Influence of cutting force and tool geometry on whole quality in glass microdrilling

M. Onozawa[1], R. Koike[1], Y. Murakami[1], Y. Kakinuma[1], T. Aoyama[1]
[1]*Department of System Design Engineering, Keio University, Japan*
onozawa@ams.sd.keio.ac.jp

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Abstract

Recently, demands for micromachining of hard and brittle materials such as glass have been increasing. However, it is difficult to find an adequate machining condition for these materials. In this study, we investigate influence of cutting force and tool geometry on whole quality in glass microdrilling by utilizing cutting force control. Furthermore, observation with a high-speed camera is carried out to capture chipping behavior of the whole outlet. The experimental result shows a high correlation between cutting force and whole quality.

Introduction

Demands for micromachining of glass have been increasing to produce optical devices such as touch panels because smartphone and tablet markets are growing drastically. However, the glass is difficult to cut because it is a kind of hard and brittle material. In order to machine glass accurately, several machining methods have been proposed. For examples, Xin *et al*. [1] presented femtosecond laser machining in high-aspect ratio, and Ghobeity *et al.* [2] proposed abrasive jet micromachining on machined whole. Although these methods make the surface quality fine, they require special apparatuses and high cost. On the other hand, cutting is highly efficient and relatively easy to introduce. Therefore, it is strongly required in glass cutting to maintain a fine machining accuracy without chipping. To machine glass finely, we have developed a prototype 3-axis high-precision machine tool with a function to realize sensor-less cutting force control. In this study, we investigate influence of cutting force and tool geometry on whole quality in glass microdrilling by utilizing the cutting force control.

1. Sensor-less force control system

Based on a motion model of cutting process, cutting force in the feed direction is estimated by utilizing information about position response and current reference [3]. The cutting force in z axis can be estimated as follows:

$$\hat{F}_{cut} = \frac{g_{cut}}{s + g_{cut}} \left(K_{tn} I_a^{ref} - M_n s \hat{v}^{res} - \hat{F}_{fric} - \hat{F}_{grav} \right) \qquad (1)$$

where g_{cut} is the cutoff frequency of the cutting force observer [rad/s], K_t is the thrust force coefficient [N/A], I_a^{ref} is the current reference [A], M is the mass of the stage [kg], v is the velocity [m/s], F_{fric} is the friction force [N], F_{grav} is the gravity force [N], (*subscript*)n is the nominal value, and $\widehat{(subscript)}$ is the estimated value. Figure 1 shows a block diagram of cutting force observer applied to a linear motor driving table in z direction designed on the bases of Eq. 1. By feeding back the estimated cutting force to cutting force controller, the sensor-less force control system is able to be designed. The block diagram is represented in Fig. 2.

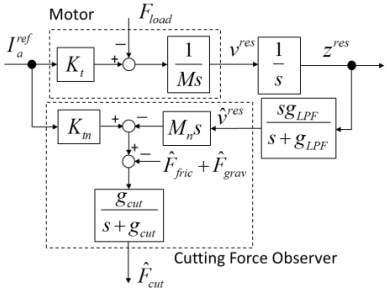


Figure 1: Block diagram of cutting force observer

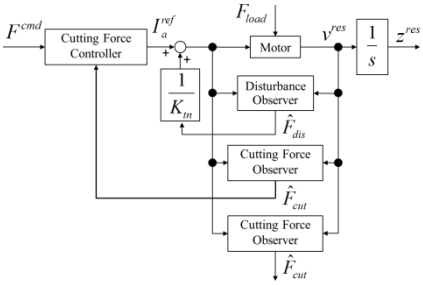
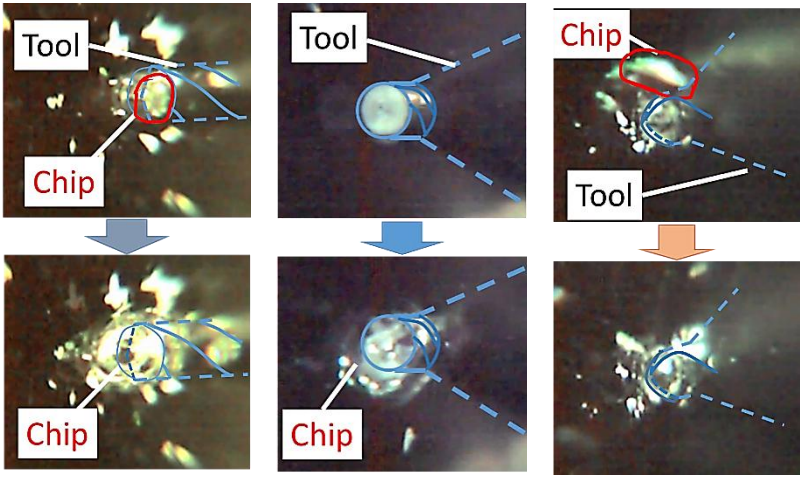


