Available online at www.sciencedirect.com
ScienceDirect
Physics Procedia 70 (2015) 118 – 121
Physics Procedia

2015 International Congress on Ultrasonics, 2015 ICU Metz

# Study of Ultrasonic Machining by Longitudinal-Torsional Vibration for Processing Brittle Materials

## -Observation of Machining Marks-

Takuya Asami and Hikaru Miura *

*College of Science & Technology, Nihon University, Chiyoda-ku,101-8308 Tokyo, Japan*

---

**Abstract**

The ultrasonic machining is a processing method using both the ultrasonic vibration of the tool horn and abrasive slurry. We studied a new ultrasonic machining method using ultrasonic complex vibration caused by the longitudinal and torsional vibration. In previous studies, we found that the machining speed and the machining accuracy when using a complex vibration are improved as compared with that using conventional ultrasonic machining method. However, the mechanism of ultrasonic machining using longitudinal-torsional vibration has not been clarified. In this presentation, we study that the observation of machining marks of soda-lime glass caused by ultrasonic machining using complex vibration.

*Keywords:* Ultrasonic ; Machining ; Torsional vibration ; Longitudinal vibration ; Abrasive slurry.

---

## 1. Introduction

Brittle materials are used for various purposes in virtually all fields of industry. Using a combination of ultrasonic vibration and abrasive slurry is effective for machining holes in brittle materials. However, conventional ultrasonic machining methods use only longitudinal vibration. The examples of the problems are the machining time and the machining accuracy. The machining time was affected by the longitudinal vibration amplitude and the processing pressure. Especially, the longitudinal vibration amplitude was the same as the diameter of the abrasive

---

* Corresponding author. Tel.: +81-3-3259-0776 .
*E-mail address:* miura.hikaru@nihon-u.ac.jp

doi:10.1016/j.phpro.2015.08.056

grain in order to achieving the fastest machining time[1]. This value of the longitudinal vibration amplitude determined the limit of the machining time. There is a possibility that the large longitudinal vibration break the processed material. On the other hand, the machining accuracy was greatly affected by the diameter of the abrasive grain. We consider that the ultrasonic machining of the longitudinal-torsional vibration is expected to improve both machining time and accuracy. We suppose that the longitudinal-torsional vibration possible to transmit the large force to the processed material without breaking. Accordingly, we have developed a new ultrasonic machining method using ultrasonic complex vibration caused by the longitudinal and torsional vibration in order to improve the machining speed and the machining accuracy compared with longitudinal vibration machining[2-5].

In previous studies, we found that the machining speed and the hole roundness error as a machining accuracy when using a complex vibration are improved as compared with that using conventional method. However, the mechanism of ultrasonic machining method using ultrasonic longitudinal-torsional vibration has not been clarified.

In this presentation, we study that observation of machining marks of soda-lime glass caused by ultrasonic machining using longitudinal or longitudinal-torisonal vibration as a basic study of understanding mechanism of ultrasonic machining method using ultrasonic longitudinal-torisonal vibration.

## 2. Ultrasonic vibration source

Figure 1 shows the ultrasonic vibration source[4,5] used in this experiment. It consists of a 20-kHz bolt-clamped Langevin-type transducer, a uniform rod with a diameter of 56 mm (designed such that the longitudinal vibration resonance frequency is 20 kHz), an exponential horn for displacement amplification (length: 155 mm; large-end diameter: 55 mm; small-end diameter: 12 mm; amplification factor: ≈4.6; material: duralumin), and two types of tool horns. The length of the tool horns is 120 mm (designed such that the longitudinal vibration resonance frequency is 20 kHz).

In the case of processing by longitudinal vibration, the tool horn is a step horn. The step position is node position of the longitudinal vibration. The diameter was changed from 12 mm to 8 mm in the step position. The ultrasonic vibration source with this horn is referred to as the longitudinal vibration source below. On the other hand, in the case of processing by complex vibration, the tool horn is a step horn with diagonal slits for longitudinal-torsional vibration converter at the node position of the longitudinal vibration[6]. The step position is node position of the torsional vibration. The diameter is changed from 12 mm to 8 mm in the step position. The ultrasonic vibration source with this horn is referred to as the complex vibration source below. Also, the tip of both tool horn is a concentric shape (outer diameter of 8.0 mm, inner diameter of 5.3 mm).

