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A Preliminary Study of Subsurface Damage in Grinding of Reaction-bonded SiC

Sai Guo[1,2,#], Chi Fai Cheung[1], Lai Ting Ho[1] and Bi Zhang[2]

1 State Key Laboratory of Ultraprecision Machining Technology, Department of Industrial and Systems Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong, China
2 Department of Mechanical and Energy Engineering, Southern University of Science and Technology, Shenzhen, 518055, China
Corresponding Author / Email: saihk.guo@connect.polyu.hk

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Poor surface integrity is usually induced in conventional machining of reaction-bonded SiC (RB-SiC) due to its extremely high hardness and low fracture toughness. With the increasing demand for a high degree of accuracy and high-resolution optical systems, there are growing demands for high surface integrity of machined RB-SiC components. Although extensive studies have investigated the surface generation and surface morphology in ultra-precision grinding (UPG) of RB-SiC, few of them focus on the alteration of workpiece subsurface damage (SSD) during grinding at various conditions. In this study, UPG and conventional surface grinding (SG) of RB-SiC were carried out to investigate the variation of workpiece surface integrity. The results reveal that the surfaces ground in UPG and SG are both characterized with typical brittle fracture features such as grinding scratches and surface pits. The SSD generated in different grinding conditions is revealed with the similar results that the major SSD features are laterally spread cracks which are mostly confined in the superficial layer below the ground surfaces. This preliminary study on SSD of RB-SiC workpieces ground in various conditions deepens the understanding of SSD features and spatial distribution below the ground surface.

1. Introduction

Reaction-bonded silicon carbide (RB-SiC) ceramic has become the preferred mirror material for space telescopes due to its excellent mechanical properties, such as excellent thermal shock resistance, structural stability and chemical inertness [1] [2]. However, RB-SiC is difficult to grind due to its extremely high hardness and low fracture toughness [3].

Ultra-precision grinding (UPG) is widely used to machine hard and brittle materials with low surface roughness and high surface integrity [4]. Surface integrity of a component is a crucial indicator to evaluate the grinding performance, which results from the interaction of the grinding wheel and the workpiece. A high-quality surface significantly improves the functional performance of components, such as fatigue strength, frictional properties and service life [5]. In recent years, with the increasing demand for a high degree of accuracy and high-resolution optical systems, there are growing demands for high surface integrity of machined RB-SiC components.

Although extensive studies have investigated the surface generation and surface morphology in UPG of RB-SiC, few of them focus on the alteration of workpiece subsurface damage (SSD) during grinding at various conditions. In this study, UPG and conventional surface grinding (SG) of RB-SiC were carried out to investigate the variation of workpiece surface integrity. This preliminary study on SSD of RB-SiC workpieces ground in various conditions deepens the understanding of SSD features and spatial distribution below the ground surface.

2. Experimental Details

In this study, UPG and SG were performed on RB-SiC (Goodfellow Cambridge Ltd., UK) using an ultra-precision grinding machine (Moore Nanotech 450UPL) and a hybrid grinding machine (Hardinge Quest GT27, USA), respectively. The grinding parameters for UPG and SG are listed in Table 1. After grinding, surface morphology was examined using a scanning electron microscope (SEM, Merlin, Zeiss, Germany) and a white light interferometer (Taylor Hobson Talysurf CCI, USA), while the SSD below the ground surface was revealed using the focused ion beam (FIB, Helios Nanolab 600i, FEI, USA) milling technique as shown in Fig.1.

In addition, three arbitrary spots on the ground surfaces were selected to expose the cross-sections using the FIB for achieving a high reliability of the experimental results. For surface morphology and SSD observations, representative figures were adopted to compare the differences subjected to different grinding conditions.

Table 1. Detailed parameters for UPG and SG

Item	UPG	SG
Grinding wheel	Resin-bonded diamond wheel Φ 20 mm, # 325	Vitrified CBN wheel Φ 118 mm, # 120
Depth of grinding a_p (μm)	5	5
Axial feed rate v_f (mm/min)	2	100
Workpiece speed n_w (rpm)	100	1000
Wheel speed n_s (rpm)	30,000	10,000
Linear speed v_g (m/s)	31.4	30.4
Cooling method	Minimal quantity lubrication	Flood cooling

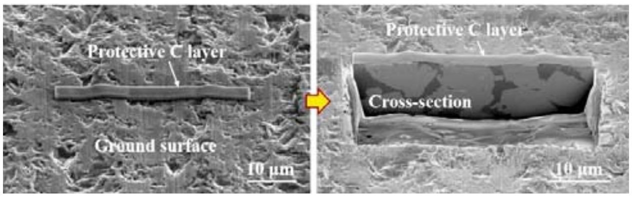

Fig. 1 The FIB milling processes indicating the location of the cross-section milled by the FIB and SSD in the cross-section observed via ion beam imaging

3 Results and discussion

3.1 Surface morphology

As show in Fig. 2, the workpieces subjected to UPG and SG present distinct surface defects including grinding scratches and surface pits, as a result of brittle fracture. The corresponding surface roughness parameters Sq (root mean square height) and Sa (arithmetical mean height) show no significant differences except that large Sz (maximum height) value is induced in the surface after SG compared to UPG.

