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Title
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MICRO DEBURRING TECHNOLOGY USING ULTRASONIC VIBRATION WITH ABRASIVE

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ABSTRACT

Burrs have been defined as undesirable projections of material beyond the edge of a workpiece during machining. Burrs are created around the edge of workpiece due to plasticity during mechanical manufacturing process. Recently, because of miniaturization and increased precision of the machined parts, the size of burrs has been also reduced and deburring became even more difficult. Generally, burrs have been removed by method of physics and chemistry. There are a few publications in the area of applying ultrasonics to deburring. When ultrasonic vibration propagates in the liquid medium, a large number of bubbles are formed. These bubbles generate an extremely strong force, which removes burrs. The object of this study is to analyze the effects of ultrasonic vibration, medium and the type of abrasive in deburring process. In this paper, we have examined such parameters of ultrasonic vibration as power, the distance between the ultrasonic horn and workpiece, deburring elapsed time, and the type of abrasive. The different abrasives were used in this experiment to examine how the properties of the abrasives affect ultrasonic deburring. It was found from the result that deburring with ultrasonic cavitation in medium is effective to micro burr.

INTRODUCTION

Generally, burrs refer to projected parts remained on the edge after material had been processed. These burrs decrease the precision of components and cause many problems in parts assembly. Especially, burrs reduce the performance of microelectronic parts. Thus, the removal of burrs becomes an important feature for automated production lines.

Recently, because of miniaturization and increased precision of the machined parts, the size of burrs has been also reduced and deburring became even more difficult. Studies on micro burrs deal with burr removal and control for which a number of methods have been offered. Currently, common deburring methods include mechanical burr removal using abrasives, barreling and brushing and chemical deburring such as etching.

When it goes to micro deburring, the smaller size of parts and higher machining precision consider more danger of damaging the processed surface. Therefore, micro deburring methods came recently into the focus. Yoshihide Shibano has studied the removal of micro burrs and surface conditions (1) , and S. H. Yeo has investigated ultrasonic deburring and cavitation (2). However, in those studies only few parameters of ultrasonic vibration have been taken into consideration. Therefore, additional experimentation is needed before the technology can be adopted for mass production.

In this paper, we have examined parameters of ultrasonic vibration such as power, the distance between the ultrasonic horn and workpiece, deburring elapsed time, and type of abrasive.

SEM and contact-free type laser have been used to check ultrasonic deburring results according to each experimental factor. To this end, the shape, size, and surface conditions of the workpiece before and after deburring have been analyzed. conditions of the workpiece before and after deburring have been analyzed.

EXPERIMENT SETUP

Experimental instruments

Fig. 1 shows the experimental device. The transducer can be adjusted along Z axis with a step of 0.01mm. Bearing bushing was used to improve movement accuracy during vertical adjustment.

For the experiment, the workpiece and the ultrasonic horn placed in water tank and water tank with abrasive. The water tank was made of rectangular pieces of acryl. Therefore, the distance between the workpiece and the ultrasonic horn as well as the distance between the bottom of the water tank and the workpiece could be adjusted. Table 1. shows the specifications of the ultrasonic transducer amplifier and the actuator. The resonance frequency, the maximum amplitude of the horn, and the maximum output power of the amplifier were 20 kHz, 70 μm, 750 W, respectively. The resonance frequency could be automatically adjusted depending on the load. The horn was inserted into the water by 10mm.

Fig 1. EXPERIMENTAL DEVICE.

Specification	Value	Specification	Value
Ultrasonic power	750 W	Horn material	Titanium (grade 5)
Resonance frequency	20 kHz	Horn diameter	13 mm
Transducer impedance	41 Ω	Maximum amplitude	70 μm

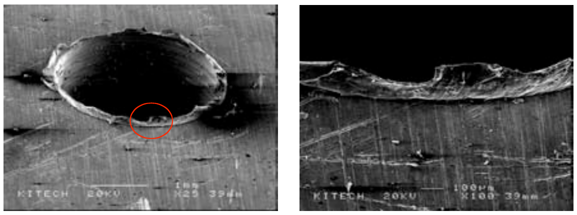
Table 1. ULTRASONIC TRANSDUCER AND ACTUATOR SPECIFICATION.

