An Investigation of Diamond Tool Cutting Edge

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Abstract

The integrity of the diamond tool cutting edge is of prime importance in ultra-precision machining. This paper reports on a study carried out to determine the effects of polishing parameters on material removal rate, surface finish and cutting edge sharpness. Consequently, the significance of the mechanical and chemical wear mechanisms on the polishing effectiveness and efficiency is deduced. Results show that the size of the diamond powder used in the polishing process is a critical determinant of the quality of the cutting edge produced. Other parameters such as the applied pressure and polishing speed have far less influence.

Introduction

The quality of the cutting edge of the diamond tool is important to achieve mirror surface finish and machining efficiency in ultra-precision machining. Diamond tool cutting edge preparation is basically a polishing process, whereby the diamond tool is pressed onto a cast iron scaife which is loaded with diamond powder. The first known study on diamond polishing was by Tolkowsky [1], who found that the material removal rate is dependent on the polishing direction. The material removal rate in the <100> direction on the {001} crystal plane is about two times that in the <110> direction. It was suggested that the material removal mechanism is largely due to the formation of the micro-cleavages along the {111} plane. Seal [2] and Bowden and Tabor [3] propounded that thermal wear is the main cause of material removal. Wilks and Wilks [4] supported Tolkowsky's micro-cleavage theory and devised a model to illustrate their claim. Results showed that the material removal rate increases linearly with an increase in the scaife speed. However, the material removal volume on the same rubbing length remains the same. This implies that the thermal effect is very minimal and mechanical wear is likely to be the main wear mechanism. Grillo and Field [5] investigated the correlation between the frictional force and the polishing direction and found that the frictional force varies along the different crystal directions. More recently, van Bouwelen provided more insight into the wear mechanisms [6]. Research work have so far been restricted to the material removal rate and surface finish on the diamond face. Little has been covered on the sharpness of the cutting edge.

Experimental Set-Up

The experiments were performed on a purpose-built diamond tool polishing machine shown in Fig. 1. The machine is equipped with an air bearing spindle, oscillating mechanism and tool holder. The air bearing is directly driven by an AC motor with a speed range from 0 to 10,000 rpm. A cast iron scaife with 300 mm diameter and hardness of HB 180 is mounted onto the spindle. The tool holder is located on a rotating stage, such that the diamond tool can be tilted to achieve different rake angles. The diamond tool is oscillated at right angles to the polishing direction during the polishing process. The oscillating stroke

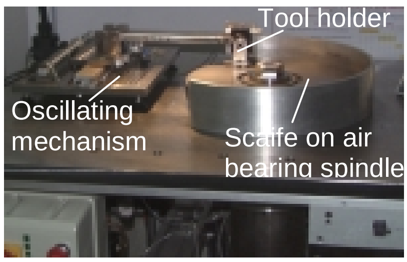
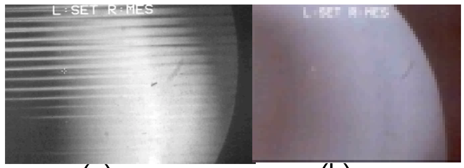


Fig. 1 Diamond tool polishing machine

can be adjusted. The {001} crystal plane was chosen as the rake face and the polishing direction is in the <100> direction, which is parallel to the tool shank. The polishing movement is always towards the diamond tool to avoid chipping of the cutting edge. Diamond powder was placed on the scaife before each polishing operation. To determine the material removal rate, the diamond tool was weighed before and after polishing. The surface finish on the diamond tool rake face was measured using the Wyko white light interferometer. The integrity of the cutting edge was judged by machining an aluminum part and subsequently inspecting the machined surface finish. A better machined surface finish is taken to reflect a sharper cutting edge. Experiments were performed with different grain sizes of diamond powder (1, 5, 10 µm), applied pressures (0.5, 1.5 kg) and polishing speeds (336, 1008 m/min).



