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The influence of different tungsten carbides (grain size and cobalt percentage) upon material removal mechanism in ultraprecision grinding

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Abstract
The removal mechanism and surface finish of tungsten carbides cobalt (WC-Co) materials with different grain sizes (0.5 and 1.5μm) and cobalt percentage (4 and 8% Co) were investigated in Ultraprecision Grinding Process. The motivation for this study is the material's high hardness and potential application for precision glass moulding. Four tungsten carbide samples with different cobalt percentages and grain sizes (4%Co/0.5μm, 4%Co/1.5μm, 8%Co/0.5μm and 4%Co/1.5μm) were subjected to tests for the determination of their behaviour under two cutting depths. The tests were conducted using an ASG 2500 Rank Pneumo™ Surface Generator. A V-shaped resin-bond 75mm diameter diamond wheel was used. The selected wheel speed was 5000rpm, corresponding approximately to a 20m/s grinding speed, feed rate of 0.05 and depth of cut of 0.5μm and 1.5μm. The surface roughness (arithmetic average value Ra) of the four microstructural tungsten carbides was measured, using a white-light optical interferometer (Wyko™ NT1100). As a result, for the larger grain size the surface roughness is finer for all cutting conditions and both cobalt percentages. For the smaller grain size the surface roughness did not vary so much for 4%Co material for both 0.5 and 1.5μm depths of cut, however for the 8%Co material the surface roughness increased significantly. For the 4%Co materials the surface finish remained almost unchanged for all cutting conditions and both grain sizes. For the larger cobalt percentage the surface roughness presented no important variation for 1.5μm grain size material for both 0.5 and 1.5μm depths of cut, however for the 0.5μm grain size material the surface roughness increased considerably. The results of the grinding process indicate that the grain size and cobalt percentage showed a significant influence on the surface roughness and material removal mechanism.

Ultraprecision Machining, Nanogrinding, Tungsten Carbides

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 [1]. 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 [2]. 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 [3].

Cobalt-bonded WC composites show high fracture toughness, hardness and strength compared to other ceramic materials. As a consequence, great attention has been paid to the evaluation of mechanical properties [4].

Therefore, this paper aims to evaluate the surface characteristics and removal mechanism of tungsten carbide cobalt (WC-Co) materials with different different microstructure (4%Co/0.5μm, 4%Co/1.5μm, 8%Co/0.5μm and 4%Co/1.5μm) in Ultraprecision Grinding using a resin-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 Procedure

Tungsten carbide samples with different microstructure were chosen with a focus on the application of precision glass moulding for optics device. Some characteristics of the tungsten carbides samples selected in this investigation are presents in Table 1.

The tests were conducted using an ASG 2500 Rank Pneumo™ Surface Generator. A V-shaped resin-bonded 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 is shown in Figure 1.

Table 1 Tungsten Carbides Samples Characteristic.

Material	Grain Size (µm)	Co (wt.%)	Hardness (Vickers)
WC-Co	1.5	8	1440
	1.5	4	1650
	0.5	8	1880
	0.5	4	2320

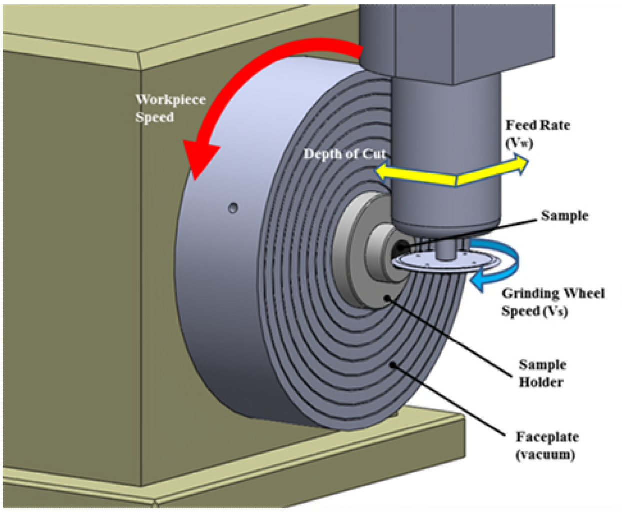

Figure 1. Grinding process of the tungsten carbide samples conducted using an ASG 2500 Rank Pneumo™ Surface Generator.

