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Material removal mechanism in ultrasonic vibration assisted polishing of micro cylindrical surface on SiC

Qingliang Zhao, Zhiyuan Sun, Bing Guo*

Center of Precision Engineering, School of Mechatronics Engineering, Harbin Institute of Technology, P.O. Box 413, Harbin 150001, China

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ABSTRACT

In consideration of the high hardness of the mold insert material SiC, ultrasonic vibration was introduced in the abrasive polishing (AP) of the linear micro cylindrical surface aiming to enhance the surface quality while improving the machining efficiency. However, the interaction behavior in between the material and polishing tool under ultrasonic vibration has not been studied so far. In this paper, the material removal mechanism of ultrasonic vibration assisted polishing (UVAP) on micro cylindrical SiC surface was investigated to fulfill a fundamental understanding of this process in comparison to the conventional polishing without employing ultrasonic vibration. The collection method of high frequency friction forces was firstly proposed to analyze the friction behavior on the SiC cylindrical surface. Then the relationship between ultrasonic vibration, friction force and micro cylindrical surface quality was studied respectively. The experimental results indicated that when the ultrasonic vibration was applied, the friction force decreased accordingly corresponding to a better surface quality. In addition, the lubrication condition was discussed in UVAP process based on the establishment of the stribeck curve. Furthermore, the wear coefficients were calculated through measuring the material removal depth, the surface morphologies were measured by a scanning electron microscopy in revealing the different material removal modes under various different polishing parameters. Through computation and analysis, it shows that the lower polishing force and relative lower speed as well as the higher vibration frequency and amplitude could result in a lower surface roughness and less polishing marks of micro cylindrical surface on SiC. Finally, the cylindrical arrays were successfully polished with the optimized parameters on precision diamond ground SiC surfaces.

1. Introduction

In recent years, owing to their superb optical performance, micro-structured optical components are widely used in micro electronic and communication products, biomedical, automotive lighting, etc. In order to meet a large demand for micro-structured optical glass components, precision glass molding with micro-structured mold inserts, such as silicon carbide (SiC), gives a promising alternative batch production solution. However, high quality micro-structured surface on these sorts molds are quite difficult to be fabricated directly by ultraprecision grinding attribute to their unique mechanical property in terms of high hardness, high brittleness and high strength, especially for silicon carbide (SiC) [1–3]. Therefore, these ground micro-structured surface of SiC molds have to be finished through subsequent polishing.

In the previous research, the laboratory for precision machining (LFM) of university of Bremen has researched the process chain for manufacturing the micro-structured optical function surface of the mold inserts. In this process chain, precision abrasive polishing experiments was carried out on the ground linear cylindrical arrays of WC, the ground linear V-groove arrays of steel x40 Cr13 as well as the electroless nickel plated steel respectively to reach the standard of optical surface [4,5]. Suzuki et al. introduced the ultrasonic vibration into the abrasive polishing of the WC micro aspheric lens. The efficiency of the ultrasonic vibration has been proved in terms of the improved surface quality and the increased material removal rate of WC with high hardness [6–9]. Yin et al. machined the macro cylindrical surface on C3601 brass by vibration assisted paper finishing. The increment of material removal rate was calculated through kinematics analysis [10,11]. In authors' group the ultrasonic vibration was also applied for the assistance of polishing the linear cylindrical surfaces on SiC in our previous research works [12]. However, these research works mainly focused on the polishing process implementation, such as the effect

* Corresponding author.
E-mail addresses: zhaoqingliang@hit.edu.cn (Q. Zhao), zhiyuanszy@163.com (Z. Sun), guobing@hit.edu.cn (B. Guo).

