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Study on constant pressure machining of single crystal SiC with ruby spheres : Effect of machining speed

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Abstract

Single-crystal SiC is a material with excellent mechanical and chemical properties and is expected to be used in various fields, such as next-generation power device materials and molds for optical components. On the other hand, its excellent properties make it extremely difficult to process, resulting in a large amount of time and cost. Therefore, further improvement in efficiency and cost reduction are desired, and highly efficient machining methods and various tools are being investigated. Currently, materials that emphasize mechanical properties, such as diamond, are used as tools. However, the cost problem cannot be solved if mechanical properties are emphasized. Therefore, it is necessary to consider tool materials that can be machined using chemical reactions to compensate for mechanical properties. The grinding of single-crystal SiC using a chemical reaction has been confirmed to be effective when grinding with a grinding wheel containing chromium oxide, which is an oxidation catalyst-based abrasive grain. We propose ruby, which contains chromium oxide in aluminum oxide, as a new tool material and investigate its usefulness in a constant-pressure machining method in which ruby is pressed against a SiC wafer at a constant pressure. In this study, the effect of machining speed on the constant pressure machining of single crystal SiC using ruby spheres as a tool was investigated.

SiC, Ruby ball, Ceramic, Machining,

1. Introduction

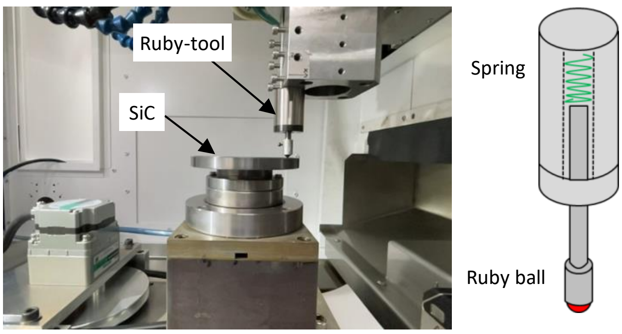
Single-crystal SiC is a material with excellent mechanical and chemical properties, and it is expected to be used in various fields such as next-generation power devices[1] and molds for optical components[2]. On the other hand, its excellent properties make it extremely difficult to machine, and therefore, various highly efficient machining methods and tools have been studied. Currently, diamond tools are mainly used for machining SiC. Our research group has proposed a constant-load machining method using ruby tools made of aluminum oxide containing chromium oxide, which is less expensive, and has investigated the usefulness of this method[3]. We have obtained good results at low loads, high speeds, and long times. However, the machining behaviour at high speed, short time, and high load is not clear.

In this study, experiments were conducted to explore the machining characteristics under high-speed conditions. These experiments involved varying the speed in constant-load machining of single-crystal SiC at a machining time of 10 minutes.

2. Experimental equipments and method

An ultra-precision vertical machining center (Shibaura Machinery, UVM-450C) was used for the experiments, as shown in Figure 1. A tool with a built-in constant-pressure spring and a ruby ball glued to its tip was used. The diameter of the ruby ball is 6 mm. A single-crystal SiC wafer (4 inches, dummy grade) was utilized as the workpiece and affixed to the jig with thermoplastic resin (NIKKA SEIKO's ADFIX). The surface properties of the wafer after machining were observed using a stylus-type surface roughness measuring instrument (Mitutoyo, SJ-410), and the surface of the ruby sphere was observed using a microscope (Keyence, VH-Z75).

Table 1 shows the experimental conditions. The wafer was rotated and processed while the tool was in contact with the wafer surface with a constant load. The machining speeds tested were 180, 200, 250, 300, and 400 m/min, and the machining time was set at 10 minutes. It should be noted that no machining fluid was used in these tests.



(a)Machining condition (b)Constant pressure tool

Figure 1. Schematic diagram of machining conditions and constant pressure tools

Table 1 Experimental conditions

Machining pressure	*p*[N]	3.0
Machining speed	*v*[m/min]	180 200 250 300 400
Machining time	*t*[min]	10

3. Experimental results

3.1. Machining volume

In the previous study, machining experiments were conducted at speeds of 100, 120, and 140 m/min for a duration of three hours. The machining volume increased in proportion to the machining speed. In this experiment, machining speeds of 180, 200, 250, 300, and 400 m/min and a machining time of 10 minutes were used. The results are presented in the same graph for comparison with previous studies. As the machining times in this experiment and the previous study differed, the results are compared as the machining volume per unit time (mm^3/min).

The machining volume of the wafer was calculated by measuring the shape of the machining scar at four locations, averaging the depths obtained, obtaining the cross-sectional area, and multiplying by the machining distance.

