SMALL-HOLE DRILLING USING DIE SINKER ELECTRICAL DISCHARGE MACHINE

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ABSTRACT

Banyak kesulitan dihadapi pada pemesinan lubang kecil. Terutama jika prosesnya dilakukan dengan proses drilling mekanik. Untuk mengatasi kendala yang dihadapi, proses pemesinan non-tradisional seringkali diterapkan. Tulisan ini melaporkan hasil studi pemesinan lubang kecil (diameter kurang dari 1 mm) menggunakan EDM die sinker. Lubang dibuat pada aluminium dengan ketebalan 3 mm. Kawat tembaga berdiameter kurang dari 1 mm dipergunakan sebagai elektroda. Untuk menghindari keausan elektroda yang berlebihan, pemesinan dilakukan dengan menggunakan parameter yang menghasilkan energi rendah. Pemilihan parameter ini juga dimaksudkan untuk mendapatkan kualitas lubang yang baik. Pengamatan dilakukan terhadap kualitas lubang yang dihasilkan. Selain itu studi juga dilakukan pada pengaruh parameter pemesinan terhadap keausan elektroda dan waktu pemesinan. Hasil studi menunjukkan bahwa lubang dengan diameter kurang dari 1 mm berhasil dibuat dengan mesin EDM die sinker. Waktu yang diperlukan untuk pemesinan berkisar antara 5 – 6 menit. Lubang yang dihasilkan memiliki kebulatan yang relative baik dan permukaan yang tajam. Peningkatan energi pemesinan menambah keausan elektroda dan memperpanjang waktu pemesinan.

*Keywords**:** EDM, small hole, drilling, electrode wear*

INTRODUCTION

Drilling small holes are frequently required in industries, such as medical, automotive, aeronautics, electronics. Traditional machining may produce the holes, however much problems were encountered in this practice. The accuracy of small hole-drillings is highly influenced by drill bending rigidity and thinning of the chisel point [1]. Vibration drilling improves the hole equality, yet the vibrating frequency has a negative effect on the drill life[2]. Application of cooling fluid in drilling small holes is difficult [2]. Small feed rate and high spindle speed increased the radius error [3]. Worn tool due to drilling process led tomicrowelding of workpiece material and increased the maximum torque [4].

To overcome mechanical problems faced in traditional drillings, non-traditional machining processes is applied. Laser drilling was applied to drill holes with diameter less than 1 mm in stainless steel and Nimonic 263 [5-7]. Despite its superiority, drilling-using-laser produced significant differences in the final hole shape [8]. Crater was also found on the hole surface due to the collision of ejected metallic particles with the solidified material surface.

Electrical Discharge Machining (EDM) drilling is another technique to produce small hole. It can drill a hole with diameter down to 170 μm[9].The help of NC and CAD minimized the machining time of small hole drilling [10]. Application of vibration on the tool or the workpiece enabled this method to produce smaller hole size [11]. Drilling micro hole with diameter down to 15μm on copper sheet was attempted by using tungsten electrode [12].

In spite of its wide application in drilling small hole, hole accuracy in EDM micro drilling is more difficult to predict due to the spark-erosion process. Surface roughness of the hole and material removal rate in EDM small-hole drilling was influenced by different variables [13]. Tool wear and workpiece material removal per discharge are important variables [14].

Hole-machining by using EDM drilling can be difficult when tiny electrode diameter is employed. Small-diameter-electrode could be sensitive on mechanical force due to rotation of the electrode. Vibration of the electrode might lead to an uncontrolled-movement. Therefore, drilling by using die sinker EDM might be more suitable since only penetration and retract movement of the electrode is required. This technique was successfully applied to drill micro-hole in low carbon steel [15]. The work was considered as the new process with less cost. With proper parameters selection, holes with diameter of less than 1 mm were successfully drilled. However, slag and recast layer were formed at the surface of the hole. Factors that contributed the slag formation were not explained on the work. This could be due to the high discharge energy that excessively melted the material. With this consideration, the present work aims to study small-hole drilling using die sinker EDM in commercial aluminum of 3 mm thickness. Having less conductivity than steel, drilling holes on aluminum could be challenging. To carry out the efforts, small-diameter copper wire was used as the electrodes. Machining parameters that could produce good holes with minimum recast layer was studied.

EXPERIMENTS SET UP AND PROCEDURES

The experiments were carried out on Mitsubishi EA8 CNC EDM Die Sinker. Normal penetration was employed during the experiment. The electrode was fed downwards under servo control of the EDM machine. Figure 1 presents the set upof the experimenta.

