Ultrasonic vibration assisted polishing of micro-structured surfaces on SiC ceramics

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Abstract

In consideration of increasing the MRR and improving the micro-structured surface quality, ultrasonic vibration assisted polishing (UVAP) of micro-structured surfaces on SiC is proposed in this paper. The experimental results shown that when compared with conventional polishing, the MRR can be improved from 34.67 nm · min^{-1} to 44.28 nm · min^{-1} in depth. Meanwhile, the polished surface roughness of micro-structures is improved to 16.5nm (Ra) by a factor of 2 over the conventionally abrasive polished (AP) surface. In addition, there are no subsurface cracks can be found in the UVAP SiC micro-structures.

1. Introduction

To meet the need of mass production of high quality micro-structured optical elements, precision glass moulding with micro-structured moulds gives a promising alternative. However, high quality micro-structured surface on these moulds are quite difficult to obtain directly by ultraprecision grinding attribute to their superb material property in terms of high hardness, high brittleness and high strength, especially of silicon carbide (SiC)[1,2]. Therefore, these ground micro-structured moulds have to be finished by subsequent AP. In this paper the ultrasonic vibration was introduced to assist AP aiming to increase the polishing efficiency and improve the surface quality. The material removal depth was on position determined by a laser displacement measurement system indicating the ultrasonic vibration assisted polishing is able to generate higher MRR. Furthermore, the surface roughness was evaluated by a contact probe profilometer, and the surface morphology was assessed by a scanning electron microscopy (SEM) illustrating that the feed marks (micro-grooves) on the AP micro-structured surface were significantly reduced through ultrasonic vibration assisted polishing. In addition, soft layer of silica oxide was detected by a X-ray diffractometer (XRD) indicating that chemical reaction occurred in between SiC and cerium oxide abrasive.

2. Experimental set-up of UVAP

The experiments were performed on the same ultraprecision grinder after grinding in order to avoid re-positioning error of workpiece. As shown in Fig.1, the SiC workpiece is fixed on the ultrasonic vibration table with the vibration direction along the parallel direction of the micro-structure. The force transducer (Kistler 9256A1) is installed beneath the vibration table to measure the polishing forces, while the laser displacement sensor is fixed above the workpiece to measure the MRR under AP and UVAP with the experimental parameters given in table 1. In this paper the MRR is defined as the material removal depth per unit time in nm · min^{-1}. As shown in Fig. 2, the original height and the height after UVAP of the micro-structure are represented by CD and AB line respectively. When workpiece moved at a certain speed along the direction of the micro groove, the laser spot scans across the whole micro groove. The difference in height between CD and AB divided by polishing time is MRR.

