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Observation of Machining Marks Caused by Ultrasonic Machining Using Complex Vibration
複合振動による超音波加工で生じた加工痕の観察

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1. Introduction

Ultrasonic machining is one method for machining brittle materials. In this method, ultrasonic vibration of a tool horn and abrasive slurry is used for processing. This does not require rotation of the tool horn, and so the method can be used for processing in square, triangular, and other-shaped holes. Conventional ultrasonic machining methods use only longitudinal vibration, although a few studies have been conducted on ultrasonic machining using complex vibration and abrasive slurry. We have developed a new ultrasonic machining method that uses ultrasonic complex vibration caused by longitudinal and torsional vibration. In previous studies, we found that the machining time was notably shorter when using complex vibration than when using only longitudinal vibration[1,2].

In this paper, we describe machining marks on soda-lime glass caused by ultrasonic machining. Marks from using longitudinal vibration are compared with marks from using complex vibration. Our aim is to elucidate the mechanism of ultrasonic machining with complex vibration.

2. Ultrasonic Vibration Source

Figure 1 shows a schematic diagram of an 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 one of two types of tool horns (longitudinal or complex).

For processing by longitudinal vibration, the tool horn is a step horn. The ultrasonic vibration source using this horn without diagonal slits is referred to as the longitudinal vibration source below. In contrast, for processing by complex vibration, the tool horn is a step horn with diagonal slits that act as a longitudinal–torsional vibration converter. The ultrasonic vibration source with this horn is referred to as the complex vibration source below. Both tool horns have an annular tip (outer diameter: 8.0 mm; inner diameter: 5.3 mm).

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3. Vibration locus at tip side

The vibration loci of the tips of the vibration sources operating at the longitudinal vibration resonance frequency (complex vibration source: 20.3 kHz; longitudinal vibration source: 20.6 kHz) were measured by observing the vibratory effect on soda-lime glass with two laser Doppler vibrometers (Ono Sokki: LV-1710). **Figure 2** shows the vibration locus for longitudinal–torsional vibration at the tip. The vertical and horizontal axes in Fig. 2 represent the values of torsional and longitudinal vibration, respectively, normalized by the maximum value of the longitudinal vibration amplitude of each vibration source. In Fig. 2, the vibration locus of the longitudinal vibration source is seen to be a straight line in the direction of longitudinal vibration. From this, an effect of vibration from the tip to the glass was found along the longitudinal direction of the tool horn. In comparison, the vibration locus of the complex vibration source describes an oblique line. Torsional vibration was generated from longitudinal vibration by the

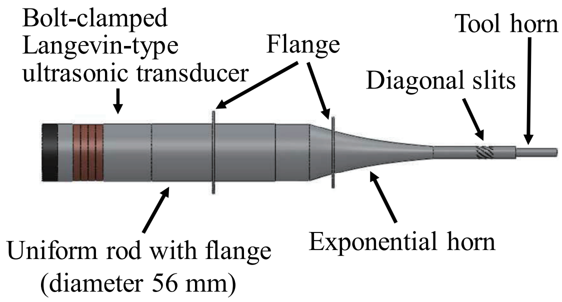


Fig. 1 Complex ultrasonic vibration source.

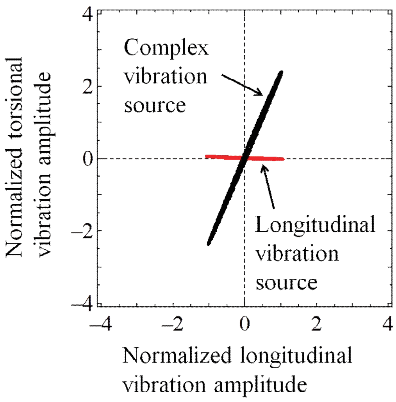


Fig. 2 Vibration loci at the tip of the tool horn.

diagonal slits, and the resulting torsional vibration was rather strong, reaching 2.3-fold the amplitude of the longitudinal vibration. From this, the effect on glass is related to the longitudinal and angular direction of the tool horn.

3. Observation of machining marks

The experiments involved a comparison of machining marks on soda-lime glass from using longitudinal and complex vibration sources. **Table I** shows the machining conditions. The recorded processing pressures correspond to the shortest processing times obtained in the previous study[2]. **Figure 3** shows photographs of the glass before and after dispersion of abrasive grain. In this experiment, the longitudinal vibration amplitude at the tip of each vibration source was 10 $\mu m_{p\text{-}p}$, and the torsional vibration amplitude of the complex vibration source was 23 $\mu m_{p\text{-}p}$.