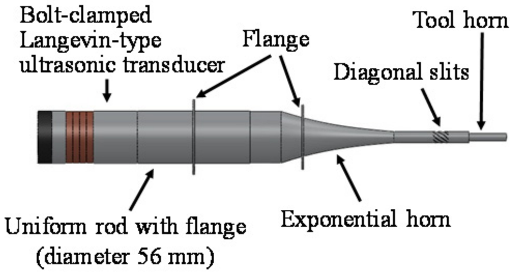


Fig. 1 Ultrasonic vibration source in the case of complex vibration.

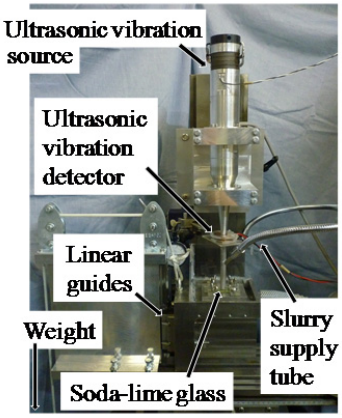


Fig. 2 Ultrasonic machining device.

## 3. Hole machining characteristics

The effects of complex longitudinal-torsional vibration on the hole machining characteristics of brittle materials were studied using the ultrasonic machining device shown in Fig. 2, which was converted from a benchtop milling machine. The ultrasonic vibration source was fixed to the device by using flanges on the uniform rod (diameter: 56 mm) and the exponential horn (Fig. 1). Both flanges were positioned at the nodes of longitudinal vibration. By using linear guides and a weight, a constant force (processing pressure) was applied from the lower side of the fixed stand to the tip of the horn in order to maintain contact between the tip and the processed material. Abrasive slurry was supplied to the cutting side of the processed material from a vertical centrifugal pump at a rate of approximately 1 L/min. The hole machining characteristics were experimentally measured and compared for soda-lime glass machining using longitudinal and complex vibration sources. Table 1 shows the machining conditions in the experiments. Abrasive grain was silicon carbide #600 (mean diameter; 20 µm).

In this experiment[5], during machining, the longitudinal vibration displacement amplitude at the tip of either vibration source was 10 $\mu m_{0-p}$ (20$\mu m_{p-p}$), and the torsional vibration displacement amplitude of the complex vibration sources were 23 $\mu m_{0-p}$. The longitudinal vibration displacement amplitude of the longitudinal vibration source was the same as the diameter of abrasive grain in order to achieving the fastest machining speed. Also, the longitudinal vibration displacement amplitude was the same in the case of the complex vibration sources and the longitudinal vibration source in order to improve of the limit of machining time by means of the longitudinal vibration displacement amplitude. The machining conditions are presented in Table 1. The processing pressure was varied between 0.50 and 2.25 MPa in steps of 0.25 MPa. The driving frequency of each vibration source was the longitudinal vibration resonance frequency. Figure 3 shows the experimental results for machining time. The shortest average machining time of the longitudinal vibration source was approximately 390 s for a processing pressure of 1.75 MPa. The shortest average machining time of the complex vibration source was approximately 261 s for a processing pressure of 1.00 MPa. The processing pressure of the shortest machining time is defined to be the optimal processing pressure. The optimal processing pressure decreased with torsional vibration displacement amplitude. The machining time also decreased with torsional vibration displacement amplitude.

Table 1 Machining conditions for hole machining.

| | |
|---|---|
| Material of tool horn | Duralumin |
| Processed material | Soda-lime glass |
| Hole dimensions | Depth: 4.0 mm; Diameter: 8.0 mm |
| Abrasive grain | Silicon carbide #600 (20 µm),<br>Weight ratio grain:water = 1:10 |
| Processing pressure | 0.50 − 2.25 Mpa |
| Displacement amplitude | Longitudinal vibration : 10 $\mu m_{0-p}$<br>(Torsional vibration : 23 $\mu m_{0-p}$) |

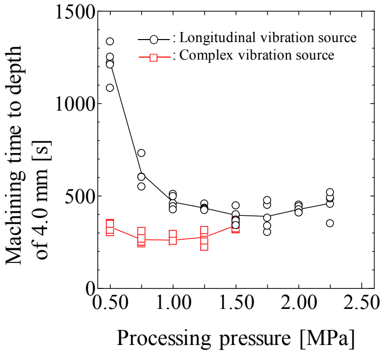


Fig. 3 Relationship between processing pressure and machining time.