Figure 2 illustrates the relationship between machining speed and machining volume. The results from previous studies are represented by black circles. The results indicate that the machining volume increased at 180, 200, and 250 m/min. The higher machining volume observed in this experiment compared to the previous study can be attributed to the initial and final phases of machining, where tool wear and reduced machining pressure may have affected efficiency. In the previous study, 180 minutes of machining were performed.

In contrast, the results of this experiment showed no change at machining speeds of 300 and 400 m/min, which were approximately constant. This is attributed to a decline in contact force between the ruby tool and the SiC wafer, resulting from dynamic pressure and other factors as the machining speed increased.

3.2. Wear volume of tool material

Figure 3 shows an image of the ruby tool after the experiment. The image reveals the presence of striated wear marks at the contact point with the wafer. In comparison to the machining marks observed in the previous study, the present experiment reveals larger striations due to its higher machining speed.

Figure 4 illustrates the relationship between machining speed and wear volume. A comparison of the wear volume reveals that the average volume in the previous study was $5.3 \times 10^{-3} mm^3$, $3.5 \times 10^{-3} mm^3$ at a speed of 200 m/min, and $2.9 \times 10^{-3} mm^3$ at a speed of 300 m/min in the present experiment. This indicates that the wear volume decreases as the machining speed increases. This can be inferred from the fact that the contact force between the tool and the wafer decreased as the machining speed increased, as described above. The first is that the machining tool was splashed by the unevenness of the workpiece. Secondly, the dynamic pressure exerted on the ruby tool by high-speed machining is a contributing factor. The dynamic pressure exerted on the ruby tool due to high-speed machining is the second point. It is believed that the air flow on the wafer surface accelerated due to the rise in the wafer rotation speed, leading to the generation of dynamic pressure between the tool and the wafer. Assuming that the air flow on the wafer surface is equivalent to the peripheral velocity, the dynamic pressure is estimated to be approximately twice as large at 200 m/min and approximately five times as large at 300 m/min compared to a wafer rotation speed of 150 m/min. In this experiment, the tool was pressed down with a machining load of 3 N. It is considered that the machining load was reduced by the tool being pushed up from below.

4. Conclusion

Experiments were conducted to study the high-speed machining of single-crystal SiC using ruby spheres as tool material. The results demonstrated that the machining load decreased due to the dynamic pressure between the tool and the wafer when the speed increased excessively. It is therefore essential to ascertain the relationship between the appropriate rotational speed and machining load in future studies.

References

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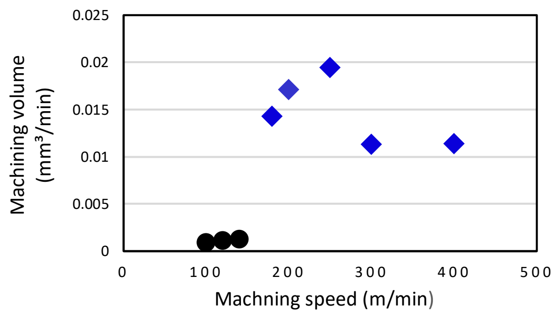
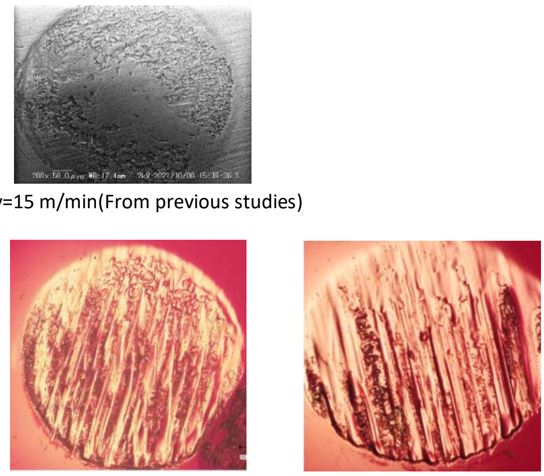


Figure 2. Relationship between machining speed and machining volume



(a)v=15 m/min(From previous studies)

(b) v=200 m/min

(c) v=300 m/min

Figure 3. Observation image of the ruby tool after the experiment

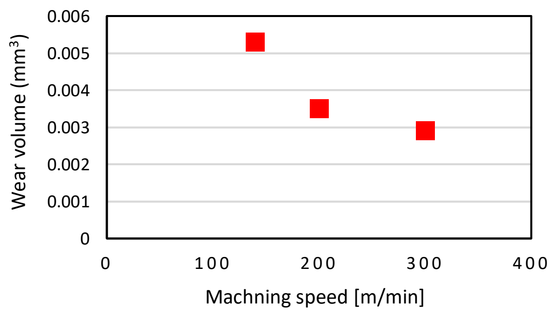


Figure 4. Relationship between machining speed and wear volume