euspen's 21st International Conference & Exhibition, Copenhagen, DK, June 2021
www.euspen.eu

Constant-pressure machining of single crystalline silicon carbide using a ruby sphere

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Abstract

Single-crystal SiC consists of 1:1 covalent bonds between carbon and silicon. SiC is the third hardest compound on earth after diamond and boron carbide, and it has excellent hardness, thermal conductivity, thermal expansion, oxidation resistance, heat resistance, corrosion resistance, and electrical properties. Furthermore, it has significant chemical stability and a high dielectric breakdown strength. Consequently, it is applied widely, e.g., in mechanical seals, chemical pump bearings, next-generation power device materials, and molds for optical components. However, it is extremely difficult to machine owing to its excellent properties. Therefore, several studies have investigated measures to improve its machining efficiency and surface characteristics. Herein, we focused on the materials of the tools used for SiC machining. In this regard, diamond tools are commonly used; however, they undergo wearing and incur costs accordingly. Therefore, we examined a lever-type dial gauge, composed of rubies as an alternative tool material, for constant-pressure machining of SiC. The conditions of the ruby and machined surface of the SiC were observed via white light interferometry and scanning electron microscopy. The results confirmed the feasibility of using rubies to machine SiC wafers. Moreover, the possibility of mechanochemical reactions was examined.

Keywords: ruby sphere, single crystalline silicon carbide, constant-pressure machining, dial gauge

1. Introduction

Single-crystal SiC has excellent properties such as hardness, high dielectric breakdown strength, and significant chemical stability. Therefore, it is expected to be used in various applications such as next-generation power devices and molds for optical components. Meanwhile, SiC is a brittle material that is extremely difficult to machine. Consequently, several studies have focused on SiC machining to improve its machining efficiency and surface characteristics [1].

The machining of single-crystalline SiC wafers was investigated in [2], where a trace was produced on the surface of the SiC wafer and measured using a ruby sphere lever-type dial gauge. The traces might be considered that SiC could not be machined under normal circumstances, because the modified Mohs hardness of SiC is higher than that of the ruby. The main component of ruby is aluminum oxide, also called corundum, and Hirooka et al. reported that corundum has the same level of machinability as that of cemented carbide for tools [3]. In [4], the effect of machining speed on the constant-pressure machining of single crystalline silicon carbide using a ruby sphere was studied.

With this background, in this study, the effects of constant-pressure machining on SiC using ruby spheres as tool materials were compared with those on the single-crystal SiC.

2. Experimental equipment and methods

An ultraprecision vertical machining center (TOSHIBA MACHINE, UVM-450C-V2) was employed, and a rotary table (TOSHIBA MACHINE, ABC-50) with aerostatic bearings was installed on the table. Figure 1 shows a schematic of the experimental apparatus. A commercially available leverage dial gauge was used as a tool, were used to assess the influence of the measuring probe material on the machining of SiC. A TI-113HRX ruby sensor was used, manufactured by Mitutoyo, with a diameter of 2 mm and a measuring force of 0.3 N or less. The workpiece was a poly type 4H-N SiC wafer, which was fixed to the jig using a thermoplastic resin (Nikka Seiko, ADFIX). Post-machining wafer surfaces were observed using white light interferometry (Zygo, New View 6300) and scanning electron microscopy (SEM; Hitachi High Technology, SU4200).

The wafer was machined while the probe was in contact with the wafer surface at a constant pressure of 0.3 N. The processing conditions are listed in Table 1. The machining speed v was 100 m/min, and no cutting fluid was used to evaluate the basic machining characteristics.

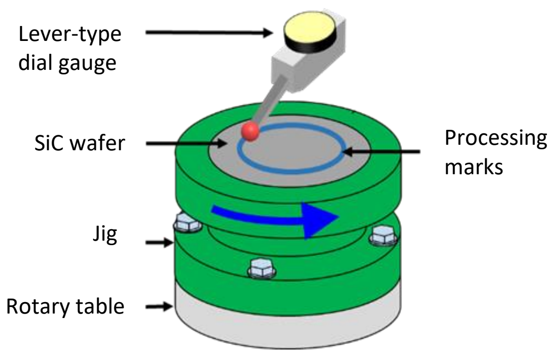


Figure 1. Schematic of the experimental apparatus

Table 1 Machining conditions

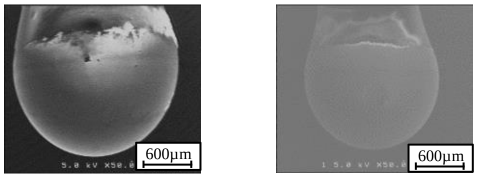
Measuring power p [N]	0.3
Machining speed v [m/min]	100
Machining time t [min]	10,20,30,40,50,60

3. Experimental results

Figure 2 shows SEM images of the ruby sphere before and after processing. The appearance of the specimen was not significantly damaged or changed. In a previous study [4], no significant change was observed in the appearance of specimen, which confirmed that the ruby sphere was not affected by SiC during processing.