(a) (b)

Fig. 2 Polished surface finish (a) without oscillating movement, (b) with oscillating movement

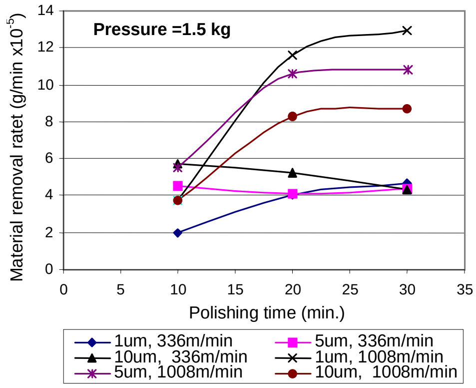


Fig. 3 Material removal rate vs polishing time

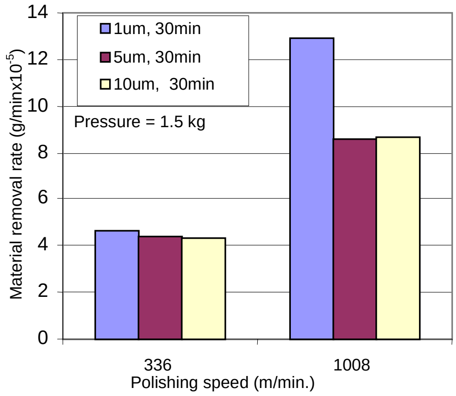


Fig. 4 Material removal rate vs polishing speed

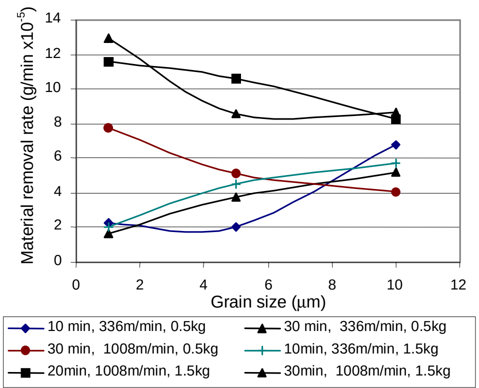


Fig. 5 Material removal rate vs the grain size of the diamond powder

Results and Discussion

Surface finish

A good finish on the diamond tool surface is desirable as it reduces the frictional forces at the tool-chip interface and reduces the adhesion of the work material onto the tool rake face. The results show that when there is no oscillatory movement of the diamond tool across the polishing direction, grooves are found along the polishing direction (see Fig. 2 (a)). This is likely to be caused by the imprint of the imperfections of the scaife surface onto the diamond tool surface. The surface roughness measured is about 40 nm Ra. With the application of oscillatory movement, the grooves were eliminated and the surface finish is significantly improved to 1 to 3 nm Ra (see fig. 2 (b)). It was observed that the surface finish of the diamond tool is not grossly affected by the polishing parameters.

Material Removal Rate

With the lower polishing speed of 336 m/min the material removal rate (MRR) remains constant with time (see Fig. 3). This implies that the effectiveness of the abrasive diamond powder is not adversely affected for the whole duration of the polishing process. At the higher polishing speed of 1008 m/min it was surprising to find that the removal rate actually increases initially before it tapers off. Work is continuing to try to explain this unexpected trend.

Fig. 4 shows the effect of the polishing speed on the MRR when a loading pressure of 1.5 kg is applied. When the polishing speed is increased from 336 to 1008 m/min, the MRR increases linearly. When the MRR is plotted against the polishing length, it is found that the amount of material removed is almost the same for the high and low polishing speeds. This is consistent with the findings of Wilks and Wilks who concluded that only fracture wear exists during the diamond polishing [4]. The opinion of the present authors is that chemical wear may also be prevalent during the polishing process. High temperature generated at the high polishing speeds is likely to induce substantial chemical wear. Concurrently, the softening of the diamond at the contact surface would lower the incidence of fracture wear. The net outcome is that the amount of material worn remains substantially the same.

At the lower polishing speed, the MRR increases with an increase in the grain size of the diamond powder, while at the higher polishing speed, the MRR decrease with an increase in the grain size, as shown in Fig. 5. At the lower polishing speed, the predominant material removal mechanism is fracture wear. Therefore, the MRR increases with an increase in grain size. At the higher polishing speed, chemical wear plays a greater role. With smaller grains, the contact area between diamond tool and the scaife is larger. The increased contact produces more chemical wear and raises the material removal rate.

