Investigation of micro-optic polishing characteristics by vibration-assisted polishing

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Abstract

The micro-optic polishing characteristics are investigated. The material removal rate and surface roughness under different vibrating motions are compared. The relationship between polishing pressure and material removal rate is revealed. It is found that the result does not follow the Preston's equation completely because the material removal rate decreases when the polishing pressure exceeds a certain value. A model of material removal mechanism in micro-optic polishing is proposed and illustrated.

1 Introduction

Recently, the vibration-assisted polishing method has been proposed to finish the micro-optic mould and some good results have been reported [1-2]. To well control the polishing performance and investigate the material removal mechanism, in this paper, some fundamental experiments are conducted to investigate the micro-optic polishing characteristics. Firstly, the experimental setup and polishing conditions are illustrated. Then the material removal rate and surface roughness under different vibrating motions are compared to find the suitable polishing condition. After that, the relationship between polishing pressure and material removal rate is revealed. Finally, a model of material removal mechanism in micro-optic polishing is proposed.

1 Experimental setup and polishing conditions

The experimental setup for micro-optic polishing characteristics investigation is shown in Fig. 1. It was presented in the previous research which consists of a magnetostrictive vibrating polisher, a real-time polishing force control system and a

5-axis NC machine [2]. Major polishing conditions are summarized in Table 1. The workpiece made of tungsten carbide is lapped prior to polishing. Tool dwell control method by Zigzag scanning is adapted to polishing experiments as shown in Fig. 2.

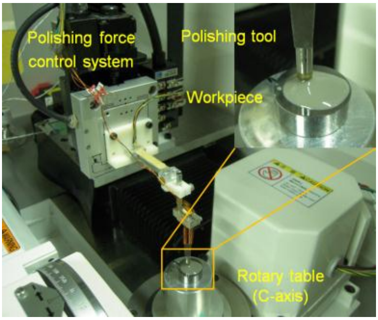

Figure 1: Experimental setup for polishing Characteristics investigation

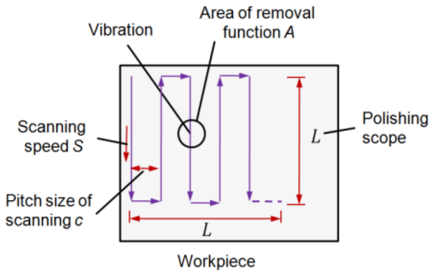

Figure 2: Tool dwell control method by Zigzag scanning

Table 1 Main polishing conditions

Workpiece material	Binderless tungsten carbide
Polisher head Radius Hardness	Polyurethane 1 mm IRHD 90
Abrasive Grain size Density	Diamond slurry 0.1 μm 1 wt%
Polishing forces	5.0 - 50.0 mN (Increment: 5.0 mN)
Polishing scope	400×400 μm^2
Scanning speed	3.5 mm/min
Pitch size	20 μm

2 Relationships between polishing parameters

2.1 Material removal rate and surface roughness

Some experiments are conducted to compare the material removal rate and surface roughness under different vibrating motions. The magnetostrictive vibrating polisher scanned on the work-piece with the lateral, elliptical (phase difference of 45 deg) and circular vibrating motion, respectively [2].

The polishing force is set to 5 mN and the grain size of diamond slurry is opted to 0.1 μm with polisher radius of 1 mm. The data is measured by NewView 6000 (Zygo Corporation) and the results are summarized in Table 2. It is proved that circular vibrating motion has the highest polishing efficiency with the removal depth up to 50 nm/min.. The surface roughness is reduced over 50% by the 2D vibrating motion such as elliptical and circular vibration than that of the 1D or lateral vibrating motion..

Table 2 Removal depth and surface roughness under different vibrating motions

Vibrating motion	Removal rate*1	Surface roughness*2
Lateral	30 nm/min.	8 nm Rz (1 nm Ra)
Elliptical	40 nm/min.	3.4 nm Rz (0.35 nm Ra)
Circular	50 nm/min.	3.1 nm Rz (0.4 nm Ra)

*1 Average in 10 times *2 Measurement area size: 70 x 50 μm^2

2.2 Polishing pressure and material removal rate

Further investigations are conducted to check the relationship between polishing pressure and material removal rate. The circular vibrating motion and the grain size of 0.1 μm of diamond slurry are adopted.

The results are shown in Fig. 3. It is found that the material removal rate shows agreement with Preston's equation when the polishing pressure is under 345 kPa. But when the polishing pressure exceeds 345 kPa the removal rate decreases gradually with the increasing of polishing pressure.

In order to explain this phenomenon, a model of material removal mechanism for micro-optic mould polishing is proposed for the first time in this research as shown in Fig. 4. Although the fundamental material removal mechanism is poorly understood and a holistic knowledge still does not exist since the physical scale of material removal processes in polishing is difficult (practically impossible) to be observed directly [5], there is a general view that two kinds of abrasive motion which are two-body abrasion and three-body abrasion effect on the work-piece during loose abrasive polishing process. Two-body abrasion happens when abrasives become embedded and slide over the surface, while three-body abrasion is generated when abrasives become freely rolling abrasives [3]. In this experiment, the urethane polisher is soft and the polishing spot which is the area of polishing removal function is very small (under 0.2 mm^2). So when the polishing pressure is over 345 kPa the number of two-body abrasives between the polisher and work-piece decreases with the polishing pressure. The two-body abrasives are dropped out due to the high pressure and the number reduces, although maybe some of them transform to the three-body abrasives, the total material removal rate decreases.

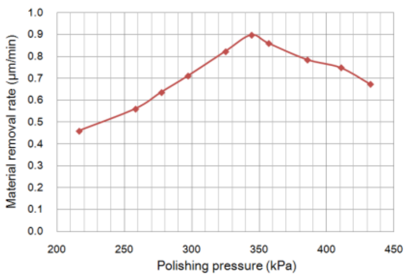

Figure 3: Relationship between polishing Pressure and material removal rate

Figure 4: Material removal mechanism in micro-optic mould polishing

3 Conclusions

According to the above-mentioned experiment results, it can be concluded that in case of micro-optic mould polishing, there is a certain value of polishing pressure which the material removal rate researches to a maximum. In other words, the material removal rate does not always increase in linearity with the polishing pressure, and when the polishing pressure exceeds a certain value, it decreases. So it will be a great complement to the application of Preston's equation in micro-optic polishing.

References:

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