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Possibility of Metal Processing Using Ultrasonic Cavitation Jet

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Utilizing a high-intensity ultrasonic cavitation, a processing experiment was conducted with the aim of performing volumetric flow adjustment of a fuel jet nozzle to be used for a small engine, which cannot be carried out by a method such as machining. At the bottom of the nozzle used for the experiment, which is in the shape of a cup, a nozzle hole with a diameter of 0.15 mm is drilled. In this experiment, we make adjustments in the volumetric flow by grinding and removing the machining burr with the aid of the processing power of ultrasonic cavitation. The processing effect is highly dependent on the ultrasonic cavitation intensity. In the experiment, the processing reservoir was filled with pressurized highly deaerated water to increase the processing force by allowing cavitation with high intensity to be generated. The processing principle is to utilize the effect of a cavitation jet flow passing through the nozzle hole. To restrain the intake of the bubbles into the flow circuits during the pressure reduction cycle of the vibrator, the water flow was discharged into a pressure reduction reservoir. By allowing the horn tip with a diameter of 6 mm at a frequency of 28 kHz to approach the sample, followed by high-intensity ultrasonic irradiation, powerful cavitation was generated. As a result of the evaluation of the processing efficiency made based on the volumetric flow increase and microscopic observation of the nozzle, burrs smaller than 10 μm were almost entirely removed within 15 min of initial irradiation, resulting in a volumetric flow increase of more than 0.4%/min. However, in the case of burrs of more than 10 μm, no force that could remove the burrs was found. It was surprising for the burrs to generate deformation rather than to be removed.

KEYWORDS: ultrasonic, cavitation, fluid dynamics, cavitation jet flow, metal processing, deaerated water

1. Introduction

A high-pressure grinding-liquid jet is one of the methods of fine processing of metal parts.[1)] However, this method has a tendency to cause clogging when grinding particles adhere to the workpiece cavities or the nozzle hole is too small. Thus problems often occur and it is often difficult to remove the grinding particles. Problems are occasionally encountered because the grinding particles cause abrasion of the jet nozzle or piping equipment, and the processing operation is dangerous because it involves handling of high-pressure water.

In this report, we describe a method of solving the problems referred to above by metal processing of the fuel jet nozzle utilizing the unique effect of cavitation or progressing flow in the case that high-intensity ultrasonic is irradiated into the water.[2,3)]

2. Experimental

A schematic of the experimental device is given in Fig. 1. Highly deaerated water whose air-dissolubility is around 3 ppm is fed into the filter through the piping, by pressurizing to air pressure P_A using a pressurizing tank. Using the filter, the water is filtered to remove the solid particles. Via the volumetric flow gauge, the water fills the ultrasonic irradiating reservoir. The ⊗ mark in the figure indicates the individual types of valves. Using a resonance frequency automatic tracking oscillator, the vibrator is driven at a power of approximately 27 W.

A horn of the Langevin-type ultrasonic vibrator, which has a resonance frequency of 28 kHz and a diameter of 6 mm, is inserted into the nozzle, and an ultrasonic wave is irradiated in the direction of the nozzle hole. In this way, the grinding/removal of drill-machining burrs is conducted. Concurrently, the change of the volumetric flow is measured to examine the processing effect.

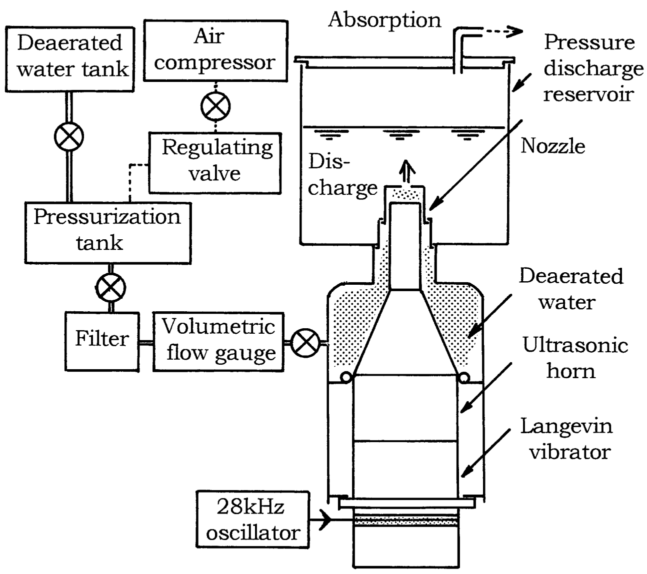

Fig. 1. Outline of the experimental device.