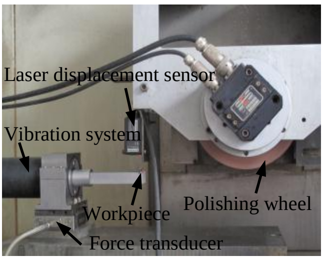


Fig. 1 The experimental set-up

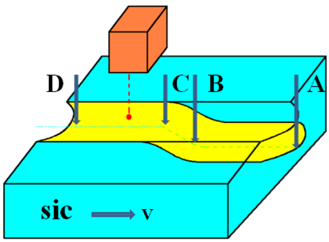


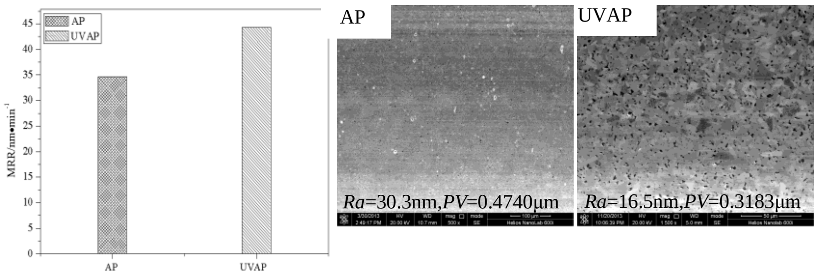
Fig. 2 The measurement principle of MRR

Table 1: experimental parameters of UVAP

Designed structure profile/mm	Width 0.8, Depth 0.09, Radius 1.0
Polishing liquid	Cerium oxide (grain size: 100nm)
Vertical polishing force *F*/N	0.5
Polishing time *t*/min	35
Wheel rotational speed *n*/rpm	50
Workpiece feed speed *v*/mm · min^{-1}	25
Vibration amplitude *A*/μm	2.0
Vibration frequency *f*/kHz	25

3. Experimental results and discussions

The MRR and surface topography of the micro-structured surface generated by AP and UVAP are shown in Fig. 3 a) and Fig. 3 b) respectively. The MRR increases from 34.67 nm · min^{-1} by AP to 44.28 nm · min^{-1} by UVAP indicating a higher MRR could be obtained through UVAP. The surface roughness finished by AP decreases to 30.3nm from 121.6nm finished by grinding, while it could be improved to 16.5nm by introducing ultrasonic vibration assistance under the identical polishing parameters with AP. Furthermore, AP generates a profile accuracy of the cylindrical groove of 0.4740μm while through UVAP the profile accuracy can be improved to 0.3183μm. According to the SEM images shown in Fig. 3 b), the better surface quality can be generated through UVAP than AP featuring the diminished scratches and grinding marks, owning to the different kinematics in between.



a) MRR b) Surface morphology scanned by SEM

Fig. 3 Comparison of MRR and surface morphology under AP and UVAP

After the UVAP experiment, the chemical compound on the micro-structured surfaces were detected by X-ray diffractometer (XRD), as shown in Fig. 4. The soft layer of silica oxide was generated during UVAP meaning the chemical reaction occurred between SiC and cerium oxide polishing liquid. Therefore the material removal process could be explained as the continuous formation and removing of the oxide layer with a relative lower hardness than SiC. The further research task will be extended to know whether the chemical reaction can be accelerated by UVAP over AP or not, resulting in a higher MRR and a higher surface quality via assisted ultrasonic vibration. In addition, the cross-section of the UVAP generated micro-structure was fabricated by ion beam polishing and then scanned by SEM, as shown in Fig. 5, there are no cracks generated in subsurface.

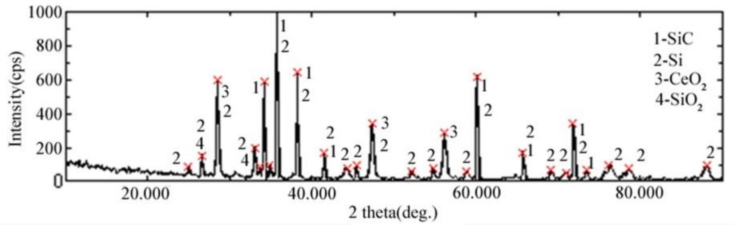


Fig. 4 XRD pattern of the micro-structure

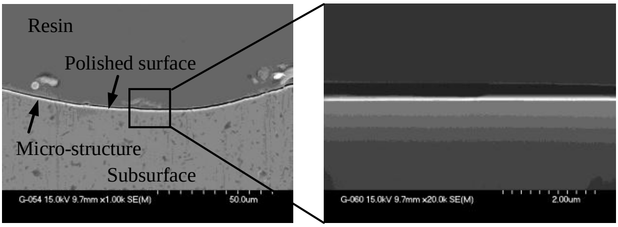


Fig. 5 The subsurface status via SEM

4. Conclusion

Experimental results show that when compared with the conventional abrasive polishing, the application of ultrasonic vibration can effectively increase the material removal rate and improve the surface quality as well as a crack free subsurface. It is proved that, the UVAP is an applicable and feasible technology for machining the micro-structures made of hard-brittle ceramic materials typically represented by SiC, in terms of higher efficiency and improved accuracy.

Acknowledgement

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