Polishing fused silica glass by incorporating ultrasonic vibration into fixed abrasive polishers

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Abstract

We applied ultrasonic vibration to a recently developed fixed abrasive polisher intended for optical glass polishing. The preliminary experiments, all of which were under the conditions without aqueous addition or polishing fluid, exhibit that the material removal rate can be increased up to >50% upon the introduction of ultrasonic vibration.

1 Introduction

It is well know that grinding/cutting performance, i.e. material removal rate and/or surface quality of machined workpiece, can be improved by introducing ultrasonic vibration into manufacturing processes. Thus we transferred the fundamental concept to fixed abrasive polishing in the hope of achieving analogous results to those in ultrasonic vibration assisted grinding. Then ultrasonic vibration assisted chemo-mechanical fixed abrasive polishing (hereafter named UV-CMFAP) was propsoed in an attempt to further boost the material removal rate and hence to reduce the processing time to fabricate an optical component [1]. It is referred to as chemo-mechanical machining because the glass material is removed due to the synergy of chemical and mechanical actions. The hardness of abrasive CeO_2 in fixed abrasive polishing is comparable to fused silica [2]; therefore, it is unlikely to remove the fused silica material purely mechanically. The chemical effect makes all the difference for the fixed abrasive polishing [3]. We evaluated the performance of UV-CMFAP in terms of surface roughness and material removal rate (MRR) in this article. We found that the MRR in UV-CMFAP can be increased considerably while the surface roughness is not deteriorated appreciably. The experiments and corresponding results will be detailed in the following parts.

2 Experimetnal

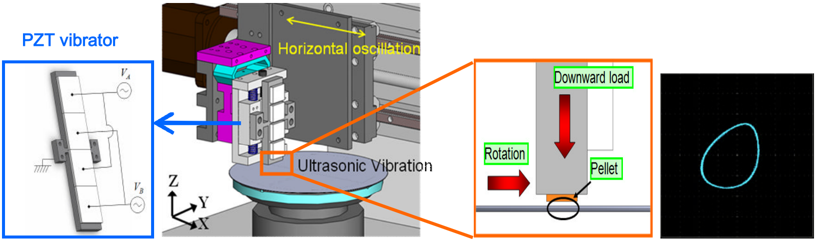
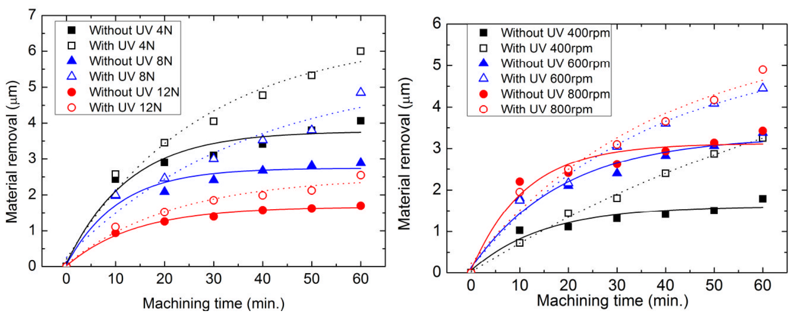


Fig. 1 The sketch of ultrasonic vibration polishing machine; the motion of polishing pellets and measured vibration of the vibrator (phase difference:135°).

The experimental setup is depicted in Fig. 1. A customized ultrasonic vibrator produced by bonding a PZT ceramic device onto a metallic body is installed together with a force sensor. The detailed structure and dimensions of the vibrator were determined by FEM using a commercial software (PIEZO plus 4.0) given the prerequisite f_{L1} (the frequency of 1st longitudinal vibration mode of the vibrator)=f_{B4} (the frequency of 4th bending vibration mode of the vibrator). Thus, an elliptical (i.e., 2D) ultrasonic vibration can be generated on the end face of the metallic body when two phases of AC voltages with a phase difference are applied to the PZT device at the same frequency of f=f_{L1}(=f_{B4}), resulting in the elliptical ultrasonic vibration of fixed-abrasive polishing pellets glued to the end face of the metallic body. The pellet is composed of ceria, prevailing abrasives in glass polishing community. The external downward load was supplied by a pair of compression springs and was calibrated with the force sensor (a dynamometer Kistler 9257A, Switzerland). The platform is able to rotate with its central axis. In addition, the vibrator can oscillate in horizontal direction with amplitude of A and velocity of V_x.



