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DIAMOND AND RELATED MATERIALS

Nanoscale grinding of ceramics using diamond fibres

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Abstract

Diamond fibres have been manufactured by CVD on to W wires. The fibers were used to grind optical glass and alumina. The surfaces were studied using Talysurf, SEM, and atomic force microscopy. Nanoscale surface roughness values have been obtained and ductile grinding was produced on glass. The results suggest that the shallow depth of cut produced by the surface diamond facets will lead to reduced surface damage, and the high density of cutting sites will allow high rates of material removal. © 1997 Elsevier Science S.A.

Keywords: CVD; Diamond; Fibres; Machining

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1. Introduction

Diamond is the hardest known material (~ 113 GN m^{-2}), and synthetic high pressure high-temperature synthesised diamond particle grits are widely used in superabrasive grinding wheels [1]. Studies of diamond grit grinding of brittle ceramics [2] have shown that very small depths of cut can lead to a significant reduction in the severity of surface cracking. Using specially designed high-stiffness machines, a precision tool feed and single-point diamond cutters, glass has been machined under ductile crack-free conditions [3]. CVD diamond produced by chemical vapour deposition possesses many of the physical and mechanical properties of natural diamond, and CVD diamond fibres have been manufactured by deposition on to tungsten wire [4]. Ductile grinding of ceramics has been carried out using these diamond fibres. The topography of ground surfaces on glass and alumina is described in this paper.

2. Experimental technique

Diamond fibres ~ 100 μm diameter (Fig. 1) were produced by CVD of diamond films ~ 25–40 μm thick on to 25-μm diameter tungsten wire in a hot filament reactor, as described elsewhere [4]. In the diamond film the long columnar grains oriented in the radial direction around the fibre axis led to crystal facets with edges and points on the cylindrical surface of the fibre (Fig. 1). With a diamond grain diameter at the surface of ~ 5 μm, the number of edges and points on the fibre surface was about 10^4 mm^{-2}. Grinding was carried out using the surfaces of single fibres of length $L_F = 1$ or 5 mm as shown in Fig. 2. A fibre was embedded in resin to a depth of about the half the fibre diameter and attached to a balanced arm in contact with a glass disc rotating at 25 rpm. In a simple pin-on-disc machine. A weight placed on the arm applied a normal force of ~ 2 N. The test samples for various glasses and alumina were ~ 50-mm diameter discs and the wear track radius dictated the surface speed of ~ 0.05 m s^{-1}. All grinding was carried out in air without lubricant.

The fibre axis was oriented normal to the grinding direction. Under low loads and small depths of cut, typical of ductile grinding conditions, only the highest diamond facets initially made contact with the glass. The track was composed of individual grooves made by the highest diamond facets. With increasing number of revolutions or load, the depth of cut increased and more facets made contact with the surface. Eventually the grooves covered the whole width of the track and the track width equalled the fibre length (Fig. 2).

