Effect of cobalt content on the machinability of WC-Co and the subsequent moulding process

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Abstract

In response to the huge demand for precision glass optics in various sizes and shapes from the optical, opto-electronic and photonic industries, many researches have been conducted to improve the production efficiency and to replace the conventional lapping/grinding, polishing routine. Glass moulding process (GMP) is considered as a very effective technique for mass producing high precision optical components such as spherical/aspheric glass lenses and free-form optics. However, only a handful of materials can sustain the chemical reaction, mechanical stress and temperature involved in the glass moulding process and almost all of these mould materials are classified as hard-to-machine materials. This makes the machining of these materials to sub-micrometer form accuracy and nanometer surface finish a rather tough and expensive task. Amongst those handful choices, tungsten carbide (WC) is by far the most commonly used mould material in GMP industry. WC, also known as sintered/cemented WC with cobalt (Co) binder, is a metal matrix composite of WC particles and Co matrix. Cobalt concentration plays an important role in shaping mechanical properties of the obtained WC/Co materials. This research aimed to investigate the effect of Co concentration on the grindability of WC/Co materials. Efforts have been made to correlate grinding parameters such as spindle speed, cut depth and feed to the obtained surfaces. It is found that, despite of higher hardness values, better surface finish can be achieved on WC/Co specimen of lower Co concentration.

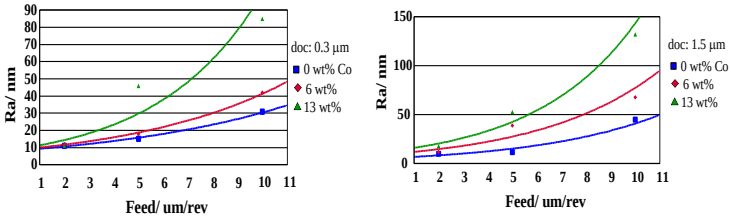
1. Introduction

Driven by the huge market demand, the glass lenses made of various optical glasses are required to be smaller, to possess more diversified shapes, to have better form accuracy and to be more competitive in price. The high level camera lenses for mobile phone and pick-up lens for blue-ray DVD are the typical products out of these ranges. Glass moulding process (GMP) can mass replicate high precision optical components by a set of precision mould inserts [1]. This means that the accurately machined mould inserts is the most critical factor in determining whether a moulding process is economically viable. However, most of these moulds are made of extremely difficult to machine materials such as WC and SiC. Tungsten carbide (WC) is by far the most commonly used mould material in GMP industry. WC, also known as sintered/cemented WC with cobalt (Co) binder, is a metal matrix composite of WC particles and Co matrix. Cobalt concentration plays an important role in shaping mechanical properties of the obtained WC-Co materials. Being in a rather hostile high temperature, high pressure working environment, these expensive mould inserts can easily get deteriorated or be damaged if the interfacial chemical reaction is to be triggered between optical glasses mould materials [2-4]. Cobalt, though can make the make WC-Co material tougher, is notorious for its tendency to diffuse out during the moulding process. The diffused Co can trigger chemical reactions between glass and mould materials an can drastically reduce the service life of the expensive mould inserts. That is why the so-called cobaltless tungsten carbide is frequently used in moulding process. However, in comparison to those with cobalt as binder, the cobaltless tungsten carbide is more brittle and expensive. The price gap is considered to be acceptable when making mould inserts for small lenses. It will make a huge difference when dealing with large moulds such as those to be used for moulding 3D cover glass of mobile phone. This research aimed to investigate the effects of Co concentration on the grindability of WC-Co materials and the subsequent moulding process. Efforts have been made to correlate grinding parameters to the obtained surfaces. Effort was also made to study the effect of different diffusion barrier/anti-stick coating designs. The machined WC/Co mould insert would be useless for glass moulding application if cobalt could not be prevented from diffusing out and interacting with glass during the high temperature moulding process.

2. Machinability

Grinding experiments were performed on a NACHI-ASP01 precision grinding machine. Resin bond diamond grinding wheels of #2000 mesh size and 2.5 mm in diameter were used to grind the tungsten carbide specimens at a work spindle speed of 100 rpm and wheel spindle speed of 40000 rpm. A series of grinding tests of various cut depth and cross-feed were carried out on the WC-Co specimens of 0wt%, 6wt% and 13wt% cobalt concentrations. The depth of cut was kept under the acquired critical cut depth and cross-feed ranged from 2 μm/rev to 10μm/rev. The generated surface was subsequently observed under optical microscope, scanning electronic microscope and laser confocal microscope for surface characteristics and surface finish. In all tested machining conditions, 0wt% Co achieved better surface finish then those of 6wt% Co and 13wt% Co. It is found that at low cross-feed and small cut depth, a big variation in cobalt concentration, say from 0% to 13%, made only a small difference (3~5nm) in the obtained surface roughness (Ra) (Fig. 1(a)). However, when cross-feed is pushed to 10μm/rev, half the variation in cobalt concentrations, say from 6% to 13%, made a big difference (40~80nm) in the obtained surface roughness (Ra) (Fig. 1(a)~Fig. 1(b)).

Thus, both the cut depth and cross-feed have to be kept at a very low level (0.3 μm, 2 μm/rev) if a reasonable surface finish (15nmRa) is to be generated on 13wt% Co specimen. In the cases of 0wt% and 6wt% Co specimens, the outcomes of measured Ra are rather consistent as long as the cross-feed is kept low (2 μm/rev). Amongst all the tested conditions, 0wt% Co specimens offer the most consistent results. The 6wt% Co specimens, on the other hand, can still be regarded as a suitable mould material as long as cut depth and feed are kept low during the grinding process.



(a) (b)

Figure 1. Surface roughness obtained on precision ground WC/Co under various feeds and cut depth of (a) 0.3 μm and (b) 1.5 μm. .

3. Moulding Experiments

Apart from having superb surface finish and precise form accuracy, sufficient chemical resistance at elevated temperature is also part of the basic requirements for mould materials. To minimize the chemical reaction so as to prolong the service life, various protective coatings are designed and plated on the mould inserts. At high temperature, cobalt can diffuse from WC/Co mould to the coating layer and trigger the reaction between glass and protective coatings. A thin layer of Ta was deposited on the WC/Co substrate as the diffusion barrier using a magnetron sputtering system, and followed by the deposition of Pt/Ir film as the protective layer. Twenty layers of Pt/Ir film with individual thicknesses of 5nm were then coated onto Ta film to form a protective film of 200nm total thickness. It is found that under the same testing conditions, the severity of interfacial reaction can be related to the Co% in WC/Co, the higher the Co%, the higher the tendency of severe interfacial reaction.

4. Summary

1. In all tested machining conditions, 0wt% Co achieved better surface finish then those of 6wt% Co and 13wt% Co.
2. Amongst all the tested conditions, 0wt% Co specimens offer the most consistent results. The 6wt% Co specimens, on the other hand, can still be regarded as a suitable mould material as long as cut depth and feed are kept low during the grinding process.
3. It is found that under the same testing conditions, the severity of interfacial reaction can be related to the Co% in WC/Co, the higher the Co%, the higher the tendency of severe interfacial reaction.

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