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Fundamental Study of Hole Machining of Brittle Materials by Ultrasonic Complex Vibration

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Abstract: Ceramic materials, in comparison with metals, have many advantageous properties. Ultrasonic longitudinal vibration is currently used in combination with polishing slurry as an effective method for machining holes in brittle materials. However, this method suffers from the disadvantages of low removal rate and low machining accuracy. We aim to resolve these issues by using ultrasonic complex (longitudinal-torsional) vibration. In this study, soda-lime glass is used as the processed material in both ultrasonic longitudinal and complex vibration, and the machining time is measured to assess the hole machining characteristics. The results demonstrate that ultrasonic complex vibration shortens the machining time.

1. Introduction

Ultrasonic longitudinal vibration is currently used in combination with polishing slurry as an effective method for machining holes in brittle materials. However, this method suffers from the disadvantages of low removal rate and low machining accuracy. Here, we aim to resolve these issues by using ultrasonic complex (longitudinal-torsional) vibration. Therefore, we have developed a new method for machining holes into brittle materials by using polishing slurry together with an ultrasonic complex vibration source with diagonal slits on the vibration converter, which generates longitudinal and torsional vibration [1-3]. In this study, we used soda-lime glass as the processed material and measured the machining time to assess the machining characteristics of holes (diameter: 8 mm; depth: 4 mm) created using longitudinal or complex vibration sources with a processing pressure of 0.5 MPa (14 N).

2. Ultrasonic vibration source

Figure 1 shows the ultrasonic vibration source, which consists of a 20 kHz bolt-clamped Langevin-type transducer, a uniform rod with a diameter of 56 mm (designed such that the resonant frequency is 20 kHz), an exponential horn for amplitude amplification (amplification factor: ≈4.6; material: duralumin) and two types of horns.

Figure 2 shows the schematics of the complex vibration horn with diagonal slits. The dimensions of the complex vibration horn are as follows. Length: 120 mm; position of the extension part: x = 80–120 mm (x = 80 mm is the position of the torsional vibration node); diameter of the extension part: 8 mm; and diagonal slit position: x = 50 mm. The external appearance of the diagonal slits is shown in Fig. 3, and the ultrasonic vibration source with the complex vibration horn is referred to as the complex vibration source below. Furthermore, the longitudinal vibration horn is Fig. 2 without diagonal slits and of position of the extension part at x = 60–120 mm (referred to as longitudinal vibration source below). In addition, an edge (diameter: 5.3 mm; depth 10 mm) is fabricated at the tip of the two horns for hole machining.

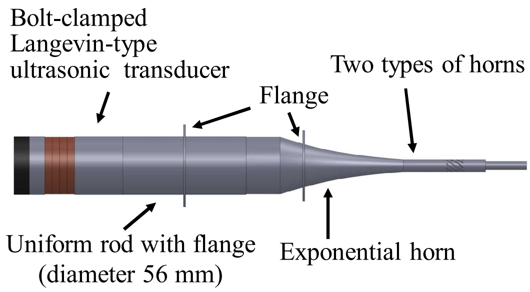


Fig. 1 Ultrasonic vibration source.

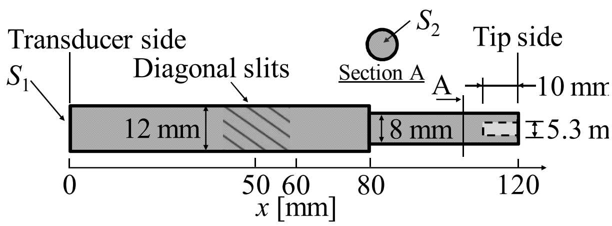
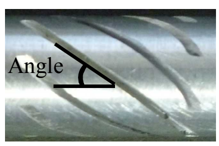


Fig. 2 Complex vibration horn.



Center position: x = 50 mm
Slit length: 19 mm
Slit groove width: 0.5 mm
Slit depth: 3.5 mm
Slit inclination angle: 35°
Number of slits: 8

Fig. 3 Appearance and characteristics of diagonal slits in this study.

