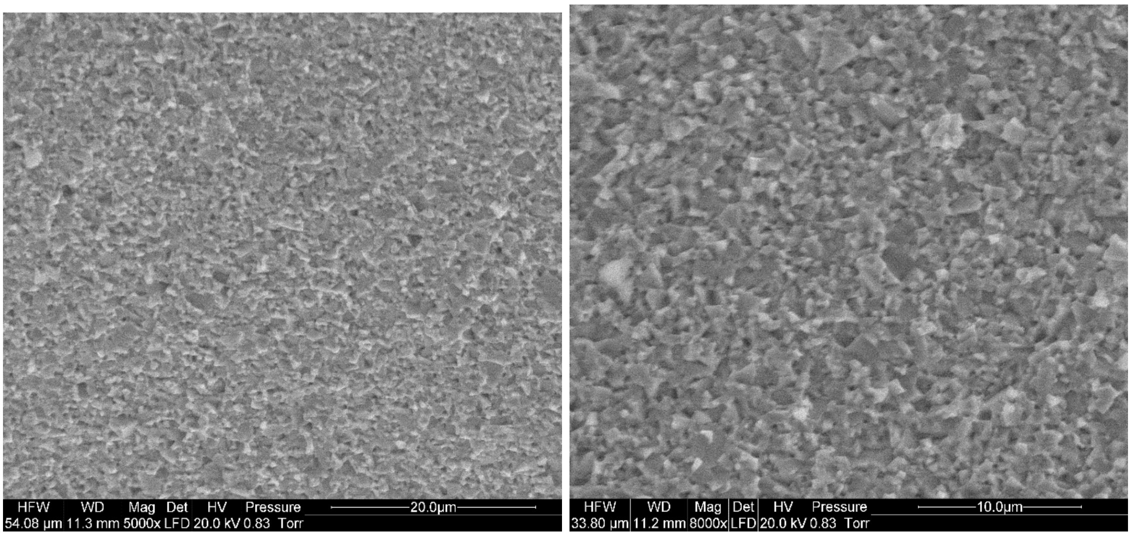
Figure 7 shows the microstructure of blade fractures. The analysis of the image of the micro-structure of Ultrafine blade fracture shows homogeneous, low-grain microstructure, with cobalt evenly spread over WC grains. The image of the micro-structure fractures also reveals a few pores. However, the tests showed that small internal structure porosity did not affect the durability of edges made of this material. These blades were of the highest hardness and were worn slowly.

The SEM image of Submicron blade fracture shows that the micro-structure is heterogeneous. There are larger and smaller WC grains, also pores appear. Furthermore, the micro-structure also reveals well-formed WC grains with specific sharp edges.

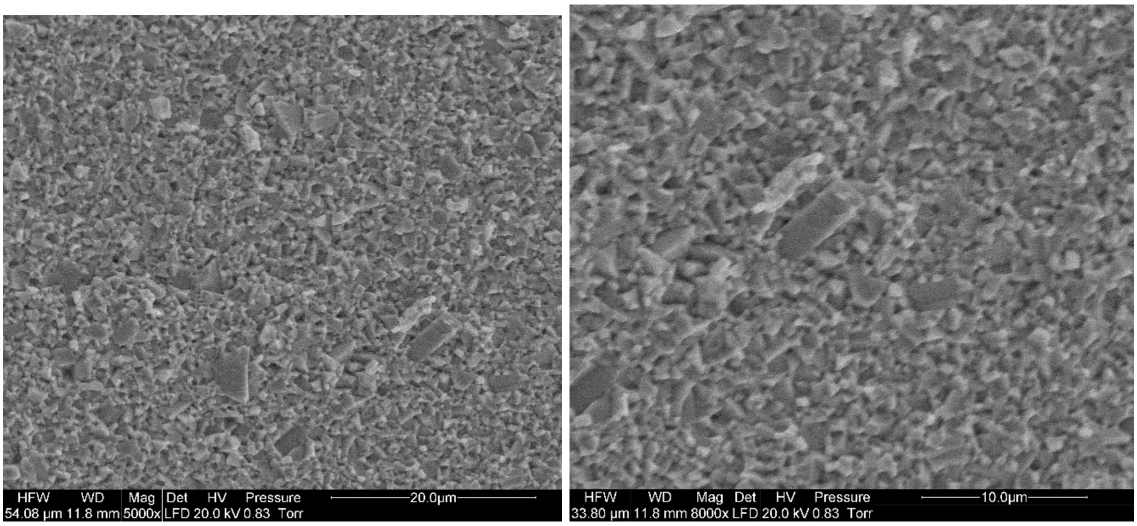
Figure 7c shows the blades characterized by the largest average WC grain size. The images of the microstructure also show heterogeneousness resulting from the presence of differently-sized WC grains. Furthermore, well-formed WC grains can be observed. Pores are not observed.



a) Ultrafine grain (0. 2<0.5 µm)



b) Submicron grain (0.5<0.8 µm)



c) Fine grain (0.8<1.3 µm)

Figure 7. SEM images of the fracture surfaces of WCCo blades

CONCLUSIONS

This study shows that cutting edges made of WCCo composite of WC grain size 0.2–0.5 µm were increasingly more durable compared to edges of larger WC grains. The lower the content of the binder (cobalt), the higher the material hardness and, as a result, the higher the durability of the blades in particleboard machining. A homogeneous microstructure of 0.2–0.5 µm blades determines high durability and even wear of the blade through abrasion. A heterogeneous microstructure in the form of differently-sized WC grains results in a decrease of tool durability as well as in chipping of the edge of the blade.

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Streszczenie: *Wpływ wielkości ziarna WC na trwałość ostrzy skrawających wykonanych z kompozytu WCCo w obróbce materiałów drewnopochodnych*. Węgliki spiekane WCCo są jednym z podstawowych materiałów narzędziowych. Składają się one w 70–96% z węglika wolframu oraz z osnowy wiążącej - kobaltu. Wysoka twardość tych materiałów decyduje o ich wysokiej odporności na zużycie ścierne. W pracy przedstawiono wyniki badań trwałości ostrzy skrawających wykonanych z kompozytu WCCo o rożnej wielkości ziarna WC, w obróbce materiałów drewnopochodnych. Badania trwałości, wykazały kilkukrotny wzrost trwałości ostrzy wykonanych z kompozytu WCCo, o wielkości ziarna 0,2÷0,5 µm w porównaniu do ostrzy WCCo o wielkościach ziarna WC 0,5÷0,8 µm oraz 0,8÷1,3 µm.

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