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Ultraprecision cutting of silicon carbide using micro milling tool made of single crystalline diamond

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Abstract

Micro aspheric glass lenses for digital cameras and mobile phones are manufactured via a glass press molding process using precise ceramic molds made of silicon carbide (SiC) or tungsten carbide (WC). The aspheric ceramic molds are ground using a diamond wheel and polished with loose diamond abrasives. However, in the conventional grinding process, the wear on the diamond wheel is significant, the wheel life is not long, and the grinding accuracy is not so high. In this study, to overcome these problems, milling tools made of diamonds are proposed and the feasibility of machining is studied. The micro milling diamond tool is fabricated via a laser scanning process. In the former report, some micro aspheric molds of WC were cut with the tool. The molds were cut in the ductile mode, and the feasibility of ultraprecision machining was clarified. In this paper, to precisely machine harder silicon carbide molds, micro milling tools made of single crystalline diamond (SCD) were fabricated. Several cutting edges were fabricated three-dimensionally by a laser beam on the edge of a cylindrical SCD. SiC wafers with a flat face were cut with the developed tool to evaluate the tool wear rate and its life. Some micro aspheric molds of SiC were cut with the tool at a rotational speed of 50,000 min^{-1}. The molds were cut in the ductile mode. The form accuracy obtained was approximately 100 nm *P-V*, and the surface roughness was 14 nm *Rz*.

Key words: cutting, silicon carbide, milling tool, diamond, ductile mode

1. Introduction

Micro aspheric glass lenses are used in various devices, such as digital cameras, smartphones, and medical devices. The micro glass lenses are generally mass produced at high temperatures of 400°C-800°C via a glass press molding process. In this process, precise ceramic molds made of silicon carbide (SiC) or tungsten carbide (WC) were used. The micro aspheric ceramic molds were ground with a diamond wheel and polished with loose diamond abrasives. In the conventional grinding process of a ceramic mold, the wear of the grinding wheel was significant, and it was difficult to maintain the wheel's original sharp edge to machine the structured surface. As a means of overcoming these problems, milling tools made of single diamond have been proposed and the feasibility of machining a WC mold was studied. In this study, molds of SiC were machined by the developed milling tool and tool wear characteristics were evaluated. Finally, an aspheric SiC mold was machined for application trial.

2. Development of micro milling tool of SCD

Fig. 1 shows the fabrication process for a micro milling tool form single crystalline diamond (SCD). First, the SCD chip is machined to cylindrical shape using a laser beam and is then bonded with a silver alloy onto a cemented carbide shank. Finally, the end face of the SCD chip is fabricated three-dimensionally through a laser beam, and the cutting edges of the structured surface were fabricated. **Fig. 2** shows scanning electron microscopy images of the developed micro milling tools of the SCD that was fabricated using the laser fabrication process. Specifications of the SCD tool used in cutting the experiments are shown in **Table 1**.

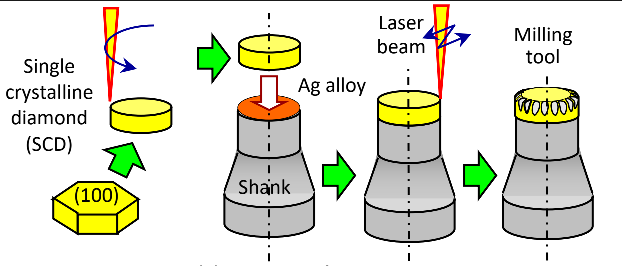


Figure 1 Laser fabrication process of the micro milling tool made of a single crystalline diamond

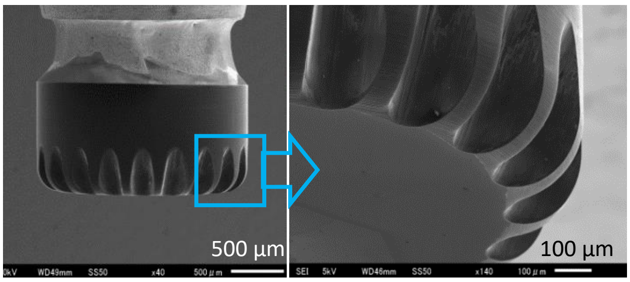


Figure 2 Scanning electron microscopy images of the fabricated milling tool of SCD

Table 1 Specifications of milling tool

Outer diameter	Φ2 mm
Number of cutting edges	20
Edge radius	0.2 mm
Width of cutting edges	0.075 mm

3. Cutting experiment method

The flat shape of the CVD (chemical vapour deposition)-SiC and single crystalline SiC are cut with the developed tool to evaluate the tool wear in the SCD tool. Finally, the actual aspheric molds of the CVD-SiC are test cut and the form accuracy and surface quality are measured and evaluated. Cutting conditions are shown in **Table 2**. The SCD microtool was attached to a 4-axes (X, Y, Z, and C)-controlled ultraprecision machine, ULG100A(HY), as shown in **Fig. 3**. The tool spindle is an air-bearing spindle with a maximum rotational speed of 50,000 min^{-1}. The tool was actuated in the X-, Y-, and Z-axes by the linear scale feedback system with 10-nm positioning resolution. Attachment of the tool was adjusted a concentricity below 0.5 µm.

In the tool wear evaluation experiment, the aspheric lens molds were machined by actuating the tool in the Y direction. The processing of each aspherical lens mold was cut 20 times with a 2-µm depth of cut. After cutting nine ellipsoidal arrays, the replica of the tool shape was made onto the graphite carbon plate near the SiC workpiece on the machine. This replica was measured by a non-contact type of laser probe scanner, the change of tool shape is measured, and the volume of tool wear was calculated.