Figure 4 shows the machining marks on the surface of soda-lime glass from the longitudinal and complex vibration sources. The concentric circles in the figure shows the outer diameter and the inner diameter of the tip of the horn. The white parts of the figure are regions of glass removed by the abrasive grains and ultrasonic vibration. The areas of glass removed from the concentric circles, as measured by binarization, are 2.9 mm^2 (longitudinal vibration) and 10.7 mm^2 (complex vibration). **Figure 5** is an enlarged view of Fig. 4. The machining marks made with the longitudinal vibration source are often discrete points. In contrast, the machining marks made with the complex vibration source are often linear. We attribute this linearity to the scraping of glass by torsional vibration. Additionally, the area of glass removed was increased by using complex vibration. We therefore suggest that the time needed to machine holes would be reduced by using a complex vibration source.

4. Conclusions

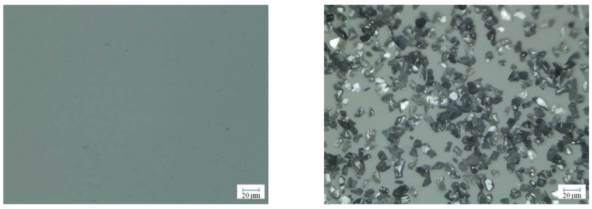
In this study, we observed surface machining marks made on glass by ultrasonic machining using complex vibration. As a result, the following points were clarified. First, the area of removed glass was increased by use of complex vibration. Second, the machining marks caused by a complex vibration source were linear rather than discrete points.

References

1) T. Asami and H. Miura : Jpn. J. Appl. Phys. **51** (2012), 07GE07.
2) T. Asami and H. Miura : Proc. of Symp. on Ultrasonic Electronics, Vol. 34, pp.273-274(2013).

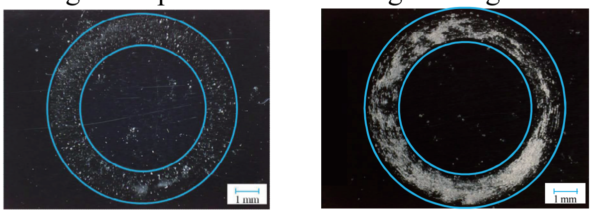
Table I Machining conditions.

Material of tool horn	Duralumin
Process materiaol	Soda-lime glass
Abrasive grain	Silicon carbide ＃600 (20 μm)
Processing pressure	1.75 MPa (longitudinal)
	1.00 MPa (complex)
Number of cycle	600 (sine wave)



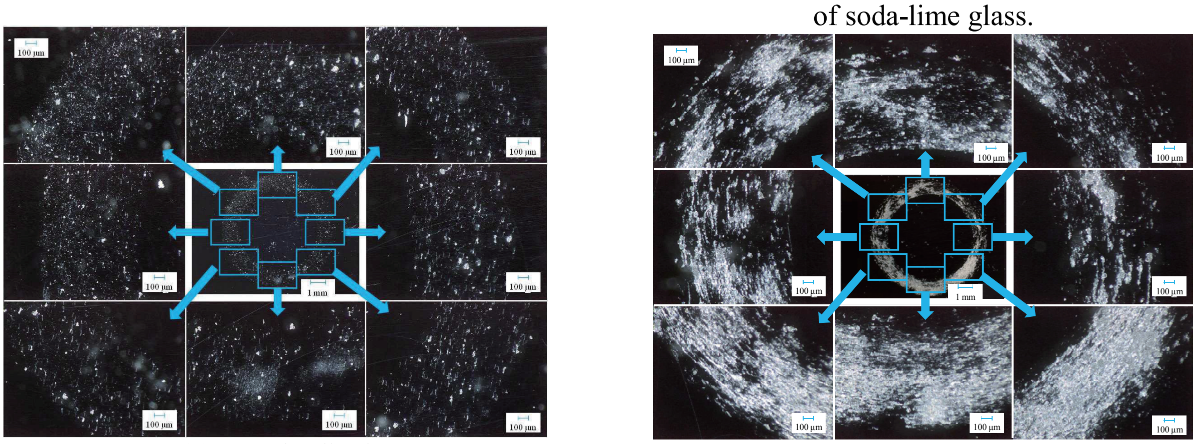
(a) Before dispersion (b) After dispersion

Fig. 3 Dispersion of abrasive grain to glass.



(a) Longitudinal (b) Complex

Fig. 4 Machining marks on surface of soda-lime glass.



(a) Longitudinal (b) Complex

Fig. 5 Detail view of machining marks on surface of soda-lime glass.