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3. Characteristics of Hole Machining Time

The experiments involved a comparison of machining holes in soda-lime glass using longitudinal and complex vibration sources. Figure 4 shows the ultrasonic machining device, which is a converted benchtop milling machine. The ultrasonic vibrator is affixed to the device with flanges on the uniform rod (56 mm in diameter) and the exponential horn (Fig. 1). Table 1 shows the machining conditions. Five soda-lime glass plates were glued together to prevent chipping. Polishing slurry was supplied to the processed surface of the glass at a rate of approximately 1 L/min. To increase the cutting depth, pressure was applied from the bottom side of the soda-lime glass. The longitudinal vibration amplitude at the tip side of both vibration sources was 10 $\mu m_{0\text{-}p}$ during machining. In addition, the torsional vibration amplitude of the complex vibration source was 23$\mu m_{0\text{-}p}$ in this study.

Figure 5 shows the experiment results for the relationship between processing depth and machining time. The vertical and horizontal axes in Fig. 5 represent the machining time and the processing depth, respectively. According to Fig. 5, the machining time increasing with increases similarly for both vibration sources the processing depth in the 0.0–1.5 mm range. The machining time in the case of the complex vibration source is linearly proportional to machining depth in the 1.5–4.0 mm range, and the average machining time for depths of up to 4.0 mm was 333 s. On the other hand, the machining time of the longitudinal vibration source increases abruptly with respect to machining depth in the 1.5–4.0 mm range, and the average machining time for depth of up to 4.0 mm depth was 1220 s.

These results suggest that the machining speed of the longitudinal vibrator decreases with increasing processing depth, whereas the machining speed of the complex vibrator is constant. Also, complex vibration source are expected to improve the machining time as compared with longitudinal vibration source in the measurement range since torsional vibration is considered to facilitate the movement of polishing slurry, thus allowing it to circulate more easily and thus making the process of machining hole more efficient.

4. Conclusions

In this study, a longitudinal vibration source and a complex vibration source were used for machining holes in a brittle material (soda-lime glass). The machining speed of the longitudinal vibration source was found to decrease with increasing processing depth, whereas the machining speed of the complex vibration source was constant.

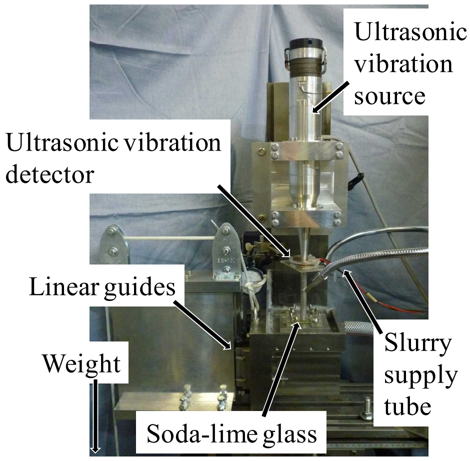

Fig. 4 Ultrasonic machine.

Table 1 Machining conditions.

Horn material	Duralumin
Processed material	Soda-lime glass
Hole dimensions	Depth, 4.0 mm: Diameter, 8.0 mm
Abrasive grain	Silicon carbide #600(20 μm) Weight ratio grain:water = 1:10
Processing fluid	Water
Processing pressure	0.5 MPa (14 N)

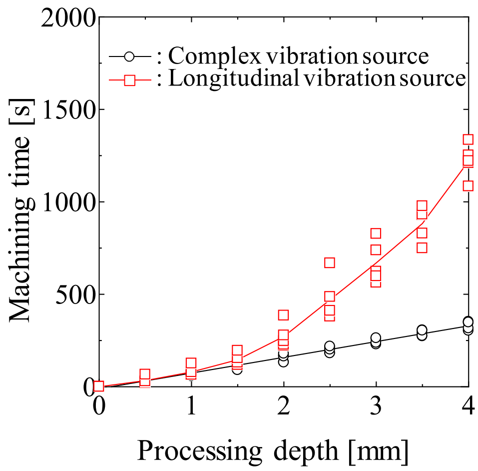

Fig. 5 Relationship between processing depth and machining time.

References

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