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ULTRAPRECISION GRINDING OF THE TUNGSTEN CARBIDE

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Abstract. *The surface characteristics and removal mechanism of tungsten carbide cobalt (WC-Co) materials with different compositions (88% WC, 90% WC and 94% WC) in Ultraprecision Grinding were investigated. The motivation for this study is the material's high hardness and potential application for micromolds. The tests were conducted using an ASG 2500 Rank Pneumo™ Surface Generator. A V-shaped metal-bond 75mm diameter diamond wheel was used. The surface roughness (arithmetic average value Ra) of the three microstructural tungsten carbides was measured, using a white-light optical interferometer (Wyko™ NT1100). The results of the grinding process indicate that the average surface roughness was smaller than 10 nm Ra for all grain sizes. The results indicated that, depending on the cutting conditions, it is possible to grind WC in the plastic regime resulting in damage-free smooth surfaces. The grain size of the WC-Co samples and the depth of cut showed little influence on the surface roughness and material removal mechanism without induction of grinding damage in the WC-Co materials. Ultraprecision grinding showed to be a viable option for the fabrication of components made of tungsten carbide with submicrometer surface finish possibly eliminating traditional optical manufacturing processes such as lapping and polishing.*

Keywords: *ultraprecision, grinding, tungsten carbide, integrity surface*

1. INTRODUCTION

In recent years, the demand for optical glass lenses is substantially increased due to the rapid developments of the optics/photonics, microelectronics and biotechnology industries. Currently in the lens manufacturing industry, the mass production of glass lenses is via injection molding, which thus requires the fabrication of moulds made of hard and brittle materials, such as the Tungsten Carbide (Sun *et al*., 2010). Cemented carbides have been successfully used as optical inserts in ceramic powder injection molding and glass injection molding processes for optics in electric devices, optical devices and advanced optical transmission equipment due to their excellent combination of high hardness, ductility and fracture toughness. In order to produce optical components, the profile quality requires a low surface roughness on the nanometer scale, stringent form accuracy on the submicron scale, as well as a low amount of surface damage. In some cases, grinding acts as the final finishing process, therefore polishing processes can be eliminated. Ultra precision grinding has been successfully used in machining of hard steels and silicon carbide, producing optical quality surface of 10 nm Ra with submicron form accuracy (Yin *et al*., 2004). The previous studies were largely concerned with the development of abrasive technologies for machining the glass lens moulds made of the WC with high profile accuracy and mirror surface finish. The studies clearly indicated that the efficient machining of high quality WC moulds needs a comprehensive understanding of the deformation and removal mechanism of the WC material. Apparently, to gain such knowledge would be beneficial to both the machining associated cost and the product quality (Jia and Fischer, 1996).

Cobalt-bonded WC composites show high fracture toughness, hardness and strength compared to other ceramic materials. All of these properties make the composites attractive for use in challenging environments like those in metal cutting, drilling and tool inserts. As a consequence, great attention has been paid to the evaluation of mechanical properties (Han and Mecholsky, 1990).

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Tungsten carbide (WC) has been well known for its exceptional hardness and wear/erosion resistance. Matrices of ductile metals, such as cobalt, greatly improve its toughness so that brittle fracture can be avoided. Cemented tungsten carbides are commercially one of the oldest and most successful powder metallurgy products (Sarin, 1981). These composites are essentially aggregates of particles of tungsten carbide bonded with cobalt metal via liquid-phase sintering. The properties of these materials are derived from those of the constituents – namely, the hard and brittle carbide and the softer, more ductile binder. The cutting tool and wear part applications arise because of their unique combination of mechanical, physical, and chemical properties.

Therefore, this paper aims to evaluate the surface characteristics and removal mechanism of tungsten carbide cobalt (WC-Co) materials with different compositions (88%WC, 90%WC and 94%WC) in Ultraprecision Grinding using a metal-bond diamond wheel in an ASG 2500 Rank Pneumo™ Surface Generator due to material's high hardness and its potential for use in glass injection molding.

2. EXPERIMENTAL PROCEDURES

Some characteristics of the tungsten carbides samples selected in this investigation are presents in Tab. 1.

Table 1. Characteristics of the tungsten carbides (88%WC, 90%WC and 94%WC).