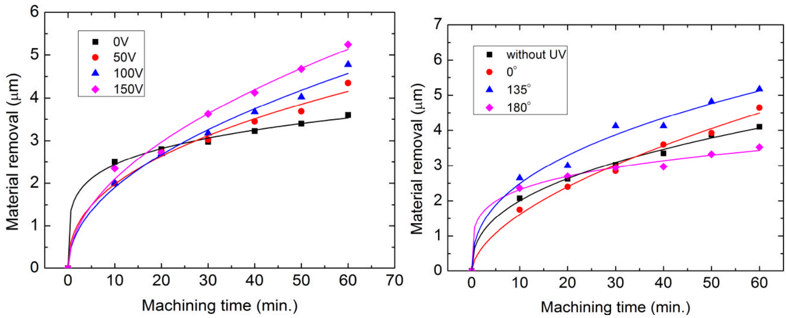


Fig. 2 Material removal rate "without" ultrasonic vibration and "with" ultrasonic vibration under the conditions of various processing parameters and specs of ultrasonic vibration.

3 Results

Referring to Fig. 2, we can understand that the material removal rate is indeed increased by introducing ultrasonic vibration, regardless of the processing parameters (downward load, rotation rate) under the conditions of elliptical vibrations (phase difference=135°). It is chemical actions that enable the removal of material from the glass surface in our cases. The material removal process is conceived as follows: firstly, the ceria reacts with silica in solid-state phase under the circumstances of exceedingly high pressure to form new substances with lower hardness than glass bulk and ceria on the topmost of fused silica and then the resultant softer substances are removed by ceria abrasive mechanically and plastically; alternatively, the Ce in ceria abrasives bonds with Si in glass via O atoms, next silica material is torn away from glass as a lump on account of greater strength of Ce-O bond than Si-O bond and lastly the lump is disengaged and this way the glass material is removed (Fig. 3). The reason for the outstanding performance in material removal rate by "with UV" process may lie in the exceptional capacity to dispose the polishing debris between pellets and surface being machined. The debris is considered to be detrimental to machining in grinding process. In our experiments, the debris resulting from the chemical reaction products and/or silica can increasingly cover the surface of pellets and thereby undermine potential reactions between CeO_2 and SiO_2. As a result, the material removal rate is decreased accordingly because of the accumulation of polishing debris. The surface roughness was also compared after there were no discernible cracks left by grinding. The results show that the surface roughness Ra by "with UV" polishing populates the range of 2~5nm while that by "without UV" mostly falls into 1~4nm, lightly smaller than that in "with UV" polishing. The best surface roughness by both machining techniques is <2.0nm.

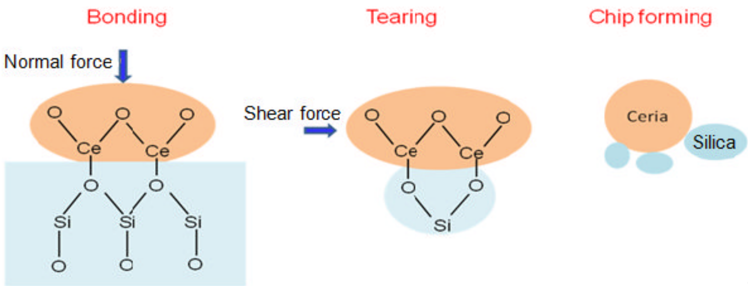


Fig. 3 Mechanisms of material removal and chip forming.

4 Summary

The material removal rate can be increased by >50% with the new method while surface roughness is not degraded significantly. The mechanism of material removal is evidently considered to be due to the synergic effects of chemical and mechanical actions. In ultrasonic vibration assisted polishing, the greater material removal rate is attributed to the exceptional ability to discharge polishing debris, which can, to a considerable extent, retard the chemical reactions between ceria in polishing pellets and silica in fused silica glass and thereby deter the machining process. The surface roughness Ra by ultrasonic vibration fixed abrasive polishing process and conventional fixed abrasive polishing can be as low as <2nm.

References:

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