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An Approach to Cutting State Monitoring in End Milling of Hard and Brittle Materials

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Abstract

Microfabrication techniques are indispensable to manufacturing small parts of the tablet-type device, the cellular phone, and so on. In recent years, microfabrication by using a small diameter end mill has been used widely in manufacturing process of optical components and semiconductor because high speed machining by using a small diameter end-mill has been put into practical use. Therefore, since the effect of cutting edge on the machining accuracy is very large, it is very important to detect the state of small diameter end mill in real time. However, since the size of tool wear of small diameter end mill are very small, it is difficult to detect the state of tool. On the other hand, glass materials are widely used for the optical components in recent years. However, glass materials are difficult to cut because they are hard and brittle materials. In addition, the glass materials must be machined as the ductile-mode cutting without brittle cracks. The purpose of this study is to propose an effective method for monitoring the cutting state of glass milling in real time. For this purpose, cutting tests were performed in order to investigate the effective parameters for monitoring the cutting mode in glass milling. As a result, it was found in the experiments that the RMS value of cutting force showed different tendencies between ductile-mode and brittle-mode cuttings. Consequently, the cutting mode of the glass could be estimated by the RMS value of cutting force.

Keywords : Glass, RMS value, Monitoring, Cutting Force, End Mill

1. Introduction

In recent years, microfabrication using small-diameter end mills has been used widely in the manufacture of optical components and semiconductors as high-speed machining using small-diameter end mills has increasingly been put to practical use. Many researchers have tried to clarify the mechanism of micro-milling [1,2].

Glass materials have been widely used in optical components in recent years because they are chemically stable and are well suited for use in optical devices. Examples of glass optical components are the lab-on-chips and micro total analysis systems (µTAS). However, glass materials are difficult to machine because they are hard and brittle materials. In addition, final fracture can easily occur once-cracking occur. Therefore, glass materials must be machined using ductile-mode cutting to prevent brittle cracks [3]. In ductile-mode cutting of glass, the cutting thickness per cutter must be very small. Therefore, the feed rate must be very low. Consequently,

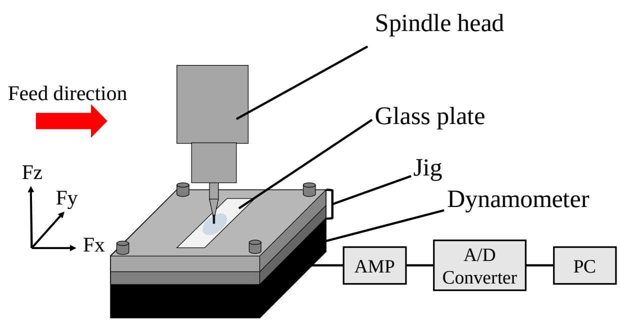


Figure 1. Experimental apparatus

it is important to monitor the cutting state during glass milling.

The purpose of this study is to develop an effective method for real-time detection of the cutting state in end milling of hard brittle materials. To this end, cutting tests were performed to identify parameters that are useful in monitoring the cutting state in glass milling.

2. Experimental Apparatus

The experimental apparatus used in this study is shown in Fig. 1. Cutting tests were performed using a vertical machining centre. The milling tools were ball-end mills with a radius of 0.2 mm made of cemented carbide.

Each end mill was mounted in such a way that the eccentricity of the end mill would be 1µm or less, as measured using a dial gauge, as shown in Fig. 2. The cutting conditions are listed in Table 1. In the cutting tests, the groove on the workpiece was formed by a milling cutter moving horizontally. The cutting conditions were determined in preliminary cutting

Table 1 Cutting conditions

Work piece	Glass	Crown glass
Tool	Type	Cemented Carbide Ball-end mill
	Nose radius [mm]	0.2
	Number of flutes	2
	Overhang [mm]	15
Rotational speed N [min^{-1}]		10000 , 12500 , 15000
Feed rate f [mm/min]		0.05 ~ 0.50 , 0.10~0.60 , 0.15~0.70
Inclination angle [deg]		90
Axial Depth of cut [µm]		20
Cutting fluid		Water

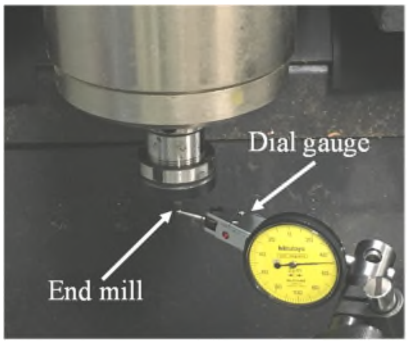


Figure 2. Measurement of tool eccentricity

tests. The workpiece to be machined had a microgroove 20μm in depth from the surface. The workpiece was made of crown glass plate 1mm in thickness. The workpieces were attached in such a way that the inclination of the workpiece was 1μm or less, as measured using a dial gauge.