Drilling burr workpiece

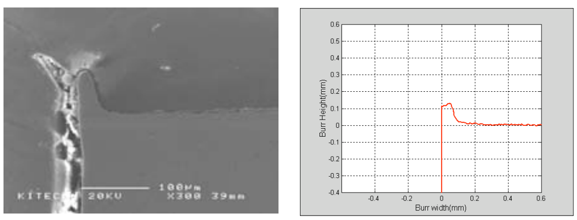
Table 2. shows drilling conditions and workpiece data. For the workpiece an aluminum part of 5mm thickness was used. Burrs were formed using a 3 mm diameter drill. Burrs showed high irregularity in size and shape depending on their location on the circumference. The average height of burrs was about 120 μm. The height of burrs was measured at two points around the circumference using contact-free laser. Burrs shape was checked using SEM picture. Fig. 2 shows burrs used in the experiment.

Tool diameter (mm)	Speed (rpm)	Feed rate (mm/min)	Workpiece thickness (mm)	Workpiece material
3	3000	30	5	Al 6061

Table 2. DRILLING CONDITIONS.



(a) Hole shape (SEM photograph) (b) Focus hole shape (SEM photograph)



(c) Focus hole shape (laser measurement) (d) Section view of hole (SEM photograph)

Fig 2. SEM PHOTOGRAPH OF BURRS.

Properties of Ultrasonic Vibration

The strength of the ultrasonic vibration differs depending on the efficiency of actuator and the output power of the amplifier.[3] The major factor, which directly affects the deburring process, is the strength of the sound pressure. The sound pressure is influenced by the element and saturation rate of the medium located between the tip of horn and the workpiece. The amplitude of the tip of the actuator is the major factor, which the most affects the sound pressure[4].

The vertical vibration of the tip was transferred through water or slurry between the horn and the workpiece. The transferred energy creates a cavitation and explosive power in the water that cause deburring. Therefore, it is necessary to calculate the strength of the frequency transferred through water. For this purpose, one can use the speed of the horn. The distribution of the frequency strength in three dimensional medium after the ultrasonic frequency is transduced is given by the equation (1) [5].

$$p(r,\theta,t) = j\frac{\rho_0 c}{2}U_0\frac{a}{r}e^{j(\omega t-kr)}\left[\frac{2J_1(ka\sin\theta)}{ka\sin\theta}\right] \quad (1)$$

a : Horn Radius , c : Sound Velocity

U_0 : Initial Velocity , ρ_0 : density

Initial values for factors used in observation of sound pressure distribution according to the distance at the tip when the amplifier output is at 100% of horn include tip amplitude of 70 µm, tip velocity of 8.79 m/s, a radius of 6.5mm and water as the medium. The distribution of ultrasonic vibration pressure was calculated in consideration of the vertical θ = 0 at the tip of the horn and shown in Fig. 3. The distribution of the ultrasonic vibration pressure depends on the properties of the medium, initial speed, density, and frequency. However, the pressure is reduced greatly with the distance. As a result, the pressure at the horn tip is about 20Pa (20bar). The term cavitation threshold is used to describe the minimum conditions necessary to initiate cavitation. It has been estimated that sound pressures of 1-8 bar are required to reach the cavitation threshold for water depending on its temperature[6]. Sound pressure is enough to generate the cavitation threshold in this experimental device.

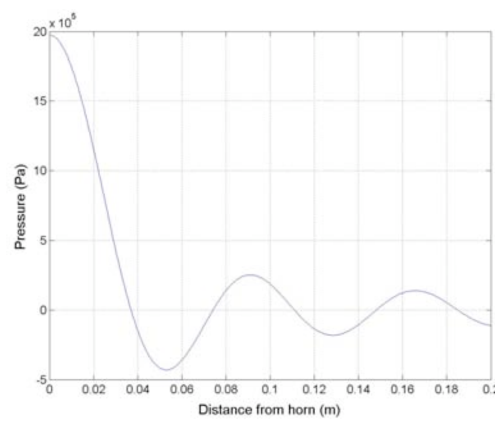


Fig 3.SOUND PRESSURE ESTIMATED ALONG THE CENTERLINE ACCORDING TO DISTANCE.

EXPERIMENT RESULTS

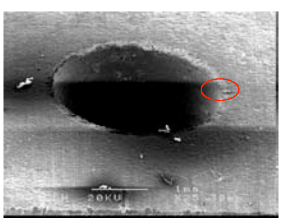
Hole shape after ultrasonic deburring

Table. 3 shows conditions under which deburring experiment was performed. Output, distance and elapsed time were 100%, 1 mm and 120 sec., respectively. Experimental results are shown in Fig 4. Burr have been completely removed as shown in Fig. 4.