The grinding process was divided in two steps: stock removal and finishing. Samples were grinded during the stock removal step to obtain a very smooth surface and free of microfractures and microcracks. During the finishing step, all samples were grinded using a feed rate of 0.05mm/min and depths of cut varying from 0.5 up to 1.5µm. In both steps the selected wheel speed was 5000rpm, corresponding approximately to 20m/sec peripheral speed and the workpiece spindle rotation varied so as to keep the speed constant at 0.5m/sec. The surface roughness (arithmetic average value Ra) of the three microstructural tungsten carbides was measured, using a white-light optical interferometer (Wyko™ NT1100). Surface damage was evaluated in a scanning electron microscope (SEM). The grinding process kinematics is shown in Figure 2.

3. Results

The ground surface roughness for the four microstructural carbides was measured using the WYKO optical interferometer and Ra roughness in micrometers is shown in Figures 2 and 3. Figure 2 shows the surface roughness as a function of the grain size. For the larger grain size the surface roughness is finer for all cutting conditions and both cobalt percentages. For the smaller grain size the surface roughness did not vary so much for 4%Co material for both 0.5 and 1.5µm depths of cut, however for the 8%Co material the surface roughness increased significantly.

Figure 3 shows the surface roughness as a function of the cobalt binder percentage. For the 4%Co materials the surface finish remained almost unchanged for all cutting conditions and both grain sizes. For the larger cobalt percentage the surface roughness had no important variation for 1.5µm grain size material for both 0.5 and 1.5µm depths of cut, however for the 0.5µm grain size material the surface roughness increased considerably.

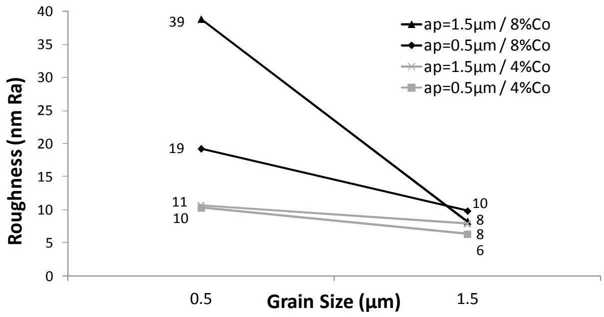

Figure 2. Analysis of the grain size influence upon the surface roughness (Ra) results

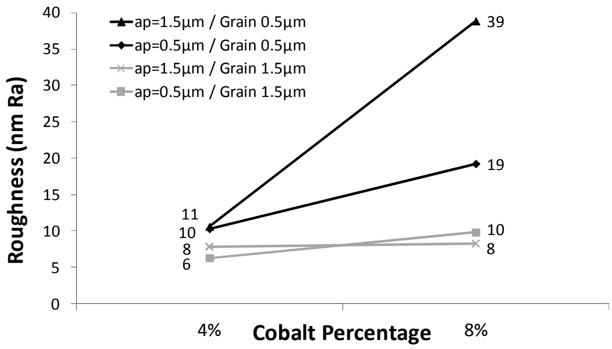

Figure 3. Analysis of the cobalt percentage influence upon the surface roughness (Ra) results.

Scanning Electron Microscope images revealed that the surface roughness is to a great extent associated with removal material mechanism.

4. Conclusion

In the present research work the Influence of different tungsten carbides upon material removal mechanism in ultraprecision grinding has been analyzed. Observing Figures 2 and 3, Tungsten Carbides samples with the larger grain size presented better surface finish results for all cutting conditions and both cobalt percentages compared with smaller grain size samples, and Tungsten Carbides samples with lower cobalt percentage presented better surface finish results for all cutting conditions compared with higher cobalt percentages samples. Therefore, one can conclude that Cobalt binder and grain size both affect the surface quality of diamond ground Tungsten Carbide and that the 1.5µm grain size and 4%Co material is more suitable for diamond grinding in terms of surface finish for the cutting conditions employed. In addition, a statistical analysis of the results using Minitab™ showed that the influence of the grain size of the WC-Co is greater than the cobalt percentage on the surface finish.

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