Figure 3 shows the 3D model for different machining times obtained using white light interferometry. For a machining time of 10 min, the average width of the machined scar was 1.4 mm, while for a machining time of 60 min, it increased to 2.6 mm (approximately 1.8 times wider). Moreover, the machining marks became wavy in shape as the machining time increased. These phenomena might have been caused by the shifting of the contact surface of the ruby sphere owing to the effect of chips accumulating with increased machining time.

Figure 4 shows the relationship between the machining time and the depth of the machined trace. The experiments were conducted three times for each machining time, and the measured values were plotted at three points for each machining mark. The smooth line represents the average of the measured values for each machining time. As shown in Fig. 4, the depth of the machined trace tended to increase with the increase in machining time: a depth increase of 0.0929 μm/min was observed, which is a linear increase, considered to be based on Preston's law. In our previous study [4], when the machining time was set to 4 min and the machining speed was varied from 20 to 100 m/min, no significant difference in the depth of the machined mark was observed. However, in this experiment, the machining time had a clear effect on the depth of the machined mark. The results of this experiment reconfirmed the possibility of processing SiC wafers using ruby spheres. However, because ruby contains a small amount of chromium oxide, the processing of ruby spheres may be accelerated as a result of the mechano-chemical reactions taking place during the grinding of SiC [5].



(a) Before (b) After

Figure 2. SEM images of the measurer before and after processing

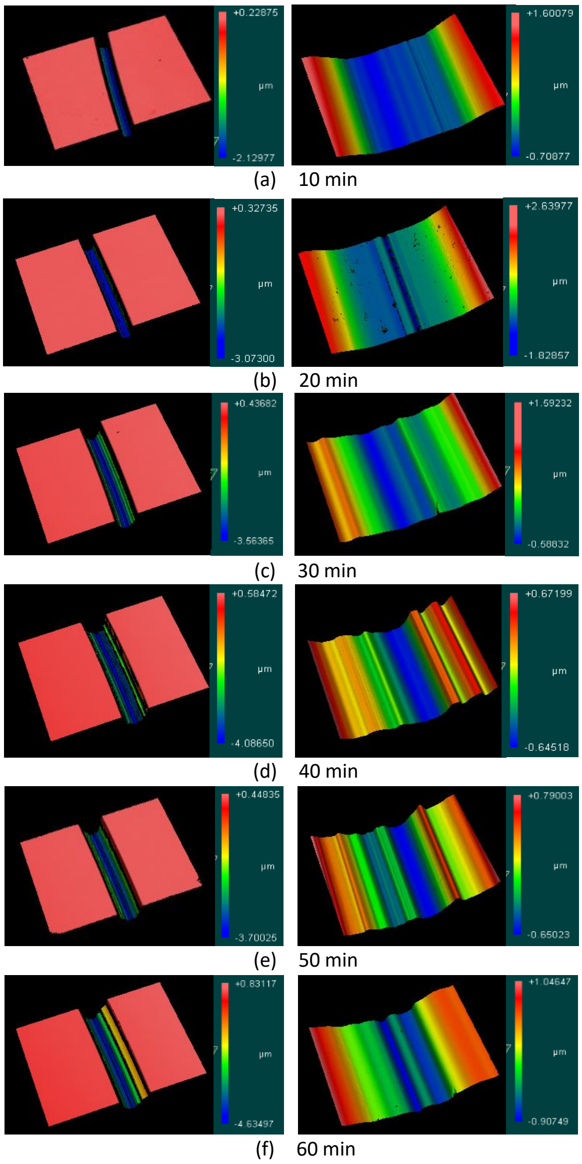


Figure 3. 3D model for each machining time
(left 5 times,right 50 times)

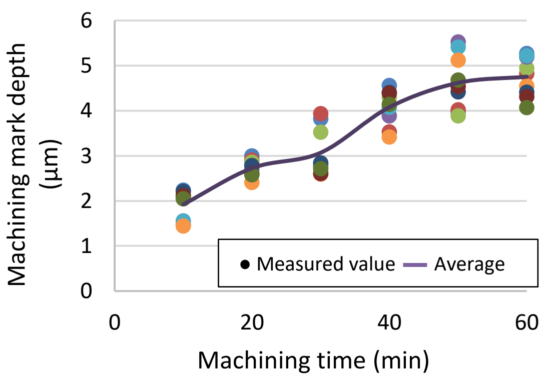


Figure 4. Machining mark depth vs. machining time

4. Conclusions

In the constant pressure machining of single crystal SiC using ruby spheres as tool material, the following results were obtained:

(1) No damage was observed on the contact surface of the ruby sphere during constant-pressure machining at a measuring power of 0.3 N.

(2) As the machining time increased, the width of the machining marks increased by approximately 50%.

(3) As the machining time increased, the shape of the machined marks became wavy and more disordered.

(4) The depth of the machining marks increased with an increase in the machining time.

we have confirmed the potential of ruby as a tool material.

References

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