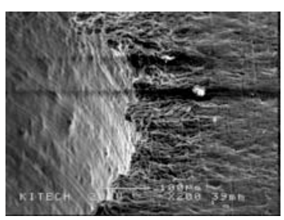
Experimental parameter		Values
Power (%)		50, 60, 70, 80, 85, 90, 95, 100
Distance (mm)		0.5, 0.75, 1, 1.5, 1.75, 2
Deburring Time (sec.)		30, 60, 90, 120, 150, 180
Abrasive (type)	SiC	#8000, #800, #320

Table 3. EXPERIMENTAL CONDITIONS.

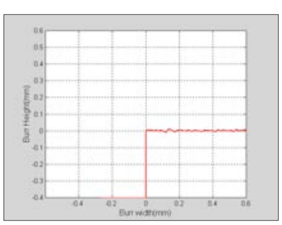
The amount of deburring is not uniform on circumstance of the hole. This is because the initial burr shape and size are different. Therefore, appropriate selection of deburring conditions is necessary. In addition, surface was damaged during deburring around the hole in the part. This is because that ultrasonic is strong enough for deburring.



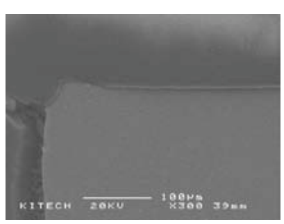
(a) Hole shape (SEM photograph)



(b) Focus hole shape (SEM photograph)



(c) Focus hole shape (laser measurement)



(d) Section view of hole (SEM photograph)

Fig 4. ULTRASONIC DEBURRING EFFECT.

Ultrasonic deburring according to the elapsed time, distance and power

This experiment was performed to examine the deburring effect on the elapsed time. Experimental conditions are shown in Table 3. The distance between the horn and the workpiece was fixed at 1mm. Deburring was performed every 30 seconds for the period from 0 to 180 seconds. Experimental results are shown in Fig 5. Only 60% of burrs were removed over 30 seconds. At least 140 seconds of deburring were needed to remove the burrs completely. However, the difference according to the deburring rate against the elapsed time is not that big. From these results, it is assumed that the ultrasonic vibration deburring mechanism requires more factors as well as correlations between the factors. Deburring effect is shown by the equation (2).

$$Deburring\ effect = \frac{(initial\ burr\ height - remain\ burr\ height)}{initial\ burr\ height} \times 100 \qquad (2)$$

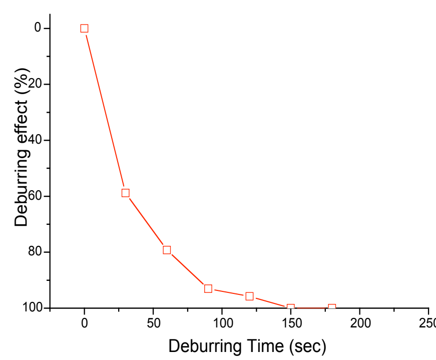


Fig 5. DEBURRING EFFECT ACCORDING TO TIME.

During the experiment the output power of the ultrasonic amplifier was changed from 50% to 100%.

Experimental results are shown in Fig. 6. Generally, the power becomes greater, the deburring effect is more increase. At least 85% of burrs are removed when the power is above 80%. On average, burr amount of over 100 μm is removed. In addition, at maximum power (100%) all burrs were removed completely in all four workpieces.

The distance between the tip of the horn and the workpiece was changed by 0.25 mm steps from 0.5 mm to 2 mm. Experimental results are shown in Fig. 7. The deburring amount until the distance between the ultrasonic horn and the workpiece reaches 1.25 mm is similar. However, the removed burr amount reduces rapidly as the distance becomes over 1.25 mm.

As shown in Fig 3, this effect is due to the fact that the ultrasonic pressure reduces rapidly with the distance. As the distance becomes greater, not only the transference of energy created at the tip of horn reduces, but also cavitations production is also rapidly reduced.

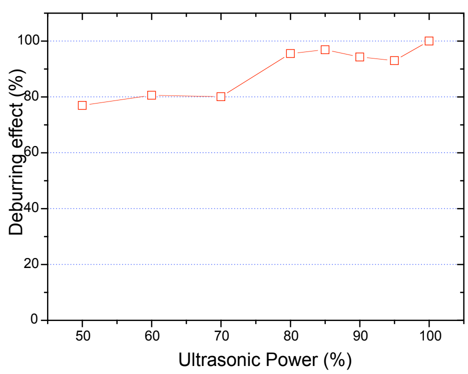


Fig 6. DEBURRING EFFECT ACCORDING TO POWER.