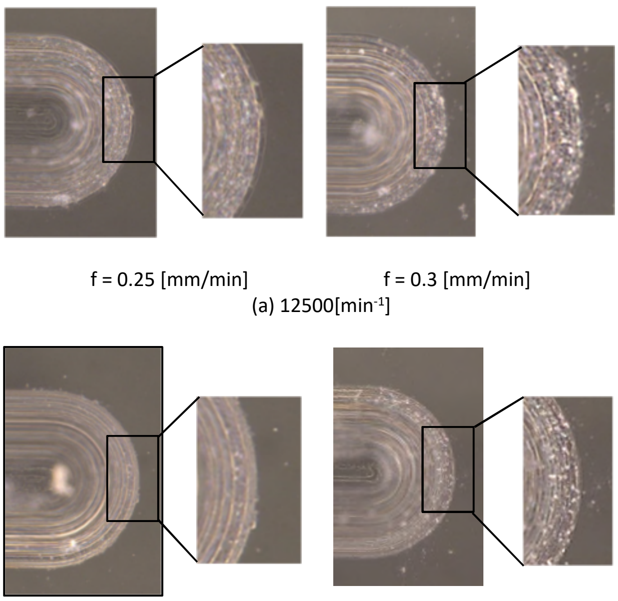
The cutting tests were performed with water on the clamping device, which has a water pool. The cutting forces Fx, Fy, and Fz were measured with a dynamometer, as shown in Fig. 1. The dynamometer was a piezoelectric quartz force transducer affixed to a table. The machined surface of the glass material were observed using a digital micro-scope.

The cutting forces measurements were transmitted to a personal computer via an A/D converter board every 50μs.

3. Experimental results

3.1. State of machined surface

Figure 3 shows the state of the machined surface. Even if the feed rate increases, the bottom of the groove is machined in ductile-mode cutting without microfracture in both rotational speeds. In upper figure, the edge of the groove is machined without microfracture at a feed rate of 0.25 mm/min, with microfracture at a feed rate of 0.3 mm/min. microfracture were observed at feed rates of 0.3 mm/min or more. In lower figure, the edge of the groove is machined without microfracture at a feed rate of 0.4 mm/min, with microfracture at a feed rate of 0.45 mm/min. Microfracture were observed at feed rates of 0.45 mm/min or more.



f = 0.25 [mm/min] f = 0.3 [mm/min]

(a) 12500[min^{-1}]

f = 0.4 [mm/min] f = 0.45 [mm/min]

(b) 15000[min^{-1}]

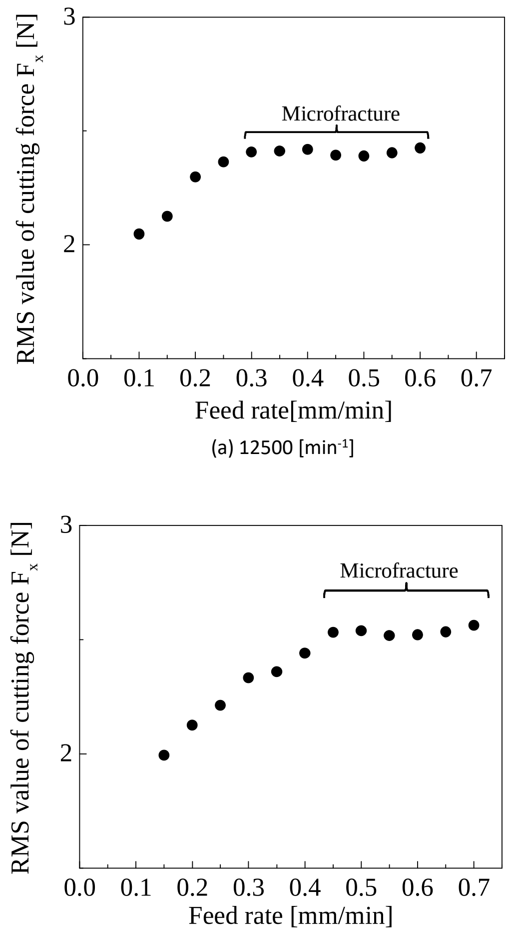
100μm

Figure 3. State of machined surface

3.2. RMS value of cutting force

The maximum value of the cutting force in each direction increases gradually with increasing feed rate. However, it is not possible to detect the transition of the cutting state from the maximum value of the cutting force in all directions. For detecting the transition of the cutting state, the RMS value was calculated from the measured cutting force.

Figure 4 shows the relationship between the feed rate and the RMS value of the cutting force Fx. The RMS value was calculated from the sampled data. As shown in both figures, the RMS value linearly increases in ductile-mode cutting area, and the RMS value is almost constant in cutting area with microfracture.



(b) 15000 [min^{-1}]

Figure 4. RMS value of cutting force Fx

4. Conclusions

The RMS value of cutting force increases with increasing feed rate in ductile-mode cutting, and it is almost constant with increasing feed rate in cutting area with microfracture. Therefore, the transition of cutting state in glass milling could be estimated by the RMS value of the cutting force.

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