Diamond Turning of Novel Materials

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Abstract

Novel materials, in particular brittle materials, have been demanded for very fine applications such as precision glass moulding, diffraction optical elements, structural components etc. This paper discuss three different approaches have been used to achieve and understand the ductile response to single point diamond turning of each of the following novel materials: Tungsten carbide, Indium Antimonide and epoxy resin carbon nanotubes composite.

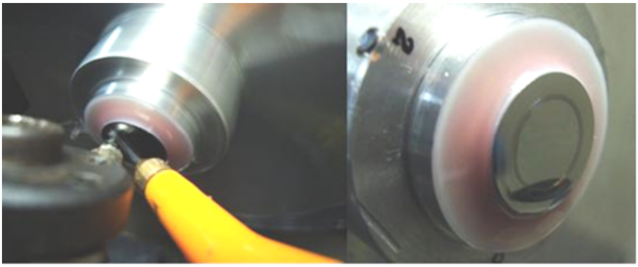
1 Introduction

Brittle materials are primarily machined using abrasive processes, where material removal is accomplished through controlled, near surface fracture. In this case, cracks are formed in the surface which may seriously degrade not only the mechanical strength but also the function, e.g., in the fabrication of optical components. Despite of the machined surface finish could be improved by means of subsequent polishing, the understanding of the material deformation and removal mechanism in such a small scale are important issues in the research of brittle materials machining. The scale of mechanical deformation is extremely small and entails considerable plastic flow. It is interesting to envisage explanations why diamond being so hard and resistant to wear, can be polished and machined by diamond, whereas tool materials harder than the materials to be machined are usually required! A plausible explanation was given in 1999 by Gogotsi and collaborators. They demonstrated, for the first time, by means of Vickers indentation that diamond can be transformed to graphite under nominal compressive stress at the maximum load (load divided by indentation area) slightly below 100 GPa. The indentation experiments indicated that the formation of a 'black layer' when diamond is polished or cut may result from compression-induced graphitization. Once the mechanism is understood, the applied process can more easily be optimized. The application of single point diamond turning to the machining of novel materials generally make use of the current knowledge and theories that have been applied. In the case of very hard materials, to find the proper thickness of cut that will successfully help to achieve a fine surface finish, various parameters should be applied to similar materials during cutting tests. In addition, mechanical properties must be checked out immediately after machining and compared in order to make plausible adjustments to the predicted values. But prediction is not explanation.

Brittle materials are influenced by specimen's size. It is common sense that the larger the deformed volume of a brittle material, the weaker it appears to be. This is attributed to its inverse capacity to store deformation energy before it fractures. However, Kendall in 1978 has proposed, based upon testing polystyrene samples, that since it is inherent to smaller body a reduced energy storage capacity, it consequently requests larger fracture stress. Because of that, for a small body, the amount of fracture stress will be so high that yielding should prevail instead.

1.1 Tungsten Carbide

Tungsten carbide is known as a very hard material and is widely used as a cutting tool material. Recently, tungsten carbide (WC) and silicon carbide (SiC) have received more attention because of the necessity of optical quality moulds for the technology of injection of optical lenses made of materials with attractive mechanical properties, especially high wear resistance [3]. Despite of its high hardness, WC can be machined in a ductile mode. The use of deterministic process to machine this material is a challenge because of the properties that call up our attention for application. Our research on this material's behavior during machining point three important aspects concerning the feasibility of diamond tools to cut it (Fig. 1a). First, the anisotropy of WC since it is a polycrystalline material (Fig. 1b). Second, the chip area adequate to cut in a ductile regime is very small but still promising (sub micrometer cutting conditions). Third, the deleterious damage suffered by the cutting tool may be one of the counterargument to invest in the application of SPDT of this material (Fig.1c).



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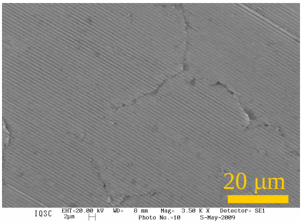

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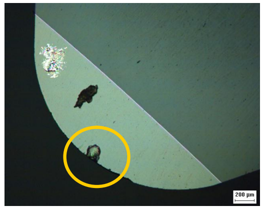


c)

Figure 1. a) Photograph of diamond turned sample WC; b) anisotropy caused by polycrystalline material generated damage within the grain boundaries; c) severe damage is observed on the diamond cutting edge.