In Fig. 2, the configuration of the nozzle used for the processing experiment is illustrated. This is the nozzle of a small engine to be used for a fuel jet, and is fabricated of stainless steel. The nozzle has an inner diameter of 8.0 mm, height of 9.0 mm, and thickness of 0.7 mm. The portion on the bottom where the nozzle hole is made has a thickness of 0.35 mm, and a nozzle hole with a diameter of 0.15 mm is formed using a drill.

With this system, high-intensity cavitation is generated and the nozzle is processed. The horn amplitude is approximately 13 $\mu m_{p\text{-}p}$ under no-load conditions. To restrain the intake of the atmosphere during the pressure reduction cycle of the vibration, the nozzle water flow is discharged to a pressure reduction reservoir of 0.5 kg·f/cm^2. This reservoir is made with

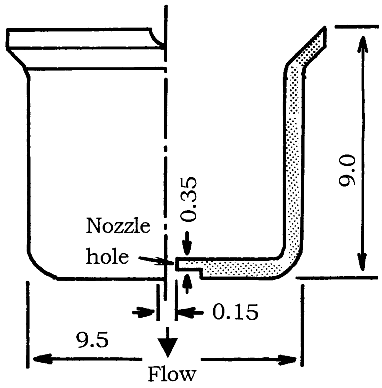

Fig. 2. Configuration of the fuel nozzle.

transparent acrylic resin in order to permit observation of cavitation and other processes. To instantly remove the bubbles which arise from the cavitation, discharge of the water is realized by holding the nozzle upward. The deaerated water is pressurized, because generating the high-intensity cavitation by raising the generated threshold value of the cavitation helps to increase the processing effect.[4)]

3. Results and Discussion

In the case that the air pressure P_A is 1.3 kg·f/cm^2, the results of the measurement of the volumetric flow at the irradiation time T for samples #a, #b, and #c are respectively, 5, 10, and 20 min, as shown in Fig. 3. Q_1 is the volumetric flow before the irradiation, and Q_2 is that after the irradiation. The change of the volumetric flow is regarded as the change of the effective diameter of the nozzle hole caused by the ultrasonic processing.

In this experiment, a volumetric flow increase of approximately 20% is noted with sample #a, that of approximately 10% is noted with sample #b, and that of approximately 15% is noted with sample #c. This implies that the irradiation has enlarged the nozzle hole.

Figures 4(a) and 4(b) are micrographs of the nozzle for which the irradiation times T of sample #d are 5 and 35 min. It is observed that the nozzle in micrograph (b) is distinctly ground compared with that in (a).

This makes it difficult to draw a comparison. However, by evaluating the experimental results while concurrently making microscopic observations, a large amount of burrs smaller than approximately 10 μm was found to be removed in a short time in the case of sample #a. In the case of sample #c, the small burrs were removed; however, the burrs larger than approximately 10 μm were left untouched and were not removed even by irradiation for 20 min, and these unremoved burrs were a cause of deformation. Thus it is not the case that such burrs made a great contribution to the increase of the volumetric flow.

Figure 5 shows the results in the case that the air pressure P_A was increased to 1.7 kg·f/cm^2. The increasing ratio of the volumetric flow is significant, approximately 0.4%/min for sample #e in the figure, corresponding to no less than 15 min from the start of the irradiation. For sample #f, the increasing ratio of approximately 0.5%/min is observed for no less than 5 min. After that, it is evident that the increasing ratio decreases for both samples, but processing continues. In considering how great the effect of the air pressure is, it is to be understood that the higher the P_A, the easier the generation of high-intensity cavitation.

