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Investigating characteristics of electrochemical machining through electrolyte absorbed with porous solid material

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Abstract

Electrochemical machining (ECM) method is widely used in the processing of difficult-to-cut materials. However, due to the fluidity of the conventionally used liquid electrolyte, it's difficult to limit the existing area of electrolyte and the machining area accurately. This is one of the important reasons for the low machining accuracy of conventional ECM. To overcome this shortcoming, a non-conductive porous solid is used as the electrolyte absorption material in ECM processing in this study for the first time. Due to the porous structure inside the porous solid, the electrolyte absorbed in it forms a current path from the anodic workpiece to the cathodic tool electrode, while the electrolyte cannot flow freely over the workpiece surface. Since the workpiece is not immersed in the electrolyte, only the area in contact with the electrolyte held in the porous solid will be machined, while the other areas of the workpiece are not affected at all. In this way, the limitation of the electrolyte existing area is realized and the ECM accuracy is improved. In this paper, the machining principle and the developed experimental setup are explained, and experimentally obtained machining characteristics are reported.

Keywords: electrochemical machining, electrolyte existing area, porous solid material, machining characteristics

1. Introduction

The electrochemical machining (ECM) method is a very useful technology in the processing of difficult-to-cut materials, for its independent of the material hardness and no heat-affected layer, no residual stresses, no cracks on the workpiece surface. In the conventional ECM process, the cathodic tool electrode and the anodic workpiece are usually immersed in electrolytes to ensure that the machining gap between them is filled with electrolytes. However, due to the fluidity of the electrolyte, it's difficult to limit the current flowing area and the machining area accurately. As effective methods of limiting the machining area in ECM, electrolyte jet machining [1], ECM with electrolyte suction tool [2], and the ECM with electrolyte confined by absorption material (ECMEA) method [3] have been proposed. Besides that, by using the through-mask electrochemical micromachining (TMEMM), many efforts have been made to improve the machining accuracy and control the machining area of ECM method [4][5][6].

It is generally known that some porous structure materials, like the sponge, have a good ability to absorb and retain water. In daily life, when a piece of sponge, which contains water inside, is used to wipe a table, only the areas rubbed by the sponge exist water, and other areas of the table are not influenced by water at all.

If non-conductive porous solids can be used in ECM processing to do as the electrolyte absorption material like what the sponge does, limitation of the electrolyte existing area and the machining area can be realized, since the flowing electrolyte is replaced with the electrolyte that is absorbed and confined in the absorption material. The schematic diagram is shown in Figure 1.

However, as shown in Figure 1, if there is no electrolyte flow or paths to evacuate by-products, such as dissolved substances and gas bubbles, by-products will gradually accumulate in the machining area and prevent the ECM process from continuing. Chen et al. have used a kind of porous metal cathode in the sandwich-like electrochemical micromachining (SLEMM) to remove gas bubbles and some nonconductive insoluble electrolytic products [7].

In this study, to reduce the impact of by-products, a porous and non-conductive ball made of maifan stone was used as the electrolyte absorption material in ECM process. Maifan stone balls, hereinafter abbreviated as MFS-ball, are generally used as the filter material for water filters.

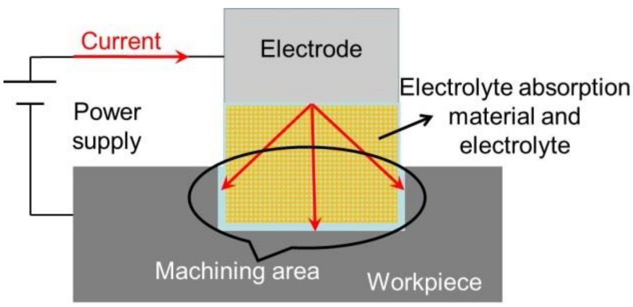

Figure 1. Schematic diagram of ECM processing with electrolyte absorption material

2. Machining principle and method

2.1. Machining principle and experimental setup

The processing schematic and picture of this method are shown in Figure 2 and Figure 3. An MFS-ball (commercial product for water filter) is inserted between the cathodic electrode and the anodic workpiece after absorbing the electrolyte. The electrode (SUS 304 plate), where there are a V-shaped cross-section track and flowing electrolyte on its surface, is placed beneath the workpiece and the MFS-ball. Different from the conventional ECM process, the workpiece (SUS 304 plate with a thickness of 1mm) is placed above the electrode and the MFS-ball, instead of being immersed in the electrolyte tank.