Material	WC (wt.%)	Co (wt.%)	Grain Size (μm)	Hardness HV (Vickers)
WC-Co	88	12	1.0 - 1.8	1446
WC-Co	90	10	1.0 - 1.8	1507
WC-Co	94	6	1.0 - 1.8	1824

The tests were conducted using an ASG 2500 Rank Pneumo™ Surface Generator. A V-shaped metal-bond 75mm diameter diamond wheel was used. Grit sizes of 400 and 1000 were tested using a water soluble oil coolant (16:1 mixture). The grinding process was divided in two steps: stock removal and finishing. During the stock removal step, the feed rate was of 1mm/min and the depths of cut varied from 2 up to 0.5μm. During the finishing step, the feed rate was 0.1mm/min and the depths of cut varied from 0.5 up to 2μm. In both steps the selected wheel speed was 10000rpm, corresponding to 40m/sec peripheral speed and the workpiece spindle rotation was 1000rpm. The surface roughness (arithmetic average value Ra) of the three microstructural tungsten carbides was measured, using a white-light optical interferometer (Wyko™ NT1100). Surface damages were observed as to the presence of microcracks using the Wyko™ interferometer. The grinding process kinematics is shown in Fig. 1.

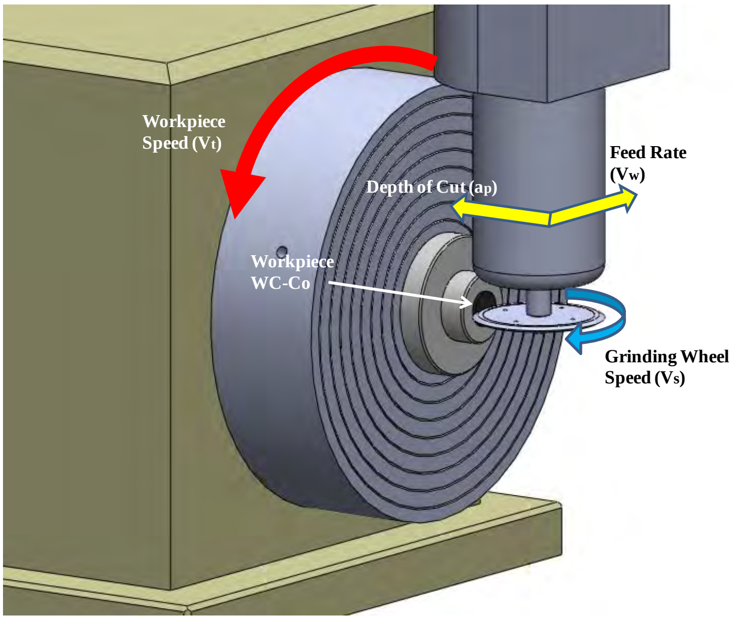

Figure 1. Grinding process kinematics of the Tungsten Carbide Cobalt (WC-Co)

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The faces of the tungsten carbide samples were divided into three zones with different process parameters. The feed rate was 0.1mm/min for all machining zones. The grinding parameters used during the finish step are shown in Tab. 2 and the Fig. 2 illustrates the machining zones in tungsten carbine samples. The ultraprecision grinding process is shown in Fig. 3.

Table 2. Grinding parameters used in finish step of the experimental procedure

	Zone 1	**Zone 2**	**Zone 3**
Depth of cut (μm)	0.5	1.0	2.0
Feed rate (mm/min)	0.1	0.1	0.1
Workpiece speed rotation (rpm)	1000	1000	1000
Wheel speed rotation (rpm)	10000	10000	10000