4. Experimental results

4.1. Tool wear evaluations of SiC cutting

Fig. 4(a) shows the change of the tool shape during cutting of the CVD-SiC. **Fig. 4(b)** shows a maximum depth of tool wear. **Fig. 4(c)** shows the change of the tool wear ratio calculated from these results. The tool wear ratio was calculated as a ratio of the removal workpiece volume divided by the volume of the tool wear and corresponds to the grinding ratio in grinding. **Fig. 5** shows the change of the tool wear ratio in cutting a single crystalline SiC with the same tool. The tool wear ratio of both the CVD-SiC and the single crystalline was 200-300. **Fig. 6** shows the change of the tool wear ratio in cutting WC. The tool wear ratio in cutting the SiC was larger by approximately 1/50 compared with that of WC workpiece.

4.2. Application test of CVD-SiC molds

A micro ellipsoidal array mold was machined with the developed milling tool**. Fig. 7** shows a photograph of the machined array mold and a Nomarski micrograph of an ellipsoidal mold from the CVD-SiC. **Fig. 8** shows a form deviation profile of the ellipsoidal mold. **Fig. 9** shows the surface roughness profile of the machined mold**.** The form accuracy obtained was approximately 100 nm *P-V*, and the surface roughness was 14 nm *Rz*.

Table 2 Cutting conditions

Workpiece	CVD-SiC, Single crystalline SiC
Tool	Single crystalline diamond (100) face
Rotation	50,000 min^{-1}
Depth cut	2 µm
Feed rate	0.4 mm/min
Cutting times	20
Coolant	Water base coolant (Solution type)

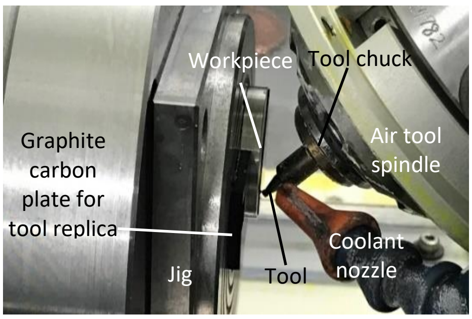
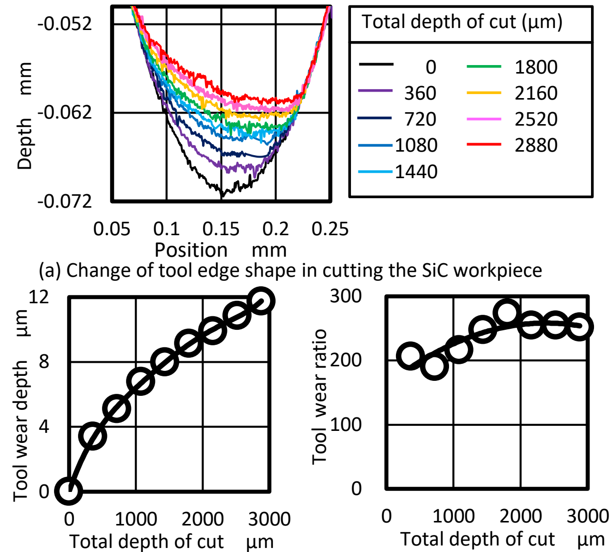


Figure 3 View of cutting experiment



(a) Change of tool edge shape in cutting the SiC workpiece

(b) Maximum depth of tool wear (c) Change of tool wear ratio

Figure 4 Change of tool wear after CVD-SiC cutting

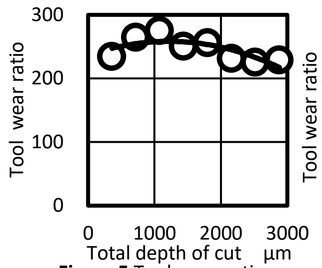


Figure 5 Tool wear ratio in cutting single crystalline SiC

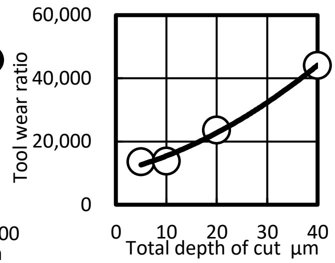


Figure 6 Tool wear ratio in cutting tungsten carbide

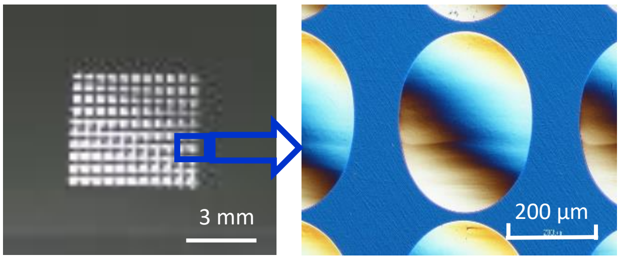


Figure 7 Nomarski micrograph image of aspheric molds

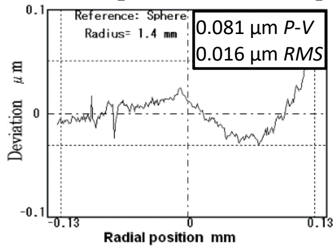


Figure 8 Form deviation profile of ellipsoidal CVD-SiC mold

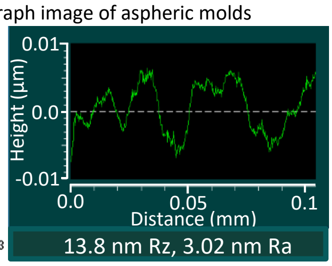


Figure 9 Surface roughness profile of CVD-SiC mold

5. Conclusion

In this study, cutting experiments of SiC with a higher hardness than WC were conducted with a single crystal diamond micro milling tool and the following was clarified. The ellipsoidal array mold of SiC was cut and evaluated for tool wear. Tool wear during cutting of SiC was approximately 50 times higher than cutting of WC.

References

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