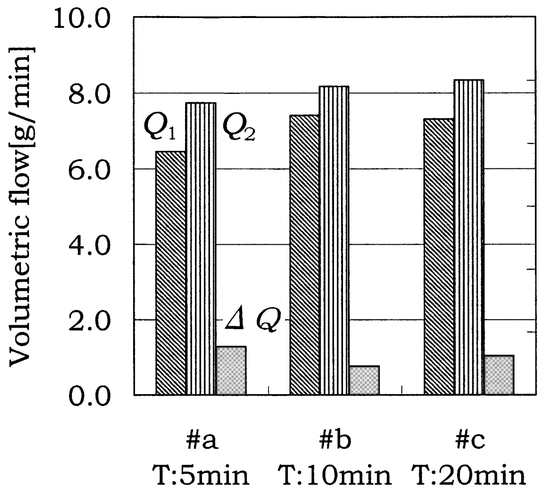

Fig. 3. Results of measurement of volumetric flow change of samples #a, #b and #c for different irradiation times. Q_1 is the volumetric flow before irradiation, and Q_2 is that after irradiation. ΔQ is the increased volumetric flow.

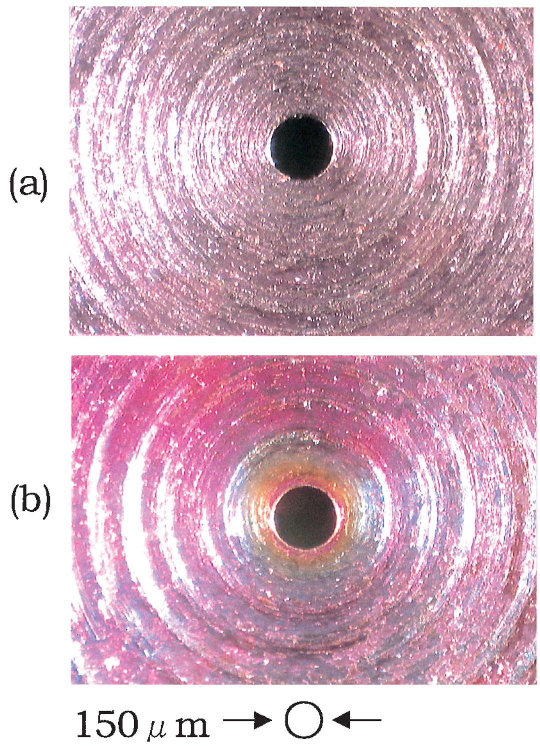

Fig. 4. Micrograph of the nozzle for sample #d. Irradiation times for micrographs (a) and (b) are 5 and 35 min, respectively.

A possible mechanism of these phenomena is that since the interval between the vibrator horn and the inner bottom surface of the nozzle is as small as 0.5 mm, the rate of cavitation water flow is considerable, 8.8 m/s in the case that the air pressure is 1.7 kg·f/cm^2. Therefore, it can be interpreted that before the machining is fully in action, the cavitation water has been discharged.

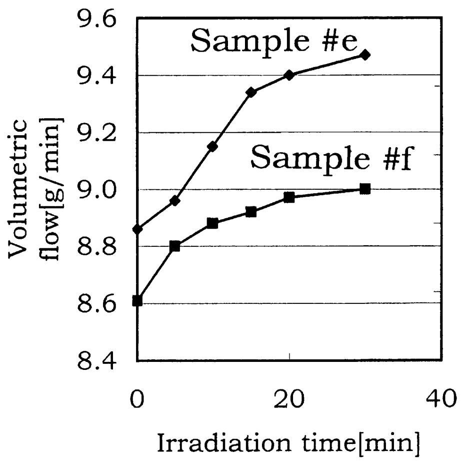

Fig. 5. Results of measurement of volumetric flow change of samples #e and #f with irradiation time.

4. Summary

We described an experiment in which an ultrasonic cavitation jet was applied to remove small burrs in drilling machining.

As a result, we found that the method is sufficiently effective for burr removal on a small scale, but large burrs are difficult to remove although deformation is induced, because an unsuitable degree of processing force is applied to large burrs.

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