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Effect of Cutting Edge Radius of Diamond Tool on Micro Cutting of Single Crystalline Silicon Carbide

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Abstract

A lot of studies of micro cutting silicon carbide (SiC) using a diamond tool have been conducted in recent years due to its difficult machinability even while it has superior engineering properties such as hardness, high thermal conductivity and chemical inertness. On the other hand, there are few studies focusing on effect of cutting edge radius under micro cutting. Micro cutting experiments of SiC are conducted using two types of tools which have different cutting edge radiuses to reveal the relations between cutting edge radius and critical depth of cut of tools. Under these experiments, critical depth of cut almost agree with the cutting edge radiuses.

Cutting, Diamond tool, SiC, Micro machining

1. Introduction

In recent years, use of aspheric glass lenses for the optical sensors of advanced automobiles and so on have been increasing. Therefore improvement of production efficiency and quality of the lenses is required. Glass mold manufacturing which uses hard material such as tungsten carbide (WC) or silicon carbide (SiC) for dies is the most suitable and widely used for aspheric lenses production. In this method, SiC is preferred material in order to make the life of dies longer because the hardness and thermal conductivity of SiC is superior to those of WC. However, SiC is difficult to machine efficiently and precisely due to its high hardness and brittleness. In order to meet the requirements of surface roughness and form accuracy (it is required under 20nmRa and 50~100nmP-V for optical dies), grinding and polishing are used to machine SiC into aspheric lens dies and now improving the machining efficiency is required.

Recently, micro cutting with single crystalline diamond tool is highlighted as an efficient way of machining SiC and a lot of studies have been conducted [1]. Some studies have reported that it is possible to machine SiC efficiently and precisely, however, basic mechanism of cutting SiC using diamond tool has not been revealed. This study focuses on the effect of cutting edge radius on surface integrity of SiC. Some researchers using Molecular Dynamics simulations have predicted that cutting would change from ductile mode to brittle mode as the undeformed chip thickness is increased from smaller to larger than the tool cutting edge radius [2]. However, the relations between cutting edge radius and cutting mode have not been fully understood and there are few studies conducting practical experiments focusing on the cutting edge radius. The authors conducted experiments cutting SiC with two types of single crystalline diamond tools to appear the effect of cutting edge radius on micro cutting.

2. Experimental method

Fig.1 shows schematic of experimental setup which describes cutting cross section made in this study. SiC wafer is attached with solid wax on a jig and rotates counter-clockwise by air bearing rotating table. A single crystalline diamond tool is set over the SiC wafer and controlled by high precision machining centre (Toshiba UVM-450C), whose driving system resolution is up to 10 nm.

As shown in Fig.1, depth of cut is changing gradually because the surface of the wafer is naturally waving in a range of approximately 10 µm due to the warp of wafer, disproportion of solid wax, and so on. Critical depth of cut (critical chip thickness) is measured by observing ductile-brittle transition using scanning electron microscope (Hitachi S-4200) and white light interferometer (Zygo New View 6300) .

To evaluate the effect of cutting edge radius on surface integrity of micro cutting SiC, two tools which have different cutting edge radiuses are used. Fig.2 shows SEM images of cutting edges of two tools. Cutting edge radius, R, of tool 1 is about 90nm and that of tool 2 is about 50nm. These images are taken from the tools which worn in machining SiC and appeared the cross sections of their cutting edges.

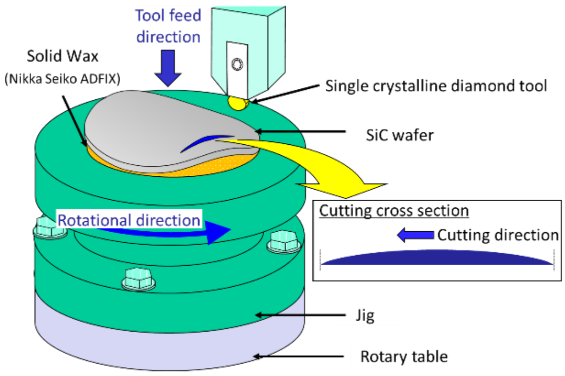
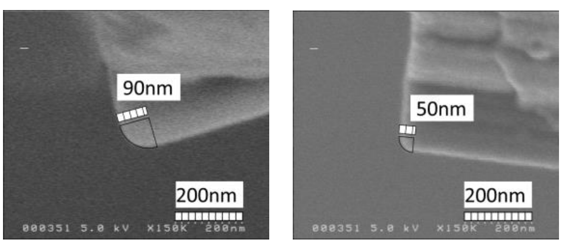


Figure 1. Schematic of experimental apparatus



(a) Cutting edge of tool 1 (b) Cutting edge of tool 2

Figure 2. Cutting edge radius of diamond tools

3. Experimental results

Fig.3 shows SEM images of the machined surface area at the beginning and the middle of cutting point. The surfaces were generated at cutting speed *v*=30 m/min. While ductile surface were generated at the beginning point of cutting whose undeformed chip thickness is small, brittle surfaces were generated at the middle point of cutting whose undeformed chip thickness is large. These phenomena shows that generated surface condition changes ductile to brittle as the undeformed chip thickness is becoming larger.

In order to evaluate the effect of cutting edge radius on surface integrity of SiC, micro cutting experiments using tool 1 and tool 2, at *v*=30, 50, 60 m/min were conducted. Fig.4 shows images of surface roughness taken by white light interferometer at the ductile-brittle transition area of machined surface. Depth of cut are measured at 4 lines, making the area between second line and third line from the bottom become at the middle point of ductile-brittle transition area. The area between first line and second line from the bottom shows ductile surface and depth of cut in the second line means the critical depth of cut, the maximum depth of cut in which condition ductile surfaces are generated.