Since the electrolyte absorbed by the MSF-ball forms a current path between the electrode and the workpiece, machining current flow from the workpiece, the electrolyte absorbed in the MFS-ball and the electrode, and finally reaches the negative pole of the power supply.

At any moment of the ECM process, dissolution of the workpiece material due to electrochemical reactions only occurs in the machining area where the electrolyte exists.

During the whole ECM process, the distance between the electrode and the workpiece is kept constant, and the workpiece is moved linearly and reciprocate along the X-axis direction. At the same time, the MFS-ball rolls on the workpiece and the electrode surfaces alone the motive direction due to the friction among them. Besides, in the areas where the MFS-ball contacts with the flowing electrolyte on the electrode surface, not only the ECM by-products adhering to the MFS-ball can be cleaned by the flowing electrolyte, but also the MFS-ball can re-absorb the fresh electrolyte and take it to the machining area.

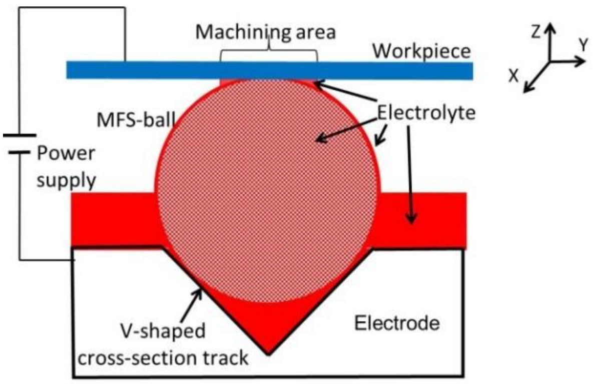

Figure 2. Processing schematic

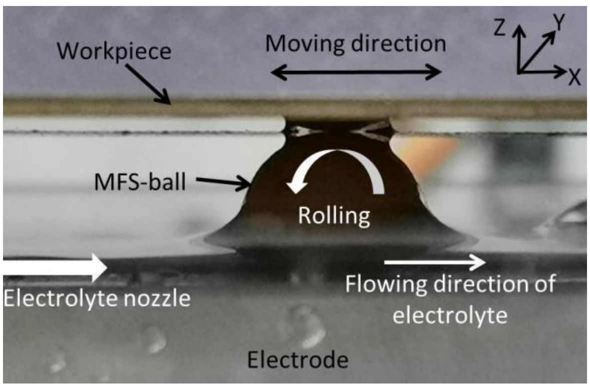

Figure 3. Processing picture

2.2. Experimental method and procedure

Before ECM experiments, in order to extrude the air contained inside the dry MFS-balls out and absorb the electrolyte, MFS-balls are put into an electrolyte container which has the ultrasonic-assisted function. Figure 4 shows the experimentally obtained relationship between the weight of ten MFS-balls absorbed with electrolyte and the electrolyte absorption time. The result shows that the weight of electrolyte absorbed in ten MFS-balls is 1.63g, which means that each MFS-ball can absorb 0.163g of the electrolyte.