The ground surface was characterised by optical and

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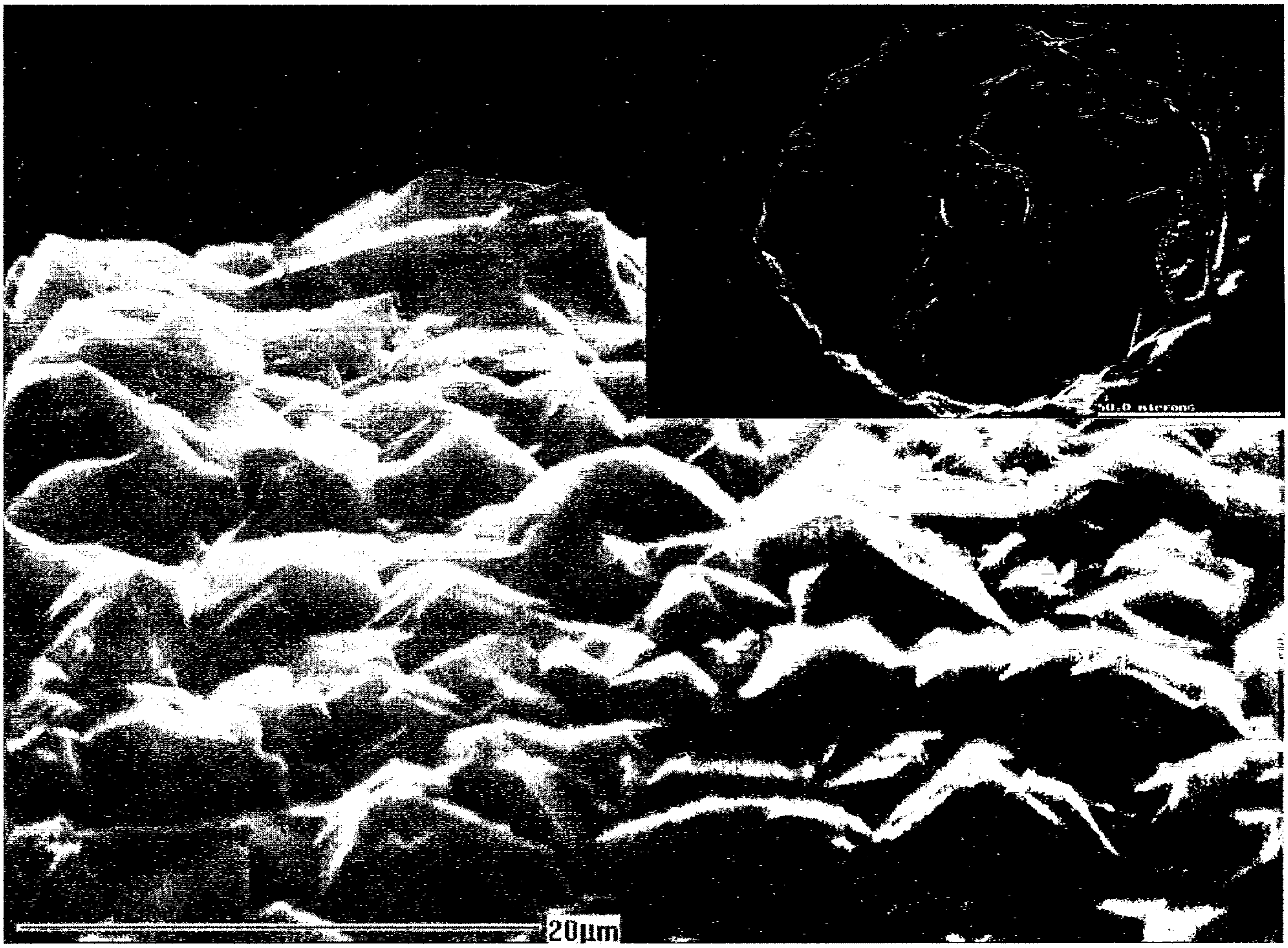

Fig. 1. CVD diamond fibre cross-section (insert) showing W-wire core (scale bar marker = 50 µm) and a magnification of the facets on the fibre surface.

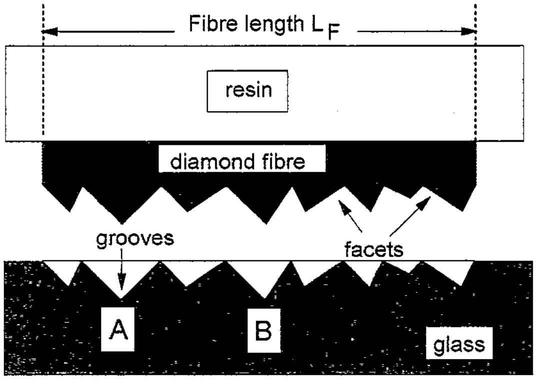

Fig. 2. Schematic of mounted diamond fibre aligned parallel to the ceramic surface and showing grooves grooves cut by facets.

scanning electron microscopy (SEM), and atomic force microscopy (AFM). The diamond fibres were examined before and after grinding by SEM and Raman spectroscopy.

3. Results

3.1. Glass surface

Grooves in a ductile ground optical glass surface are shown in Fig. 3. AFM surface profiles showed the groove depths to be <100 nm [5]. No cracks were visible either below or at the surface of these grooves. Material appeared to be removed from the grooves by plastic flow of the glass, which led to the formation of glass ribbons adjacent to the grooves with dimensions of about 1.4 µm wide and 0.3 µm thick, as shown schematically in Fig. 4. Some ribbons remained attached to the surface, but others fractured along the edge of the groove to form long filamentary glass debris. Evidence of residual stresses in the ribbons was provided by the complex shapes of the filaments. Examples of helical filament fragments and of a single filament many millimetres long, are shown in Fig. 3. Multiple grinding passes led to fragmentation of the filaments and more

