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Hole Machining of Brittle Materials by Ultrasonic Longitudinal-Torsional Vibration
超音波縦-ねじり振動を用いた脆性素材の穴あけ加工の検討

Takuya Asami† and Hikaru Miura (College of Science and Technology, Nihon Univ.)
淺見拓哉†，三浦 光（日大・理工）

1. Introduction

Ceramic materials are used for various purposes in virtually all fields of industry. However, processing of brittle materials such as ceramics is associated with a number of problems. Currently, using a combination of ultrasonic vibration and a polishing slurry has been shown to be effective for machining holes in brittle materials such as glass. However, conventional ultrasonic methods use only longitudinal vibration and only few studies have been conducted on ultrasonic machining using complex vibration and polishing slurry. Therefore, we have developed a new method for machining holes in brittle materials which uses polishing slurry together with an ultrasonic complex vibration sources with diagonal slits on the vibration converter[1, 2]. In this study, using soda-lime glass as the processed material, the machining time is measured to assess the machining characteristics of a hole (diameter: 8 mm; depth: 4 mm) created using complex or longitudinal vibration sources by varying the pressure during processing.

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 shown in **Fig. 2**.

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.

Email address: asami.takuya@nihon-u.ac.jp

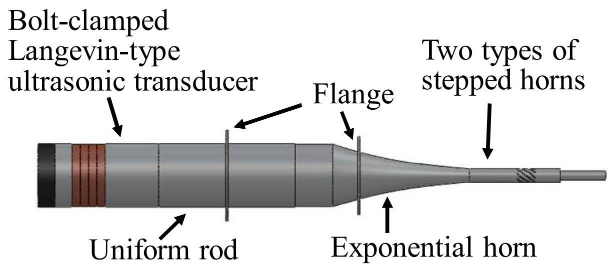


Fig. 1 Ultrasonic vibration source.

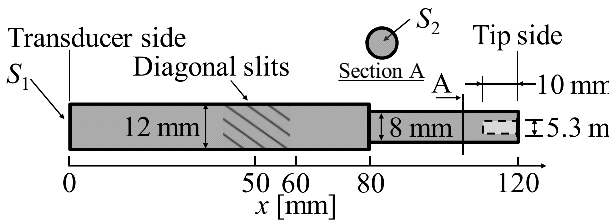
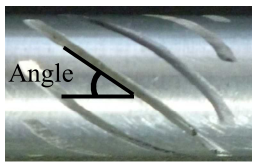


Fig. 2 Complex vibration horn.



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.

3. Experimental Processing of Soda-Lime Glass with Vibration Sources

The experiments involved a comparison of machining holes in soda-lime glass using longitudinal and complex vibration sources. Five soda-lime glass plates were glued together to prevent chipping. **Table I** shows the machining conditions. 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.

3.1 Machining time

Figure 4 shows the experimental results for machining time. The vertical and horizontal axes represent the machining time and the processing pressure, respectively. According to the figure, the machining time of both vibration sources decreases with increasing the processing pressure in the samll range of processing pressure. The shortest average machining time was approximately 261 s for the complex vibration source and 390 s for the longitudinal vibration source for a processing pressure of 1.00 and 1.75 MPa, respectively. Therefore, the optimal processing pressures for complex and longitudinal vibration sources were assumed to be 1.00 and 1.75 MPa in the measurement range, and the machining time of both vibration sources increases with increasing the processing pressure in the large range of processing pressure. Based on this result, complex vibration sources are expected to improve the machining time as compared with longitudinal vibration sources when the optimal processing pressure is applied.

3.2 Machining speed at the optimal processing pressure

Figure 5 shows the experimental results for the machining speed of the complex vibration source (processing pressure: 1.00 MPa; input electric power: 34 W) and the longitudinal vibration source (1.75 MPa, 27 W). The vertical and horizontal axes represent the machining speed and the precessing depth, respectively. According to Fig. 5, the machining speed of the longitudinal vibration source decreases with increasing the processing depth interval. In addition, while the machining speed of both vibration sources is about the same for a processing depth in the range of 0.0-1.5 mm, beyond this the complex vibration source maintains an almost constant machining speed which is greater than that of the longitudinal vibration source. Clearly, the machining time is improved by the use of a complex vibration source. We assume that torsional vibration facilitates the processing of the hole side of the glass such that the polishing slurry can circulate more easily.

4. Conclusions

In this study, the machining of soda-lime glass with longitudinal and complex vibration sources was investigated by varying the processing pressure. As a result, the following points were clarified. Firstly, the machining time when using a complex vibration source is notably shorter as compared with that using a longitudinal vibration source at the optimal processing pressure. Secondly, in contrast with longitudinal vibration sources, the machining speed of complex vibration does not decrease with increasing the processing depth in this measurement range.

Table I Machining conditions.

Material of horn	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	0.50-2.25 MPa

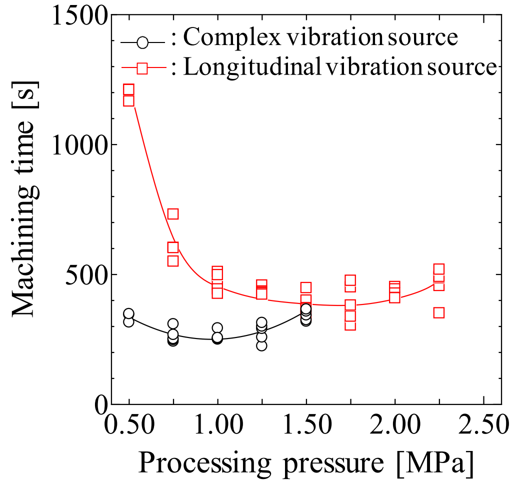


Fig. 4 Relationship between processing pressure and machining time.

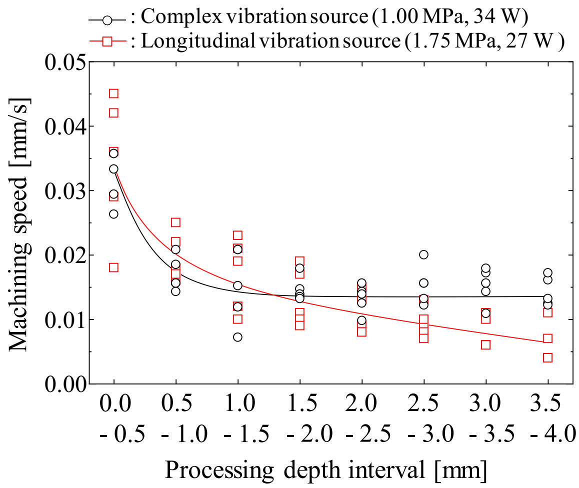


Fig. 5 Relationship between processing depth interval and machining speed.

References

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2) T. Asami and H. Miura : Jpn. J. Appl. Phys. **51** (2012), 07GE07.