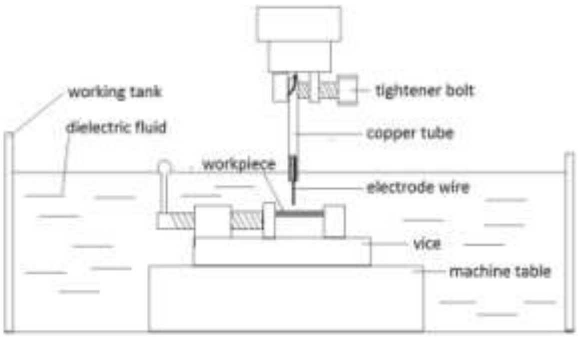


Figure 1. Experiment set up

Drillings were performed in commercial aluminum of 1 mm thickness. The electrode was 0.1 mm diameter of a very ductile pure-copper wire. To enable the clamping, the wire was inserted into a copper tube with outside diameter of 1 mm and inner diameter of 0.5 mm that is normally used as electrode for EDM hole-drilling. The electrode was tightened at one end of the copper tube. Subsequently the copper tube was clamped on the electrode fixture of the EDM machine. Besides allowing the clamping, the holding method also helped in straightening the electrode.

The workpiece was clamped on the workpiece holder. The electrode material was inserted into the tube copper leaving approximately 5 mm as the free end. This short exposed-free-end was set to avoid bending on the electrode due to its high ductility. Flushing was not applied during the process to avoid the movement of the electrode. Positive polarity was used throughout theexperiment. Machining parameters that produces smaller discharge energy were selected for the experiments to prevent excessive spark energy that might burn the electrode.

Through-hole drillings were performed on the workpiece. Drilling time was recorded using an electronic timer attached to the machine. The emergence of fine bubbles through the bottom of the workpiece indicates the completion of drilling. The length of the electrodes was measured before and after machining. The length reduction was taken as the electrode wear. The hole quality was assessed by using three dimensional (3D) Non-Contact Measurement Machine and Scanning Electron Microscope (SEM).

RESULTS AND DISCUSSION

Drillings were performed using varying EDM parameters. A serial trial was attempted. The trial was carried out with regard to obtain good holes in a sufficient time. Based on the trial, the holes could be produced under several pulse-on duration (T_{ON}) values with constant pulse-off duration (T_{OFF}) of 64μs. Focusing on lower level of discharge energy, low peak current setting (*i.e.* 2.5 Amps) was applied.

Quality of the holes

Figure 2 presents the image of the holes taken by 3D non contact measurement optical microscope. The optical micrograph shows good roundness of the holes. They were drilled by using I_p= 2.5 Amps, T_{OFF} = 64μs and T_{ON} = 64μs.

The figure shows that relatively good roundness of holes was produced. However, irregularities of the hole shape occurred. These can be observed in the SEM micrograph (Figures 3a and 3b). The figure presents the hole shape and its surface on the entrance and exit side of the hole. Very sharp edges at the entrance and exit sides of the hole can be observed from the figure. Recast layer at the micro hole drilled by EDM was reported [15]. This was found especially when drilling was performed at higher T_{ON}.

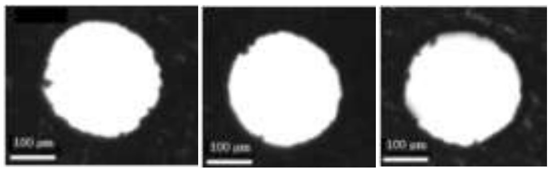
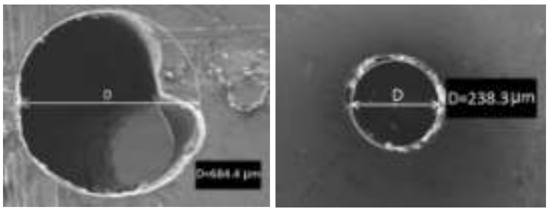


Figure 2.Hole photograph (taken with non contact measurement imaging)

In the present work, the drilling was carried out at low energy level. This might have prevented the formation of recast surface. Figure 3 shows the hole surface which is relatively free from the recast particles. High discharge energy may melt larger portion of the material. The melted-material potentially recast before it was removed away from the gap by the dielectric fluid. Machining with lower energy might produce smaller eroded particles. These would be removed more easily by the dielectric fluid before it was solidified into the recast metal. Hence, formation of the recast metal at the edge of the hole could be avoided.

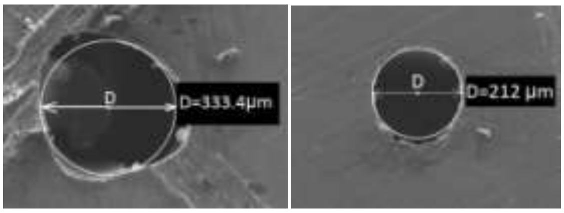
Although the sharp-edge were produced, little irregularity of the hole shape were seen at the entrance side. Conversely, much better roundness was found at the exit side. At the entrance-side image (Figure 3a), a blurry hole-shape is seen below the clear hole image. This also indicates that the hole is not straight. It is convinced with the difference of top and bottom hole diameter (*i.e.* 684μm and 238.3 μm respectively).