Table 1 shows the critical depth of cut of two types of tools, tool 1 and tool 2, measured in the ductile-brittle transition areas. In Table 1, while critical depth of cut of tool 1 increases as the cutting speed become higher, that of tool 2 doesn't increase and keeps in the range of 60-70 nm. At *v*=30 m/min, critical depth of cut of tool 2 is larger than that of tool 1, on the other hand at *v*=50 m/min, there is not significant differences between tool 1 and tool 2, and at *v*=60 m/min, the critical depth of cut of tool 1 becomes approximately 100 nm, which is larger than that of tool 2.

This implies that undeformed chip thickness which can machine SiC in ductile mode is limited by the cutting edge radius of tool. Critical depth of cut of tool 2 which has smaller cutting edge radius is limited about 60 nm and that of tool 1 is up to about 100 nm, which almost agree with the edge radiuses of two tools. Although the increasing of critical depth of cut according as the cutting speed become higher is observed using tool 1, the relations between critical depth of cut and cutting speed have not been understood and the further experiments are required in order to reveal the relations.

4. Conclusions

In order to investigate the effect of cutting edge radius on cutting SiC, using two types of single crystalline diamond tools which have different cutting edge radiuses, micro cutting experiments on SiC is conducted and following conclusions are obtained:

(1) Finished surface integrity changes ductile to brittle as the increase of undeformed chip thickness.

(2) Critical depth of cut of two tools are measured observing the ductile-brittle transition area and the maximum depth of cut in which surface conditions are observed as ductile mode almost agree with the cutting edge radiuses of two tools.

(3) The critical depth of cut of tool 1 increases as the cutting speed is higher. The further experiments are needed so that the relations between the critical depth of cut and cutting speed are revealed.

References

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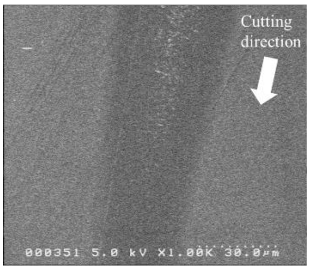
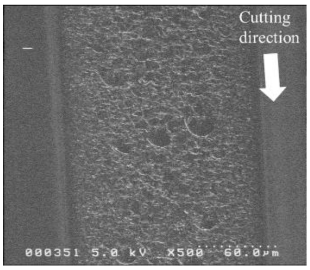
[2] John A. Patten and Jerry Jacob 2007. *International Journal of Machine Tools & Manufacture.* **47** 562–569

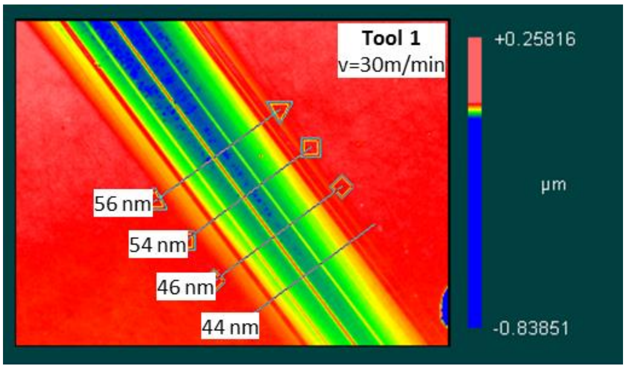


(a) Ductile mode

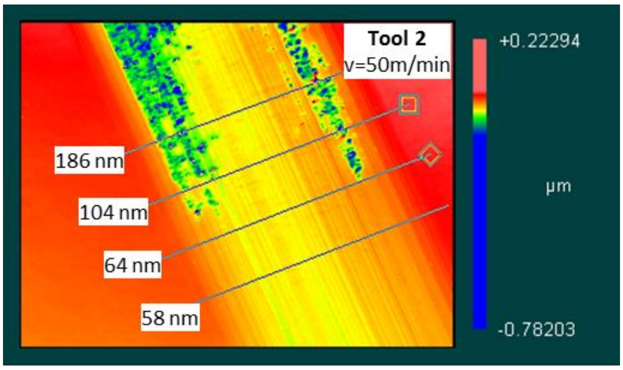


(b) Brittle mode

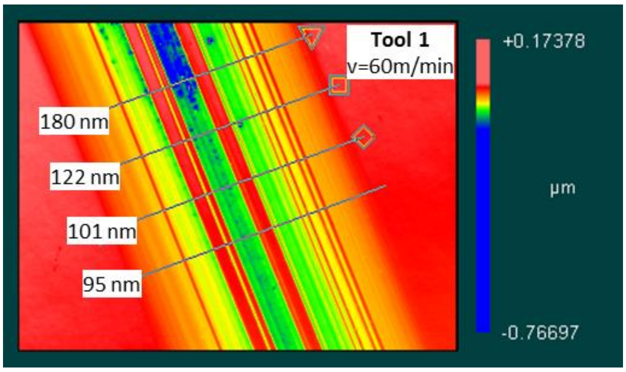
Figure 3. SEM images of ductile and brittle surfaces of machined SiC (Tool 2, *v*=30m/min)



(a) Tool 1 (*v*=30 m/min)



(b) Tool 2 (*v*=50m/min)



(c) Tool 1 (*v*=60m/min)

Figure 4. Measured depth of cut in ductile- brittle transition area by white light interferometer (Zygo new view 6300)

Table 1
Depth of cut in ductile-brittle transition area under cutting speeds

	Tool 1 (R=90nm)				Tool 2 (R=50nm)			
	Ductile(nm)		Brittle(nm)		Ductile(nm)		Brittle(nm)	
v=30 m/min	44	46	54	56	70	74	76	83
v=50 m/min	57	62	075	104	58	64	104	186
v=60 m/min	95	101	122	180	61	63	79	95