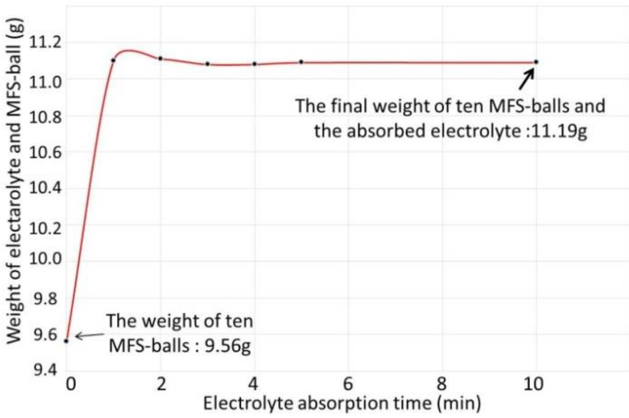

Figure 4. Change in total weight of MFS-balls with absorbed electrolyte

The experimental procedures are as follows:

Step1: During the power-off period, the workpiece is moved toward the MFS-ball along the Z-axis. Since the workpiece and the electrode are connected to the test leads of the multitester separately, once the circuit is closed due to the touch between the workpiece and the MFS-ball, the ammeter will beep. To ensure that the workpiece is in contact with the MFS-ball fully along the whole moving track, the workpiece is moved 0.1mm further toward the MFS-ball after the touching.

Step2: Turn on the switch of the electrolyte pump to allow the electrolyte to flow in the V-shaped path, and let the MFS-ball which is driven by the workpiece because of the friction between them, pre-scan in the V-shaped path along the Y-axis direction with the machining power supply off.

Step3: Turn on the power supply and the XYZ axis stage. At the same time, the MFS-ball is rolling in the V-shaped path for reciprocating scanning, and the electrochemical reactions occur on the contact area of the workpiece and the MFS-ball.

Step4: After the processing, turn off the power supply and the XYZ axis stage.

The experimental parameters are shown in Table 1.

In order to verify the feasibility of this experimental method and the influence of different experimental conditions on the machining result, the SUS 304 stainless which is wildly used in daily life has been used as the tool electrode and the workpiece in this experiment.

Table 1. Experimental parameters

Parameter	Value
Absorption material	MFS-ball
MFS-ball's diameter	10mm
Workpiece	SUS304 plate
Electrode	SUS304 plate
Electrolyte	10wt.% NaCl solution
Scanning distance	50mm

3. Experimental results and discussions

In this study, by changing the time of pro-scanning, the machining constant current (CC) value, the machining time, and the workpiece moving speed, the influences of these experimental conditions on the ECM process by using MFS-balls are ascertained.

One example of the appearance of the machined trace is shown in Figure 5. At a certain moment, the circular area, where the electrolyte exists, is etched by electrochemical reactions. The machined trace can be regarded as the overlap of the countless circular machining areas. Since the circle area is equal to each other, when using a constant current, the current density and the machining rate can be kept constant during the whole processing.

After machining, the contour measuring machine was used to measure the cross-section shape of machined traces along the measuring line shown in Figure 5.

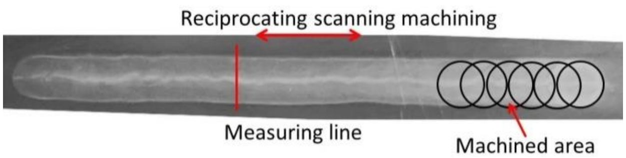

Figure 5. Example of machined surface

3.1. Pre-scanning

The purpose of pre-scanning is to store sufficient electrolyte in the machining area of the workpiece. Without the pre-scanning, the volume of electrolyte in the initial stage is relatively small and increases with machining. In this case, stable machining could not be obtained. When the constant current value is greater than 40mA, the electrolyte will be quickly consumed by the electrolysis reactions at the initial stage, which will cause electrical discharge at the machining part, which leads to the failure of ECM processing to continue smoothly. Hence, the pre-scanning is necessary for this ECM process.

In order to verify this situation and explore the maximum width of the cross sections affected by the pre-scanning time, the experimental parameters of Table 1 and the pre-scanning time from 100s to 350s at an interval of 50s were used. Other parameters were as follows: the machining time of 100s, the constant current of 40mA, the moving speed of 8mm/s.

The measurement results of cross section, processed with the time of pre-scanning less than 200s are shown in Figure 6, and the change in the trace width for all pre-scanning time is shown in Figure 7.