(a) (b)

Figure 3. SEM image of hole surface,
(a) entrance,and (b) exit side

Figure 4 gives a different kind of irregularities of the hole roundness at the entrance side. The shape of the hole is more like a triangle with round edges. Two predictions on the cause of the irregularities can be given. The first is that the imperfect roundness of the hole at the entrance side was caused by the electrode itself which is not perfectly round. Another prediction is that the irregularities might be due to the vibration of the electrode during the drilling. The vibration might cause several zones of erosion area.



(a) (b)

Figure 4. SEM image of hole surface,
(a) entrance and (b) exit side

Three round edges of the triangle might indicate that three dominant sparking areas were created at the beginning of machining process. This could be the result of vibration of the electrode tip during the initiation of machining. Larger diameter of electrode could withstand the vibration as it could hold up the mechanical force that might be occurred during the sparking. However, for the tiny electrode diameter, the electrode could be very sensitive on that movement. While the expected movement was only up and down for penetration and retraction, this movement could lead to the vibration of the electrode tip that may yield to horizontal movement. Hence several points of closer gap that produced the spark were created. The result was the hole with irregular shape as shown in the figure.

Besides shape irregularities, Figures 3b and 4b also illustrate the smaller hole diameter at the exit side. Roundness of the hole at the exit side is also better. The difference of hole size at the entrance and the exit sides shows that the electrode wears during the machining process. This yielded the electrode with smaller diameter. Erosion process during the drilling shaped the electrode into a better roundness. When the drilling was in progress, the vibration did not much affect the electrode tip. This led to the uniform sparking area between the electrode and the wall of the hole. Hence, a hole with better surface and roundness was produced.

Severely-bent electrode produced even more irregularities of the hole shape. Figure 5 shows elliptical holes that were produced. This figure was captured by 3D non contact measurement imager.

Mechanism of the elliptical hole formation is proposed in Figures 6 a and b. Figure 6a illustrates the erosion process in the drilling using straight electrode. This electrode obviously exposes round electrode that produce more uniform sparking area. Hence, the roundness of the hole would follow the shape of the electrode. With bent-tip electrode, sparking area occurs around the surface along the direction on the bending. Thus, the spark in the gap between the electrode and the workpiece produced the elliptical hole.

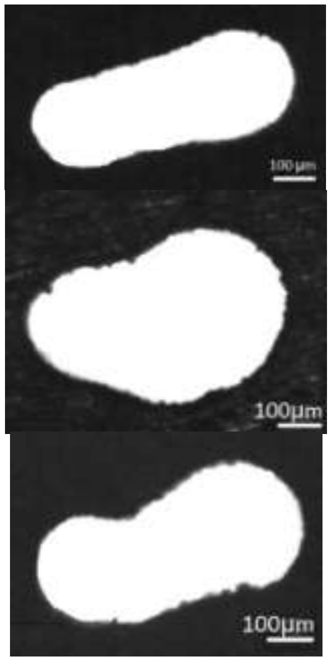


Figure 5. Elliptical holes that might be produced by drilling using bent electrode

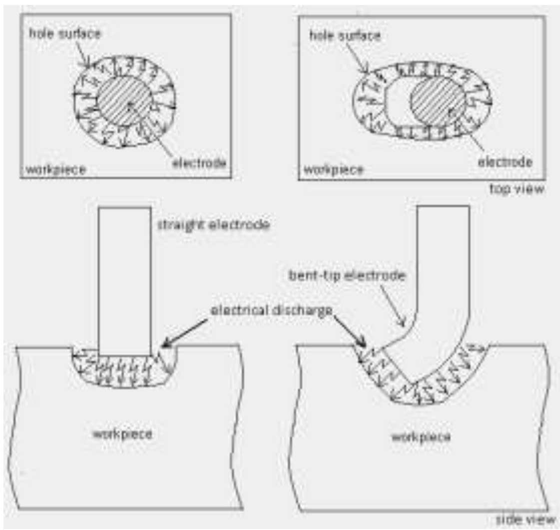


Figure 6. Illustration of spark gap on EDM drilling using straight and bent-tip electrodes;
more sparking area given

Drilling time

A series of drilling time with respect to T_{ON} are presented in Figure 7. The figure shows that around 5 – 6 seconds are required to machine the hole. Shortest T_{ON} gives shortest drilling time. The graph shows the trend of increasing the drilling time with the increase of T_{ON}. Longer drilling time could be due to lower energy produced by the parameters combination of higher T_{ON} or higher electrode that was consumed in the machining. Observation on the drilling given on the latter figure could explain this phenomenon.