3.2 SSD

As shown in Fig. 3 and Fig. 4, the cross-sections of the workpieces after UPG and SG are revealed with the similar results that the major SSD features are laterally spread cracks which are mostly confined in the superficial layer below the ground surfaces where the maximal depths of SSD in UPG and SG are ~ 1 μm and ~ 3 μm due to the specific grinding methods. It can be found that the cross-sections below the ground surfaces are revealed with high integrity without significant cracks propagating into the depth bulk material.

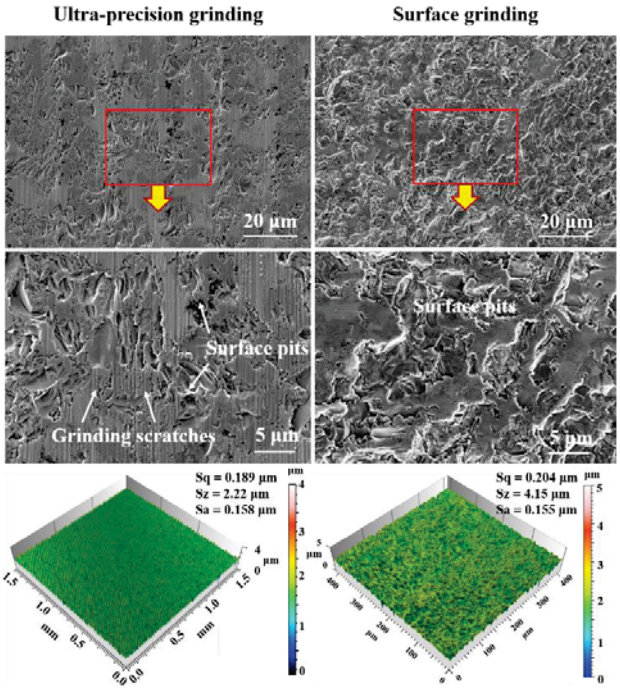

Fig. 2 Comparison of surface morphology and surface roughness after UPG and SG

Comparing the surface morphology and SSD of RB-SiC after ground in various conditions, the results indicate that although brittle fracture governs the RB-SiC material removal process, high subsurface quality is preserved since cracks and surface pits are mostly concentrated in the surface and the superficial layer below the ground surfaces.

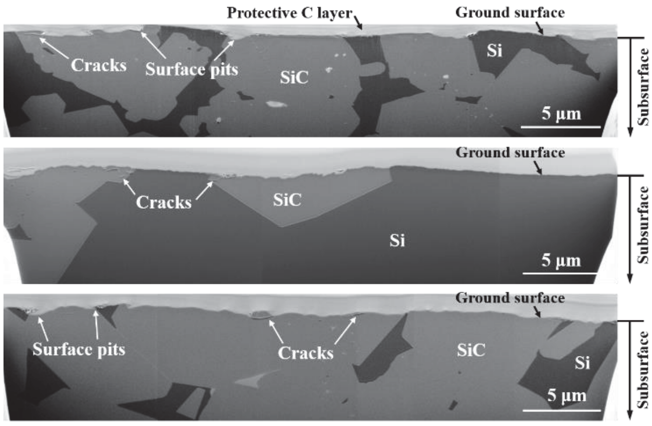

Fig. 3 Three representative spots indicating the features of SSD after UPG.

4 Conclusions

In this study, UPG and SG of RB-SiC are carried out to investigate the variation of workpiece surface integrity. The results reveal that the surfaces ground in UPG and SG are both characterized with typical brittle fracture features such as grinding scratches and surface pits. The SSD generated in different grinding conditions is revealed with the similar results that the major SSD features are laterally spread cracks which are mostly confined in the superficial layer below the ground surfaces. This preliminary study on SSD of RB-SiC workpieces ground in various conditions deepens the understanding of SSD features and spatial distribution below the ground surface.

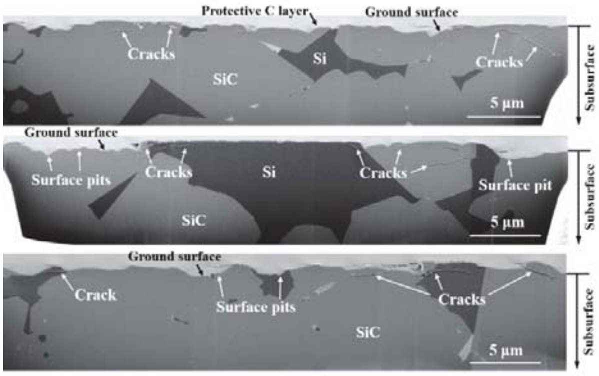

Fig. 4 Three representative spots indicating the features of SSD after SG.

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