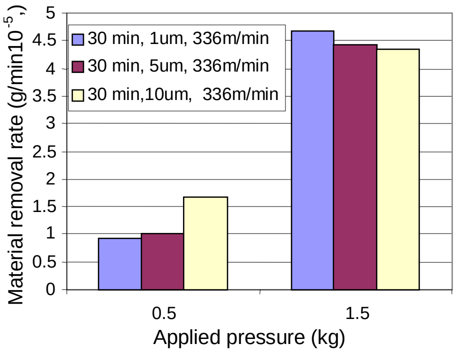
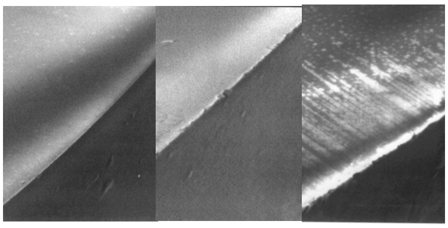


Fig. 6 Material removal rate vs applied pressure



(a) With grain size of 1 µm
(b) With grain size of 5 µm
(c) With grain size of 10 µm

Fig. 7 Cutting edge integrity under SEM

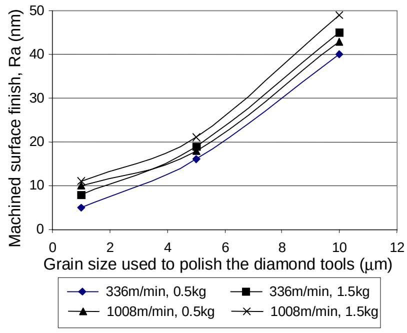


Fig. 8 Machined surface finish using polished diamond tools

A larger applied pressure increases the material removal rate, as shown in Fig. 6. The probable reason is that the larger applied pressure induces higher tensile stress in the diamond and causes more nano-cracks to form. This accelerates the material removal rate.

Cutting Edge Integrity

Fig. 7 shows the cutting edge under the SEM, at a magnification of 2000 times. The cutting edge which has been polished by 1 µm grain size diamond powder shows a well defined contour with little signs of chipping (Fig. 7(a)). When the tools are polished using 5 µm grain size diamond abrasives, some chipping along the cutting edge can be clearly seen (see Fig. 7(b)). The cutting edge is relatively blunt when compared to the previous case. In Fig.7(c) severe micro chipping on the cutting edge is observed when the grain size is 10 µm.

Fig. 8 shows the surface finish of the machined aluminum parts using the diamond tools polished with different grain sizes. Surface finishes of approximately 10, 18 and 40 nm in Ra are obtained using tools polished with grain sizes of 1, 5 and 10 µm, respectively. Since the surface finish is an indication of the sharpness of the tool cutting edge, it can be deduced that the sharpness of the cutting edge is significantly affected by the grain size of the diamond powder used in the polishing process.

The applied pressure and the polishing speed were found to have only minimal effects on the machined surface finish. A higher applied pressure leads to a slight deterioration of the cutting edge integrity, with the material removal mechanism being largely due to fracture wear. High polishing speeds can be expected to give a better cutting edge quality due to chemical wear. However, higher speeds also would induce vibration if the machine rigidity is not high enough. This would degrade the cutting edge quality. By industrial standards, a surface finish of better than 10 nm Ra is regarded to be good, 20 nm Ra as acceptable and over 30 nm as poor. Therefore, diamond tools which are polished using 1 μm grain size can cut aluminum parts to a surface finish of less than 10 nm Ra. They are considered as good quality tools. Similarly, the tools polished with grain size of 5 μm are acceptable, while tools polished using 10 μm grain size are usually rejected because of the unacceptable surface finish obtained.

Conclusions

From the study, the following observations can be made:

- Oscillatory movement of the diamond tool at the right angles to the polishing direction can significantly improve the surface finish. The diamond tool surface finish is not significantly affected by the polishing parameters.
- With a lower polishing speed the MRR remains substantially constant with time. At a higher polishing speed the material removal rate increases initially before tapering off.
- The MRR increases with an increase in the applied pressure and polishing speed.
- At higher polishing speeds chemical wear is prevalent while mechanical wear is more significant at lower polishing speeds.
- The cutting edge quality is mainly affected by the grain size of the diamond powder, and relatively affected by the applied pressure and the polishing speed. Diamond tools polished using grain size of 1 μm have excellent cutting edge integrity.

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