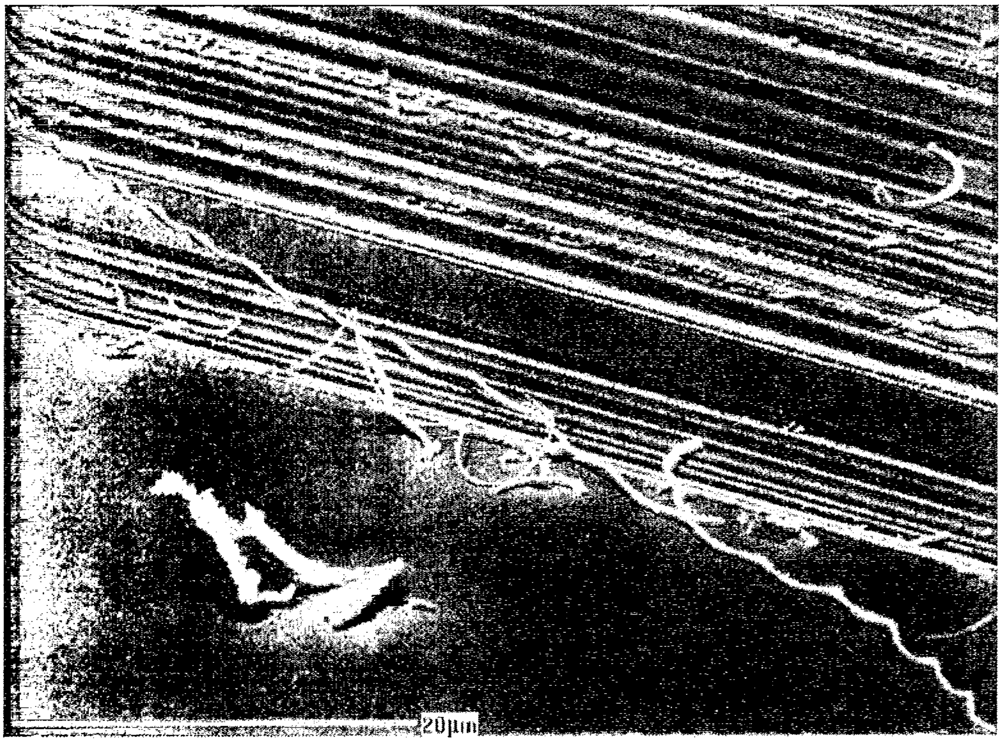

Fig. 3. Grooves cut in an optical glass surface and helical glass filaments.

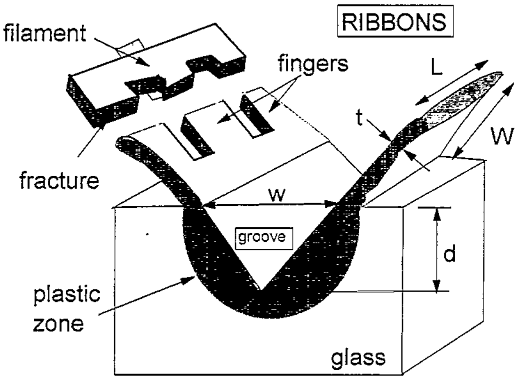

Fig. 4. Schematic of groove formation by ductile flow of glass to produce ribbons adjacent to the groove which fractures to produce filamentary debris.

equiaxed debris and a surface roughness $R_a = 28$ nm. Filamentary debris is characteristic of single point diamond precision machining of glass [3].

3.2. Alumina surface

A ground track on a porous alumina surface produced by a fibre with $L = 1$ mm under a 200-g load is shown in Fig. 5(a) after 1000 revolutions. Surface roughness values of $R_a < 30$ nm were obtained in pore free areas in Fig. 5(b). The porosity led to repeated impact of the grinding facets with the edge of the pores, but only occasional chipping of the facets and little change in the shape of the facets was observed after thousands of revolutions of the glass and alumina samples.

The surface of non-porous recrystallised alumina before and after one grinding revolution is shown in Fig. 6. Initially the grains were a few microns above and below the surface and this caused the grinding track to be discontinuous. In Fig. 6(b) is shown an example of an 8-μm wide ground track in which in which the grooves intersected a region where some grains, protruding above the surface, had been "knocked" out after intergranular fracture. There was no evidence of cracks below the smooth ground faces of the grooves. A very fine equiaxed powder debris <300 nm diameter eventually filled the spaces between the facets and prevented grinding without a lubricant.