1.2 Indium Antimonide

The machinability of a material is currently defined as a relative measure of how easily a material can be machined. The condition and physical properties of a work material may have a direct influence on its machinability. The anomalous plasticity presented by semiconductor crystals is attributed to a structural transformation into a metallic state induced by hydrostatic pressure and stress. Since the plastic response can be considered the main subject in the study of the machinability of normally brittle materials, mechanical properties are the first parameters used to predict the material's plastic behaviour, correlating the experience with metal cutting theory. It is well established that the lower the material hardness the higher the ductile response will be. If this common sense is applied to semiconductor crystals, the material response will not directly correspond to expectation. The use of the phase transformation concept to machine semiconductors crystals with large feeds is proposed. Ductile regime turning is realized at large tool feeds up to some tens of micrometers on indium antimonide which presents lower transition pressure value. This is based on the fact that the ductility of semiconductors crystals during machining is inversely proportional to the transition pressure value. The use of this concept makes it easy to generate microstructures in semiconductor crystals with single point tools (Fig. 2).

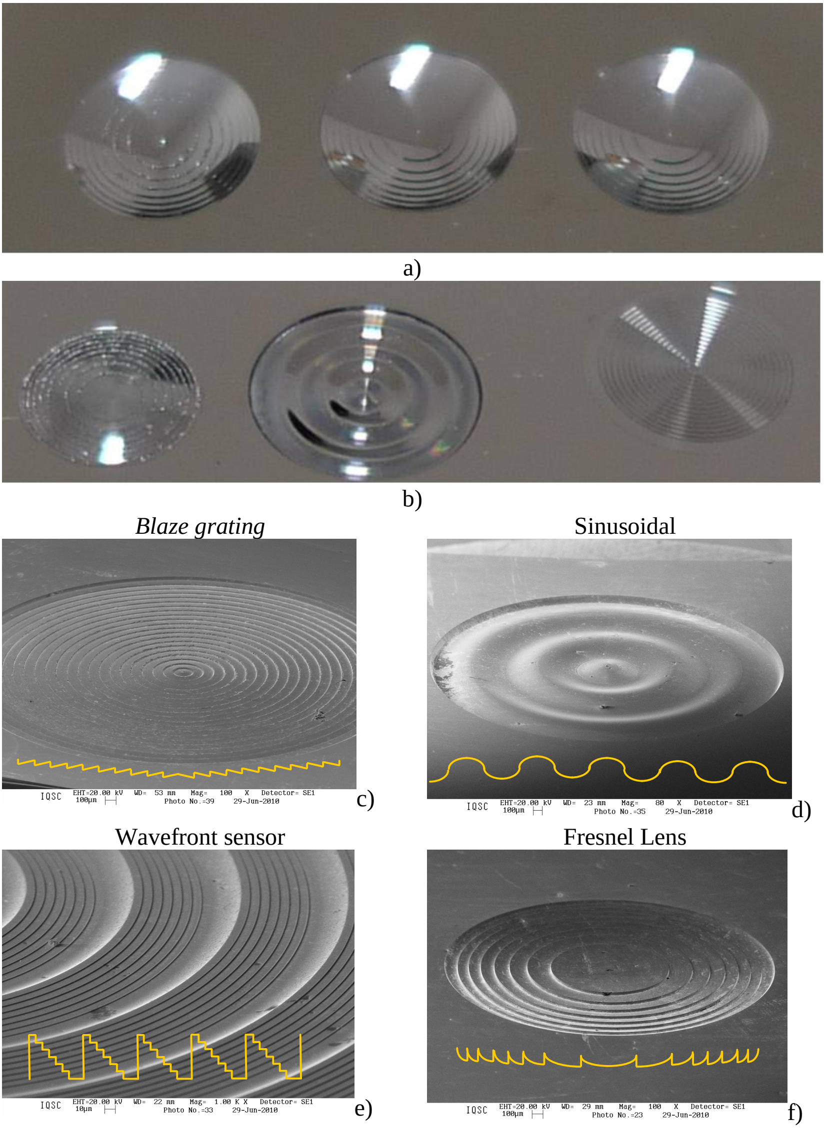
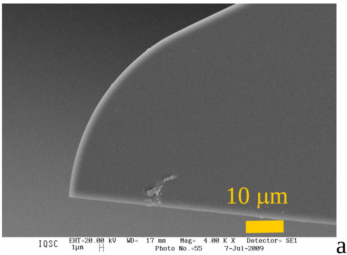
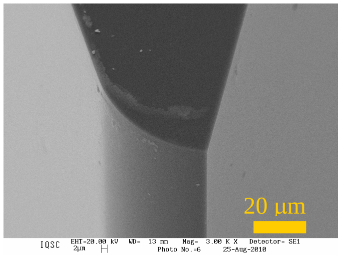