Figure 2: Block diagram of cutting force control system

2. Experiment

Drilling tests are carried out using a prototype 3-axis high-precision machine tool capable of sensor-less force control shown in Fig. 3 The z-axis stage is equipped with shaft type linear motor, air-slider, and air balancer so that the friction force and the gravity could be negligible. Besides, the shaft type linear motor is cogging-less. By these mechanisms, the cutting force can be accurately estimated. Chipping behavior of whole outlet is observed with a high-speed camera with 2000 frames s^{-1}. The observation setup is shown in Fig. 4Three kinds of tools are prepared listed in Table 1 to evaluate the relation between the tool geometry and the chipping around the whole outlet. The rotation speed is set to 30000 min^{-1}. The cutting force command is set



(a) Drilling with a drill (b) Drilling with a square endmill (c) Drilling with a ball endmill

Figure 5: Frame-by-frame images of the whole outlet (at 5 N of cutting force)

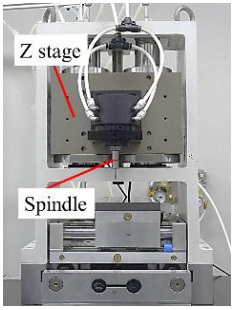


Figure 3: Prototype of 3-axis high-precision machine tool

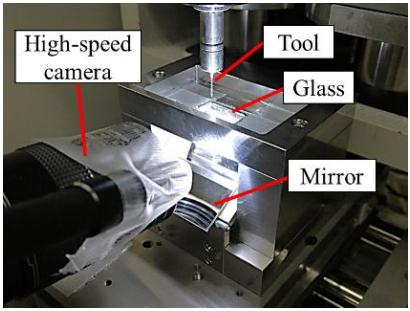


Figure 4: Observation setup

from 3 N to 7 N in each drilling test. The diameters of the tools are 1.0 mm.

Table 1: Tool specification

Tool	Geometry
Cemented carbide drill	2-Flutes, Tip angle 120 degrees
Square endmill	2-Flutes
Ball endmill	2-Flutes

Figure 5 shows the observation results of all tools for 0.015 s with the high-speed camera at the backside of glass. Two stage chipping takes place in case of cemented carbide drill, as shown in Fig. 5(a). In the first stage, the small chipping is caused by the chisel edge of the drill. In the next stage, the larger

chipping happens around the drill corner. Figure 5(b) shows that the chipping occurs before penetrating the glass with square endmill. Although the small chipping is observed at the center of rotation as well as drill, ball endmill could reduce the large chipping around the outer circumference at 5 N of thrust force.

Then, the machining accuracy is evaluated from the perspective of the chipping size at the whole outlet. In this study, the chipping size is defined as a maximum chipping length as shown in Fig. 6. The relation between controlled cutting force and the chipping size is shown in Fig. 7. In drilling with the square endmill, 3 N is not enough force to drill the glass. In case of the drill, chipping size is relatively larger than the one of other tools in each cutting force. In the square endmill, chipping size increase in proportion to cutting force. Compared between three tools, the ball endmill has a possibility to effectively reduce chipping.

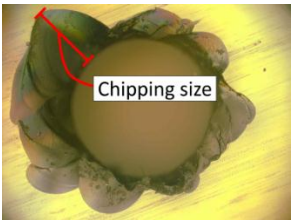


Figure 6: Chipping size

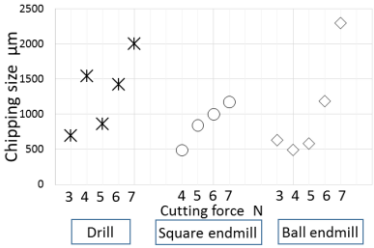


Figure 7: Relation between cutting force and chipping size (5 samples average in each)

3. Conclusion

The influence of cutting force and tool geometry on whole quality in glass microdrilling is investigated by utilizing cutting force control. From the observation result, in drilling with a cemented carbide drill, two stage chipping takes place and the geometry of the drill corner is considered to be an important portion to avoid chipping. The experimental result shows that the chipping size of the whole outlet in glass drilling depends on cutting force and tool geometry. The geometry of the ball endmill would be appropriate for reduction of large chipping.

References:

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