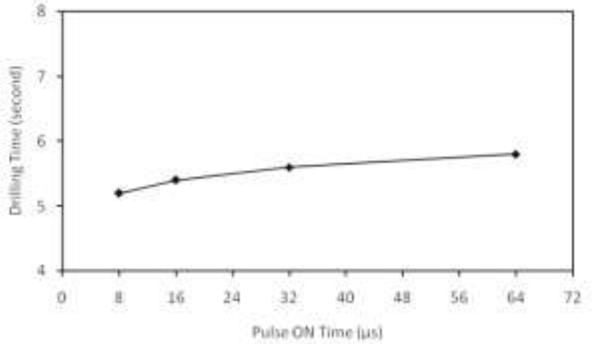


Figure 7. Drilling time

Electrode wear

Similar situation with drilling time was observed in the electrode wear during the drilling. The electrode wear that occurred during the machining with different pulse time is given in Figure 8. The increase of the pulse time increases the electrode wear. Nevertheless, the positive slope of the curve is not quite significant, as it was also observed in Figure 7.

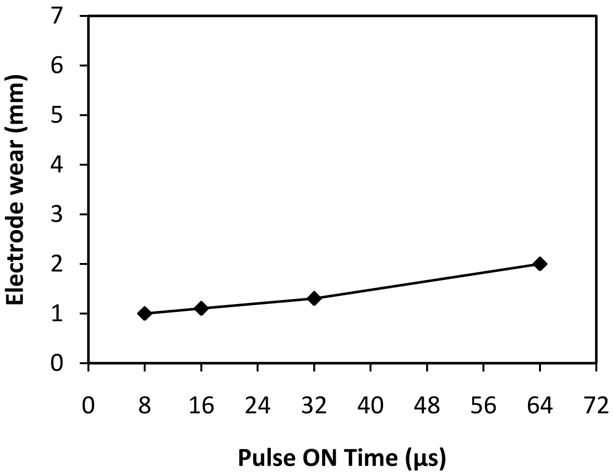


Figure 8. Electrode Wear

Based on Figures 7 and 8, a hypothesis of the energy utilization can be proposed. The I_p and T_{ON} proportionally enhance discharge energy in EDM. Therefore, adding the product value of the parameters should improve the discharge energy. Higher machining rate that make faster drilling can be expected from the high discharge energy. However, the experiments show that increasing the pulse time lengthens the drilling time and increases the electrode wear.

In EDM, besides eroding the workpiece material, electrical discharge could also wear the electrodes. Especially for the tiny copper diameter wire that was used in this experiments. Tiny diameter of copper electrode in this practice leads to a high wear sensitivity. Therefore, it is reasonable to predict that higher wear rate might be produced during the machining. This will be different with common practice of die sinker EDM to produce cavity where bulk copper electrode is employed. In this practice, heat generated during the discharge is spread and absorbed by the electrodes. The bulk copper is sufficiently capable to accept the heat and avoid much vaporization.

Figure 7 and 8 indicates that at higher T_{ON}, the discharge energy was consumed more to wear the electrode than to erode the workpiece. Hence, the drilling time was increased. It could lead to a conclusion that better machining efficiency was attained at lower T_{ON}. It means that in this condition, more energy is utilized to erode the material than to wear the electrode.

Drilling the hole at lower T_{ON} produces low discharge energy; consequently heat generated is also low. It gives an advantage of preventing the electrode wear for this practice where a very small diameter electrode is used. The lower discharge energy level was also believed to contribute the less recast layer at the hole surface. With low energy, excessive erosion of the workpiece is avoided. With this condition, the debris or particles produced by the EDM process could be immediately removed by the dielectric fluid before it was re-solidified. Therefore, the formation of slag and recast layer at the surface was avoided.

CONCLUSION

Drilling micro holes by using conventional die sinking EDM was attempted in this work. The holes were successfully drilled within 5 – 6 seconds. Sharp-edged hole with relatively-good roundness was successfully machined. Minimum recast layer was also found the surface of the hole. Slightly different holes diameter at the entrance and exit side was produced due to the change of shape of the electrode during the drilling.

Setting of parameters giving lower energy (*i.e.* low T_{ON}) drilled the hole faster. Therefore, it was recommended for the drilling. High T_{ON} produced higher discharge energy that tend to wear the electrode rather than to erode the workpiece material. Hence, the drilling took longer time.

Imperfect roundness of the hole might be resulted by the bent-tip electrode. The bent-tip electrode was also believed to produce elliptical hole. Therefore, ensuring the straightness of the electrode before the drilling is required to obtain the good holes.

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