4. Discussion and conclusions

The shallow depths of cut indicated by the roughness values for the ground surfaces of $R_a < 100$ nm and nanoscale debris are consistent with crack-free machining and low depths of surface residual stress. The high density of cutting facets is expected to lead to a high rate of material removal R in spite of the shallow depth of cut, with estimates of R for multiple fibres [5] at the top end of the rate range reported [2] for micro grinding of 10^{-4} to 10^{-1} mm^2 s^{-1}.

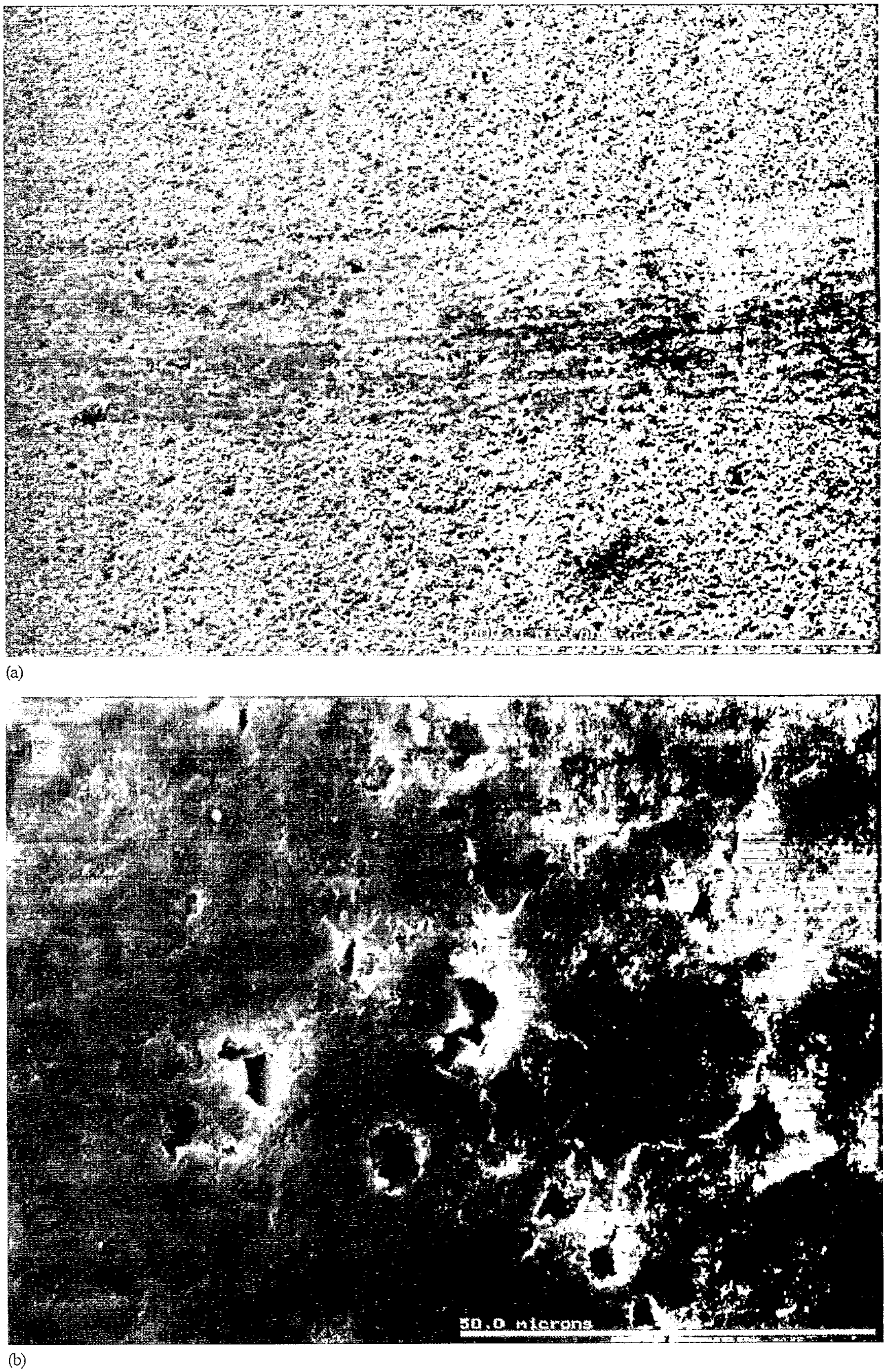

Fig. 5. Sintered porous alumina surface. (a) Ground track; (b) smooth areas between pores, $Z_{rms} < 30$ nm.