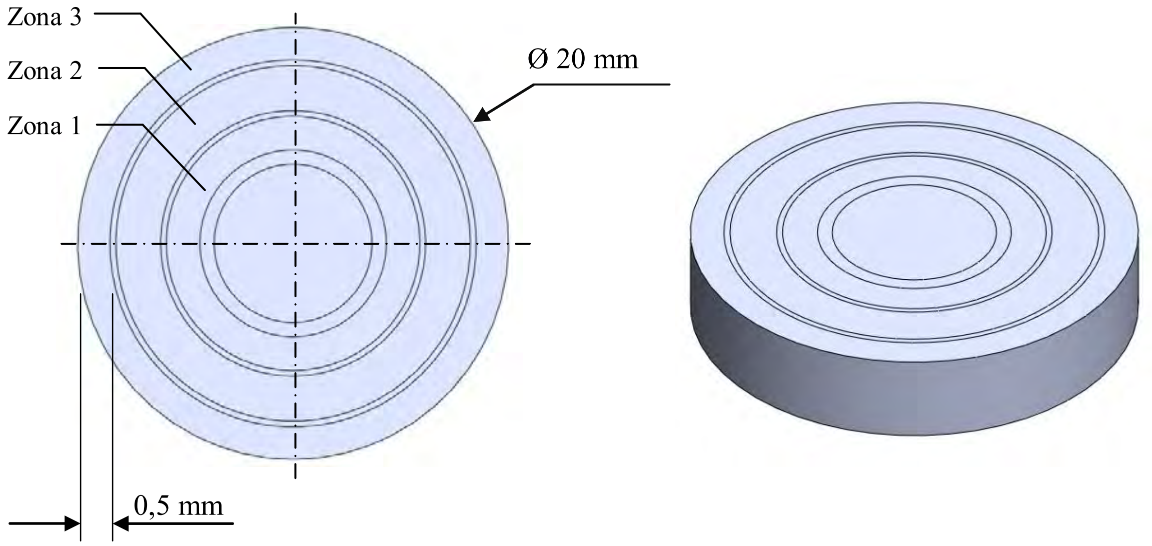

Figure 2. Illustration of the three zones of grinding in tungsten carbide samples

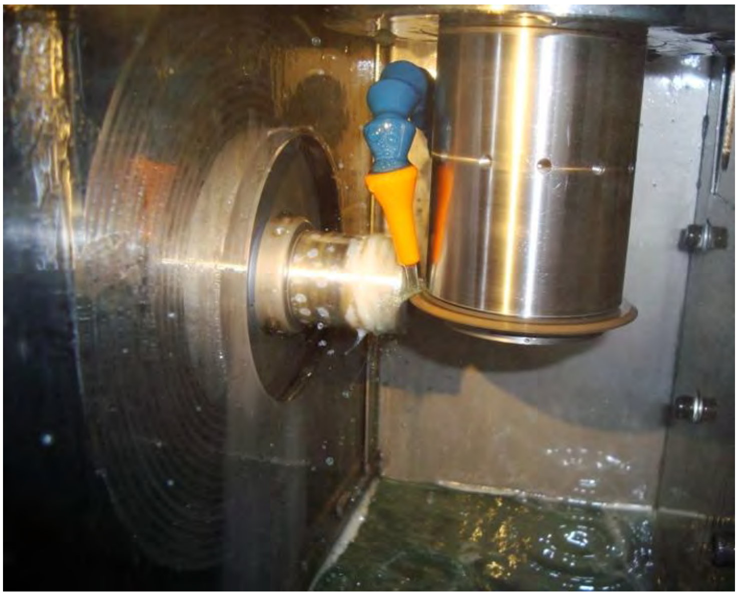

Figure 3. Ultraprecision grinding process of the Tungsten Carbide Cobalt (WC-Co)

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3. RESULTS

The ground surface roughness for the three microstructural carbides was measured using the WYKO optical interferometer. As an example, two and three dimensional interference images of one of the ground 88%WC are shown in Fig. 4. The surface roughness measured in an area of 481µm x 607µm is 3.81 nm Ra.

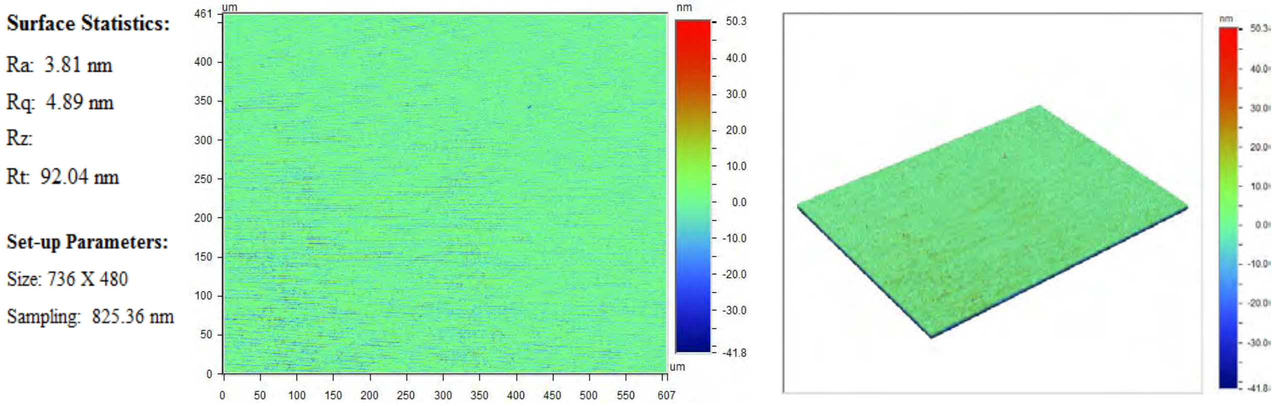

Figure 4. Three-dimensional WYKO interference image revealing the surface roughness of the ground 88%WC.