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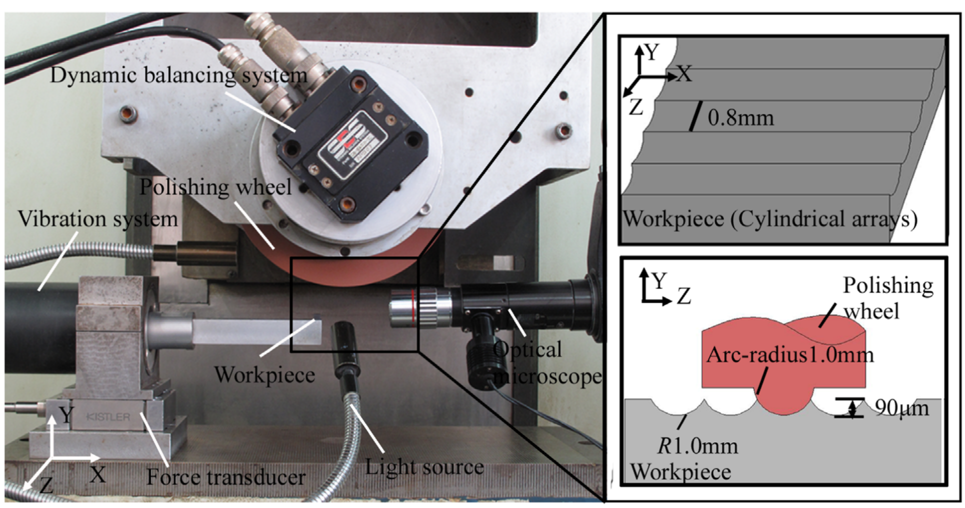
of polishing parameters on the surface quality and material removal rate, while the material removal mechanism of micro-structures on SiC has not yet been investigated either in friction behavior or in wear mechanism. Different friction forces correspond to different surface qualities, especially the friction coefficient shall be a key factor in determining the polishing process and thereafter the modification of surface layer [13–15]. Moreover, the polishing abrasive grains' behavior in between the micro cylindrical surface and the polishing wheel determines the main wear mechanism (resulting in different surface morphologies) of the micro-structure on SiC. Therefore, it is necessary to investigate the effect of polishing parameters (polishing force, polishing speed, ultrasonic vibration frequency and amplitude) on the material removal mechanism of UVAP, then to be capable of optimizing the polishing process in obtaining the controllable micro cylindrical surface on SiC.

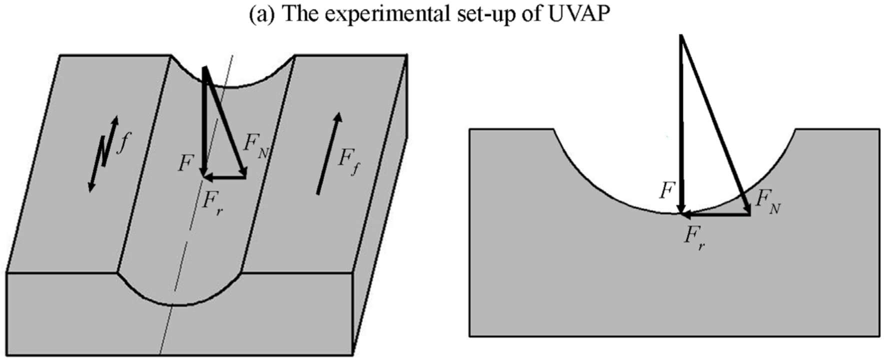
In realizing this, the friction forces and surface qualities correspond to AP and UVAP were compared under identical polishing parameters while the change of the lubrication condition was evaluated by calculating the friction coefficients. The soft layer of silica oxide detected by a X-ray diffractometer (XRD) indicates that the chemical reaction occurred in between SiC and alkaline cerium oxide abrasive. In addition, the wear coefficients were calculated through the measured material removal depth under different polishing parameters to reveal the grains' behavior during the polishing process of the micro cylindrical surface on SiC. Through analyzing the correspondence between the wear coefficient and the surface morphology measured by a scanning electron microscopy (SEM) in AP and UVAP respectively, the effect of processing parameters and ultrasonic vibration parameters on the material removal mechanism was investigated.

2. The experimental set-up of UVAP

The polishing experiments were performed on the same precision grinder (MUGK7120 × 5 horizontal spindle surface grinder) as after the grinding process in order to avoid re-positioning error of the workpiece. As shown in Fig. 1(a), the workpiece was fixed on the ultrasonic vibration platform with bonding glue, a force transducer (Kistler 9256C) was installed beneath the workpiece to measure the three dimensional forces acting on the micro structured surfaces. The vertical polishing force can be controlled by adjusting the coordinate position of the vertical axis (Y axis) of the precision grinder. During the polishing process, the polishing wheel is pressed onto the cylindrical groove with a vertical polishing force F, which will cause two components in terms of normal force F_N and axial force F_r due to the arc-shaped interaction surface. When the polishing wheel moves parallel to the groove direction, the tangential force also termed as friction force F_f will be accordingly produced on the arc interaction surface, as shown in Fig. 1(b). All of the above mentioned vertical force F, axial force F_r and the friction force F_f (tangential force) could be measured by the force transducer. The direction of ultrasonic vibration is parallel to the workpiece feed direction. The relative position of the polishing wheel and cylindrical groove can be observed by an optical microscope.



(a) The experimental set-up of UVAP



(b) Interaction force on the micro cylindrical surface

Fig. 1. The experimental set-up of UVAP.