From Figure 6, we can know that by using the same processing conditions, the width of the cross section increases gradually with the pre-scanning time. However, because the volume removal rate of ECM processing is the same in all conditions in this case, the the depth of cross section decreases as the width increases.

From Figure 7, we can find that when the time of pre-scanning is greater than 250s, the width of the cross sections does no longer increase obviously. This result means that the maximum time of pre-scanning that affects the width of cross sections is 250s, after which the width does not change.

3.2. Constant current (CC) value

By changing the CC value from 20mA to 50mA in combination with the pre-scanning time of 100s, the machining time of 100s, the workpiece moving speed of 8mm/s, experiments were carried out to investigate the effect of the CC value.

From the measurement results in Figure 8, we can know that as the CC value increases, the depth, and width of the machining trace increase, while no electrochemical corrosion on the workpiece's surface other than the machining traces was observed. This fact proves that the MFS-ball can limit the electrolyte existing area and the machining area.

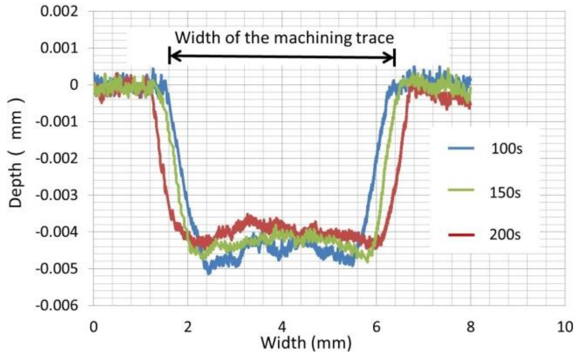

Figure 6. Cross section of machining trace under different pre-scanning time

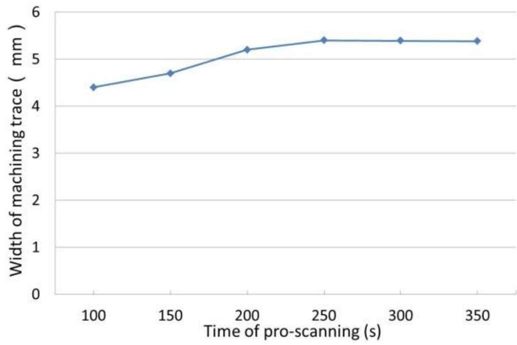

Figure 7. Result of trace width for different pre-scanning time

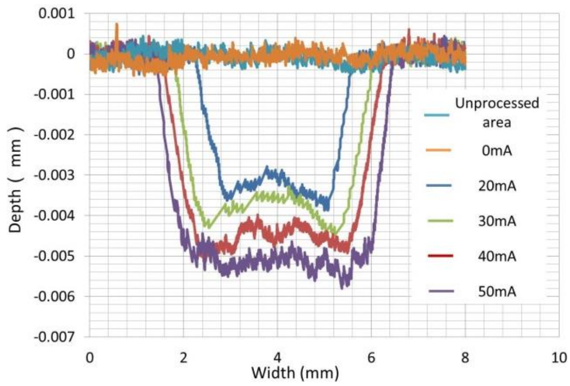

Figure 8. Cross section of machining trace under different CC value

Besides that, it can be found that the cross section of the machining trace has a W shape because the depth of the center part is shallower than the two sides of the cross section. From Figure 2 and Figure 3, it can be found that the center of the machining area is the part where the MFS-ball contacts with the workpiece, and the electrolyte in this area are mainly absorbed through the inside of the MFS-ball. It is obvious that the electrolyte amount in the center area is smaller than that on both sides, whose electrolyte comes from the surface of MFS-ball. Therefore, the ECM processing rate on both sides is faster than that on the center, which resulting in a shallower machining depth at the center of the machining area finally.

In order to confirm the influence of the MFS-ball's mechanical grinding effect, an experiment was carried out without the current supply (current: 0mA), while the other machining conditions remained unchanged. As shown in Figure 8, there is no difference between the unprocessed surface and the machined surface with a current of 0mA. Therefore, we can say that the ECM process is not affected by the grinding of the MFS-ball.