Figure 2. a) Photograph of the Fresnel lens array machined in single crystal InSb, b) Photograph of an array of micro structures – Fresnel, Sinusoidal and wave front sensor.

Figs. 2 (a) and 2 (b) present different samples. Fig. 2 (a) presents a Fresnel plano-concave lens array and Fig. 2(b) an array of lenses machined in InSb, respectively. A closer image of the arrays shown in the former figures are presented in Figs 2 (c) to 2(f) where blaze grating, sinusoidal, wavefront sensor and Fresnel are the microstructures machined on InSb single crystal. Important information about machining this III-V semiconductor crystal is that it did not presented any harm or damage to the cutting edge as can be observed in Fig. 3. No sign of wear was observed in the cutting edge 3b).



a)



b)

Figure 3. SEM view of the cutting edge of the diamond tool used a) Before machining and; b) after machining.

1.3 Carbon Nanotube composites

In terms of manufacturing engineering it is important to have materials such as CNT epoxy resin composites which present very high strength-to-weight and modulus-to-weight ratios [5]. It is worth mentioning that many product applications for this new material will involve the rapidly expanding area of miniaturization technologies owing to the extraordinary properties that can be achieved. In addition, to thoroughly understand the implications of the presence of CNTs on the machinability of the composite material, a reduced deformed area is desirable to enhance the sensitivity of the process to factors such as CNT density, their orientation/alignment and associated impacts on cutting parameters [6]. Given the nanoscale of CNT reinforcements, it is important to choose the appropriate scale of machining to study the machinability of these composites. The use of diamond turning is considered a feasible option since it is a material removal processes at the micro-/meso scale. The application of the interrupted cutting test procedure showed the uncut shoulder presented damage (Fig.4a), the chip was ribbon like. No sign of wear was detected on the cutting edge of the diamond tool used in the tests (Fig. 4b).

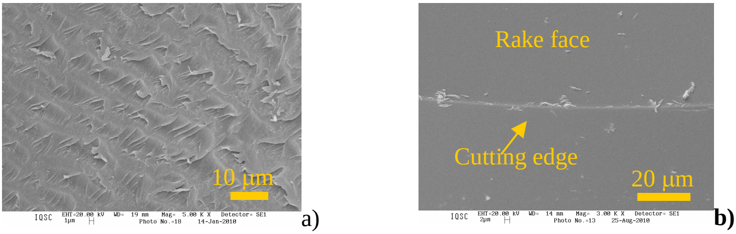


Figure 4. a) Uncut shoulder b) cutting edge after machining tests.

In summary, we have proposed that the machining of novel materials have to be investigated based upon different approaches. Fresnel lenses as well as array of small lenses can be machined on III-V semiconductor crystal based upon the fact that material with very low phase transition pressure value presents high ductility during machining. For Tungsten carbide, it was observed that ductile material removal is achievable since very small cutting conditions are applied and the disadvantage is the deleterious and rapid wear of the diamond tool cutting edge. Epoxy resin impregnated by CNT still lacks a good explanation to clear the mechanism involved during machining. A good news is that no sign of wear or fracture damage was detected on the tool edge.

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