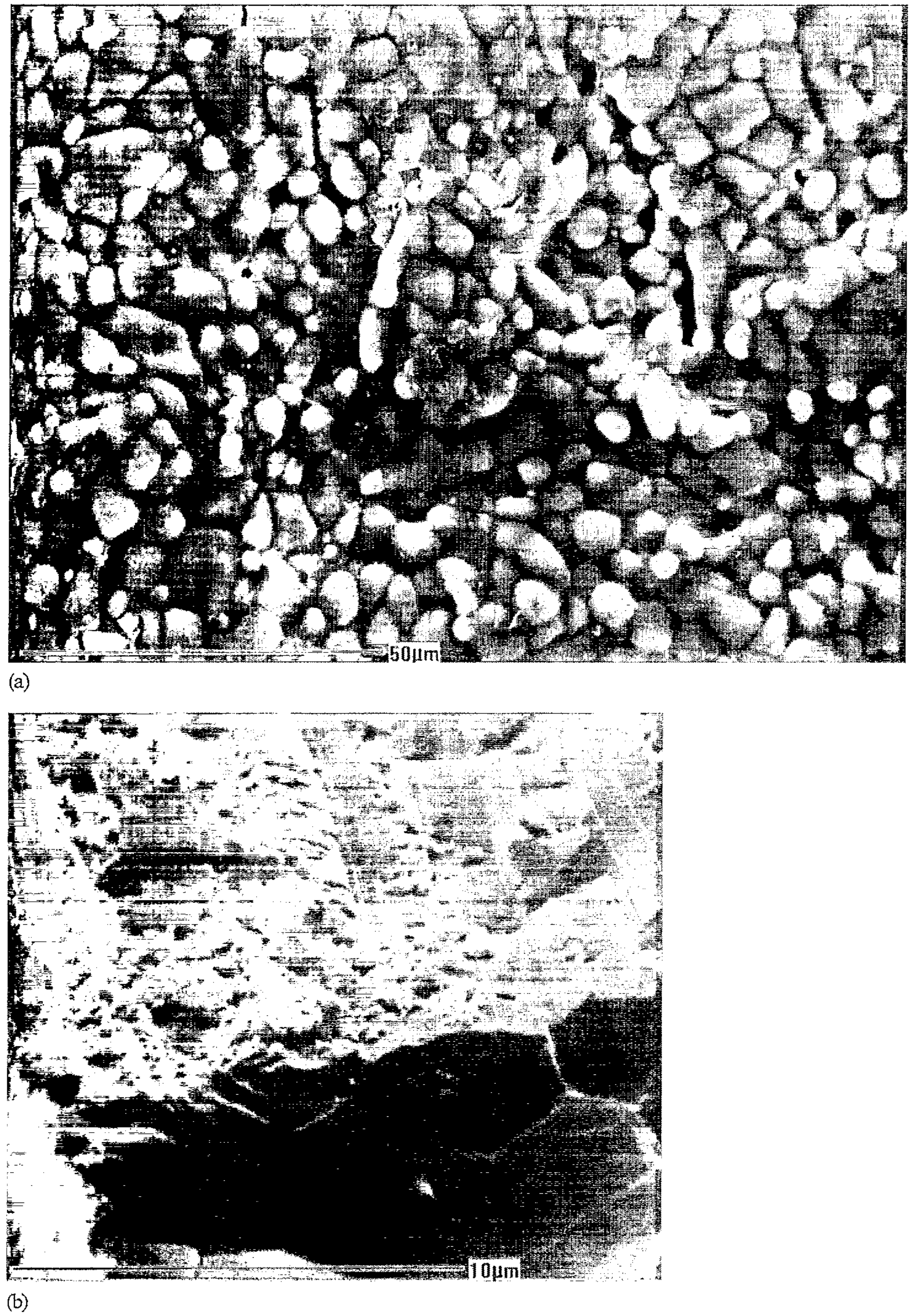

Fig. 6. Non-porous recrystallised alumina surface (a) before, and (b) after grinding.

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