3.3. Machining time

By changing the machining time from 50s to 200s in combination with the pre-scanning time of 100s, the CC value of 40mA, the workpiece moving speed of 8mm/s, experiments were carried out to investigated the effect of the machining time.

From the measuring results of Figure 9, it is found that as the machining time increases, the depth and width of the machining trace increase at the same time. The reason for the increase in the depth is that the electricity quantity increase with the machining time. Meanwhile, the reason for the increase in the width is thought to be similar to the result of chapter 3.1, that is, the longer the machining time, the more the electrolyte accumulates on the machining area. Thus, not only the depth of the machining trace but also the width increases as the machining time increases.

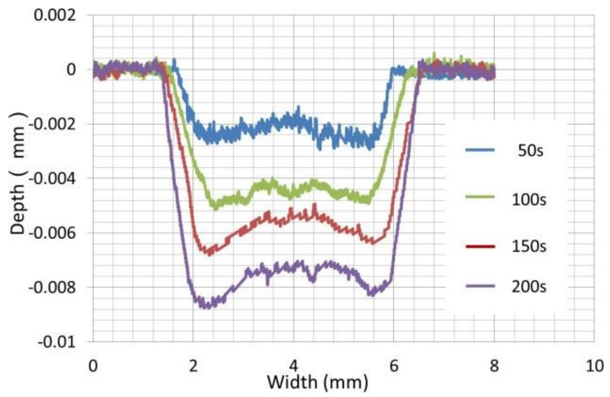

Figure 9. Cross section of machining trace under different machining time

3.4. Workpiece moving speed

By changing the workpiece moving speed from 4ms to 8ms in combination with the pre-scanning time of 100s, the machining time of 100s, the CC value of 40mA, experiments were carried out to investigate the influence of the workpiece moving speed.

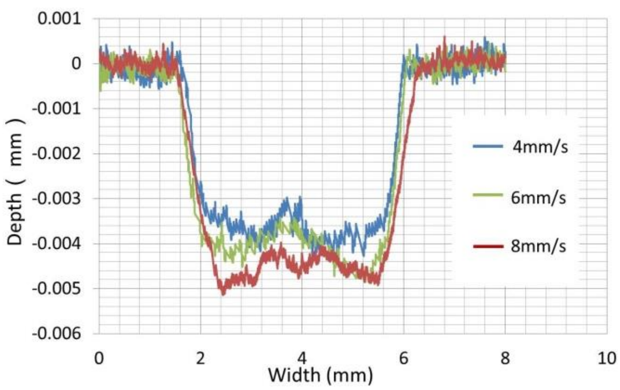

Figure 10. Cross section of machining trace under different moving speed

The measurement results by using the contour measuring machine are shown in Figure 10. From the results, it is known that as the workpiece moving speed increases, the depth and width of the machining trace increase slightly at the same time. The reason for the increase in the depth and the width is considered as follows. a faster moving speed causes a faster electrolyte renewal and by-product removal at the machining area, which speeds up the electrolysis reactions.

4. Conclusions

In this study, in order to limit the electrolyte existing area and increase the machining accuracy, electrochemical machining with electrolyte absorbed in MFS-ball was proposed and the effectiveness was experimentally confirmed. The effects of experimental conditions on the processing results were investigated. The following conclusions were obtained:

(1) The pre-scanning plays an important role in the initial stage of ECM processing. A pre-scanning time of 250s is required for a stable machining width.

(2) The rate of ECM processing increases as the increasing of the machining current value, which leads to the increase of the width and the depth of the machining trace.

(3) The depth and the width of ECM processing trace increase with the increase of the machining time.

(4) The workpiece moving speed affects the machining trace directly. A faster moving speed speeds up the refresh of electrolyte to the machining area.

Since the processing of this method is like writing with a ball-point pen, in the future this method can be applied to write characters and patterns on the surface of the difficult-to-machine metal like a ball-point pen.

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