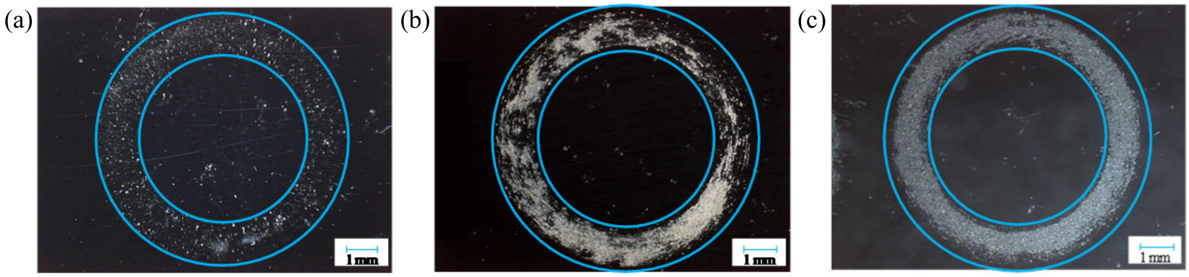
## 4. Observation of machining marks

In this experiment, the machining marks in soda-lime glass were made by using a longitudinal vibration source and a complex vibration source. Table 2 shows the conditions to made machining marks. The experiment was performed by dispersion of the dry abrasive grain on the soda-lime glass[7]. Then, the machining marks were generated by applying an ultrasonic vibration of 600, 1000 sign waves. The longitudinal vibration displacement amplitude at the tip of either vibration source was 5 $\mu m_{0-p}$, and the torsional vibration displacement amplitude of the complex vibration source was 11 $\mu m_{0-p}$. The processing pressures are the values of 1.75 MPa (longitudinal) and 1.00 MPa (complex) as optimal processing pressure obtained in Section 2. In this experiment, the vibration displacement amplitudes were small compared with those in Section 2 because of the capacity of the amplifier.

Figures 4 (a), (b), and (c) show the machining marks on the surface of soda-lime glass made by the longitudinal (600 waves) and complex (600 and 1000 waves) vibration sources. The concentric circles in the figure show the outer diameter and the inner diameter of the tip of the horn. In addition, the white part of the figure is the part of the glass that has been removed by the abrasive grains and the ultrasonic vibration. The areas that have been removed between the concentric circles are determined by binarization to be 2.9 $mm^2$, 10.7 $mm^2$, and 14.9 $mm^2$ for the longitudinal and complex sources, respectively. The machining marks made by the longitudinal vibration source are often puncticular. On the other hand, the machining marks made by the complex source of 600 waves are often linear. We think that the linear machining marks were caused by scraping due to the torsional vibration. But, the linear machining marks were not observed in the case of the complex source of 1000 waves. The almost entire surface has been processed. Thus, the machining marks of each of the abrasive grains were not observed. Therefore, in the case of large wave number, the observation of the machining marks was not suitable. Furthermore, in the case of the complex vibration, the part of the outer diameter of the horn has not been processed. This is a subject for future works.

Table 2 Machining conditions for observation of machining marks.

| | |
|---|---|
| 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) |
| Displacement amplitude | Longitudinal vibration ; 5 $\mu m_{0\text{-}p}$ (Torsional vibration ;11 $\mu m_{0\text{-}p}$) |



Figs. 4 Machining marks in soda-lime glass.
(a) Longitudinal vibration (600 waves) (b) Complex vibration (600 waves) (c) Complex vibration (1000 waves).

## 5. Conclusions

In this paper, we studied the ultrasonic machining by complex (longitudinal-torsional) and longitudinal vibration for brittle materials, such as soda-lime glass. The optimal processing pressures were found to be 1.75 and 1.00 MPa for soda-lime glass machining by the longitudinal and complex vibration sources, respectively. The machining time of the complex vibration source will be shorter when the optimal processing pressure is applied. From the observation of machining marks, the amount of glass removed using the complex vibration source was larger than that removed using longitudinal vibration source. The machining marks by complex vibration source are linear. This supports our expectation that machining time will be reduced by use of complex vibration.

## References

[1] T. B. Thoe, D. K. Aspinwall and M. L. H. Wise, Int. J. Mach. Tools Manufact. 38(4), 239 (1998).
[2] T. Asami and H. Miura, Jpn. J. Appl. Phys. **50**, 07HE31(2011).
[3] T. Asami and H. Miura, Jpn. J. Appl. Phys. **51**, 07GE07 (2012).
[4] T. Asami and H. Miura, IEEE Int. Ultrasonics Symp. Proc., 2667 (2013).
[5] T. Asami and H. Miura, Proc. of the 2013 Int. Cong. on Ultrasonics, 482 (2013).
[6] T. Ueoka and J. Tsujino, Jpn. J. Appl. Phys. **41**, 3237(2002).
[7] T. Asami and H. Miura, Proc. Symp. on Ultrasonic Electronics, Vol. 35, 473 (2014).