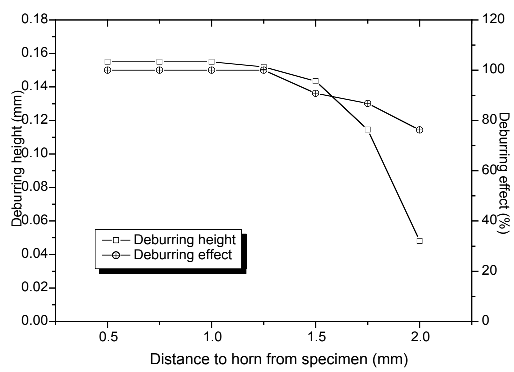


Fig 7. DEBURRING EFFECT ACCORDING TO DISTANCE.

Fig. 8 and Fig. 9 show the results of the test comparing Al 2024 and Al 6061. In the case of Al 6061, if the distance is longer than 1.5 mm, a perfect deburring effect cannot be expected. It is understood from these characteristics that since distance affects the ultrasonic deburring effect to a greater degree than any other factor, the ultrasonic power is not enough to achieve a deburring effect with the distance longer than 1.5 mm, even though the deburring is done over a long period of time.

In the case of Al 2024, if the distance is longer than 1mm, a deburring effect cannot be expected. Such difference demonstrates that the Al 2024 with higher rigidity requires greater power to achieve deburring than the Al 6061 does.

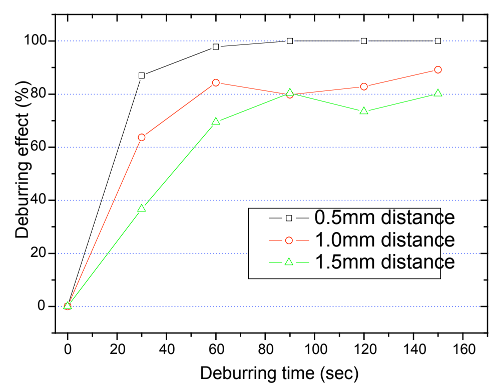


Fig 8. DEBURRING EFFECT ACCORDING TO DISTANCE AND TIME (Al 2024).

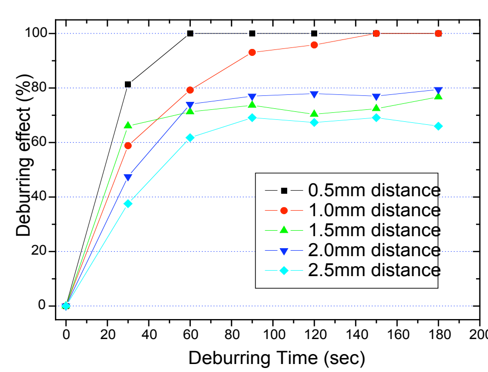
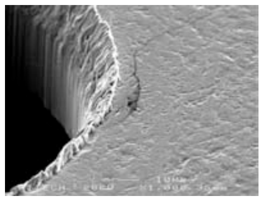


Fig 9. DEBURRING EFFECT ACCORDING TO DISTANCE AND TIME (Al 6061).

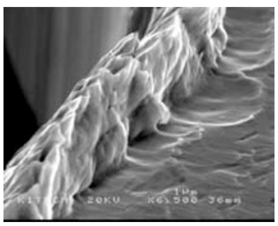
Deburring according to abrasives

For the workpiece an electric beam gun part of 0.1mm thickness was used. Material of workpiece is made of nickel steel (Fe 60%, Ni 40%). Fig. 10 shows the shapes of electric beam gun before the experiment. The average height of burrs was about 8μm.

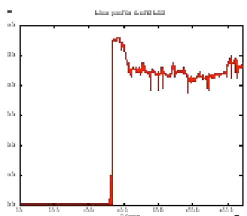
(a) Electric beam gun



(b) Focus hole shape (SEM photograph)



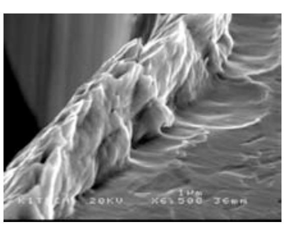
(c) Focus hole shape (SEM photograph)



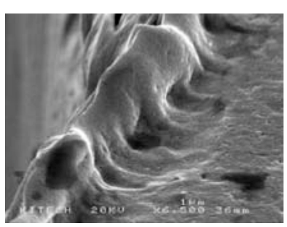
(d) Focus hole shape (laser measurement)

Fig 10. SHAPE OF ELECTRIC BEAM GUN.