The average surface roughness results (Ra) of the three microstructural carbides as a function of the depth of cut are shown in Tab. 3. The results indicate that the surface roughness increases with larger depth of cut and percentage of the tungsten carbide. Also, for larger depths of cut the material composition seems to have little influence on the surface roughness.

Table 3. Average surface roughness (Ra) of the three microstructural carbides as a function of the depths of cut.

	Roughness (Ra)		
Depth of cut (µm)	**0.50µm**	**1.00µm**	**2.00µm**
88%WC	3.81 Ra	5.43 Ra	8.40 Ra
90%WC	4.88 Ra	6.14 Ra	8.42 Ra
94%WC	6.32 Ra	7.43 Ra	9.82 Ra

Figure 5 present the surface roughness results using a white-light optical interferometer (Wyko™ NT1100).

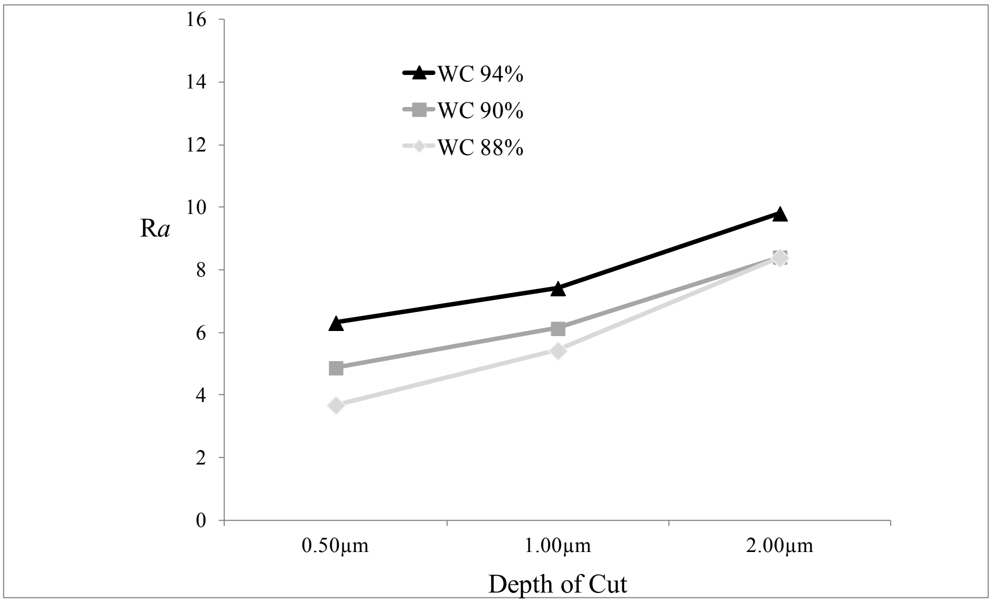

Figure 5. Surface roughness (Ra) versus microstructure of carbide materials and depth of cut.

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4. CONCLUSIONS

Results of the grinding process indicate that the average surface roughness was smaller than 10 nm Ra for all compositions of tungsten carbide. Also, no evidence of fracture or grain pull-out was found in the ground surfaces. All surfaces have a smooth and reflective appearance as shown in Fig. 6, suggesting that plastic flow dominated the material removal process. Results indicate that, depending on the cutting conditions, it is possible to grind WC-Co in the plastic regime resulting in damage-free smooth surfaces. The composition of the WC-Co showed little influence on the surface roughness and material removal mechanism without induction of grinding damage in the WC-Co materials. Ultraprecision grinding showed to be a viable option for the fabrication of components made of tungsten carbide with submicrometer surface finish possibly eliminating traditional optical manufacturing processes such as lapping and polishing.

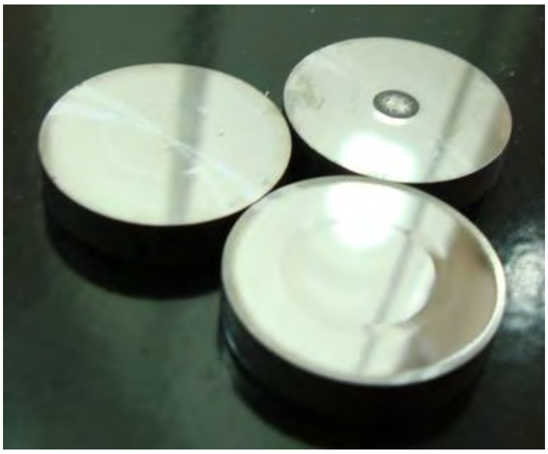

Figure 6. Tungsten carbide surfaces generated by Ultraprecision Grinding.

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6. RESPONSIBILITY NOTICE

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