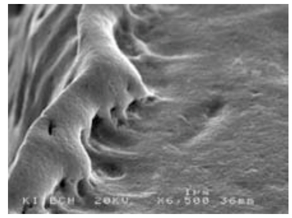
Three different abrasives were used in this experiment to examine how the properties of the abrasives affect ultrasonic deburring. Power, distance and time were fixed at 100%, 0.5 mm respectively in medium of only water medium for the first examine. The results are shown in Fig.11. In this case, Only 80% of burrs were removed over 120 seconds in only water. Deburring is not perfectly done.



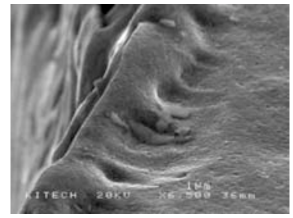
(a) Initial burr height = 8 μm



(b) After ultrasonic deburring during 30 sec.



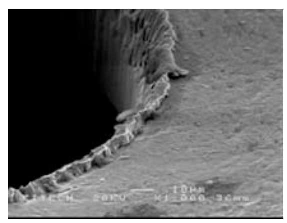
(c) After ultrasonic deburring during 60 sec.



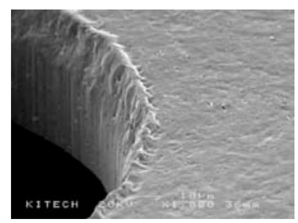
(d) After ultrasonic deburring during 120 sec.

Fig 11. HOLE SHAPE BY SEM AFTER ULTRSONIC DEBURRING WITHOUT ABRASIVE.

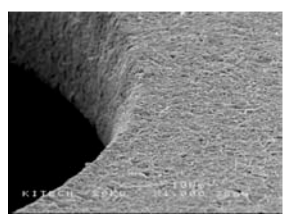
Power, distance and time were fixed at 100%, 0.5mm respectively. SiC 8000 mesh, 800 mesh, 325 mesh were used. The results are shown in Fig 12. As the size of the abrasive is larger such as 325 mesh abrasive, deburring effect is on the increase. When abrasives are used, transformations in circumstance direction occur as shown in Fig 12.



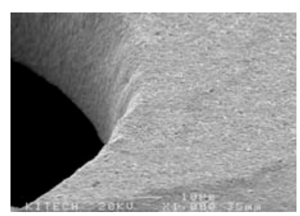
(a) Using Only Water



(b) Using abrasive of #8000



(c) Using abrasive of #325



(d) Using abrasive of #800

Fig 12. HOLE SHAPE BY SEM AFTER ULTRSONIC DEBURRING WITHOUT ABRASIVE AND WITH ABRASIVE.

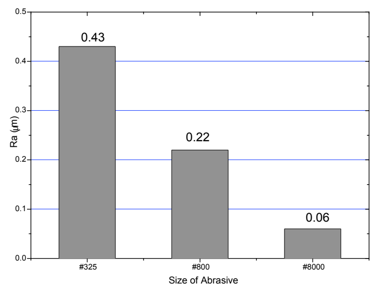


Fig 13.SURFACE ROUGHNESS AFTER ULTRSONIC DEBURRING WITH ABRASIVE

The result leads to a presumption that burrs removal is caused by abrasives impact power rather than the formation of cavitations. When abrasives are used, the results of surface roughness are shown in Fig.13.

CONCLUSION

In this study ultrasonic was used to remove burrs and examine how cavitations formed in water affect the deburring process. The obtained results let make the following conclusions:

(1) Deburring effect increases as the distance between horn and workpiece gets shorter, and is proportional to ultrasonic power and deburring time.

(2) In case of 750W (ultrasonic power) and 0.5mm(distance) , burr has been removed completely in 60 seconds.

(3) When more than distance of 1.5mm, deburring is not perfectly done.

(4) In case of using abrasive, the surface integrity of workpeice and deburring effect are better than that of using water only.

(5) The dominant factor on ultrasonic deburring is the distance between the horn and the workpiece and size of abrasive.

(6) As the size of abrasive becomes larger, deburring effect is on the increase

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