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Proposal of formation of tapered micro-hole by utilizing electrolyte flow in ECM process

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Abstract
In this report, a method was proposed to form a tapered hole by utilizing the change in the electric resistance caused by the bubble flow with the electrolyte. The influence of electrolyte flow on internal shape of machined micro hole was experimentally investigated. It was found that internal shape of micro hole is affected by the electrolyte flow. For example, tapers on the micro hole were shaped in the same direction as the electrolyte flow direction when the electrolyte flows during machining. In contrast, the tapered shape didn't appear when there was no electrolyte flow during machining.

ECM, electrolyte flow, reversed-taper, micro hole, enlarge hole

1. Introductions

It has been reported that the fuel injection nozzle with a reverse-tapered hole can improve the engine efficiency and reduce emissions due to the improved injection flow performance [1]. However, micro holes with a complex internal shape such as reverse-taper tape are hard to machine with conventional methods, especially in the case of hard-to-cut materials. Meanwhile, electrochemical machining (ECM) is considered a suitable method for such materials, since ECM has the features of non-contact machining, high removal rate, no tool wear, and can dissolve metallic materials regardless of their hardness.

Up to now, there are several reports about the formation of holes with complicated shape by ECM. Mi et al. [2] and Nomura et al. [3] proposed a method to manufacture holes with complicated shape by controlling the conductive area on the tool surface, and verified its effectiveness through experiments and simulations. However, it is difficult to apply Mi's method to micro-holes because of difficulty in preparing the micro tool. Li et al. [4] and Jo et al. [5] successfully to fabricate the complex shaped holes by controlling the tool feeding speed or machining current with a cylindrical tool insulated in side surface. The drawback of their methods is the machining time becomes longer due to the necessity of the tool feed motion.

The present study is aimed to form a tapered micro-hole from a straight through-hole by utilizing the change in electrical conductivity due to the flow of gas bubbles in the ECM electrolyte. Since there are no complicated tool feed and current control, the proposed method is simple with a high productivity. In this paper, the principle and the experimental results are explained and discussed.

2. Principle and experimental setup

The principle of the proposed method is schematically shown in Figure 1. In ECM process, hydrogen gas and oxygen gas generate on the cathode and anode surface, and the gases flow with the electrolyte flow. When a cylindrical tool is inserted into a pre-drilled hole and a voltage is applied between the tool and the workpiece, the disctrution of gas bubbles is influenced by the flow as shown in the figure. Since the electrical conductivity decreases due the existence of bubbles, the current density, and finally the removal amount of workpiece along the axial direction changes. Thus, a tapered hole is generated.

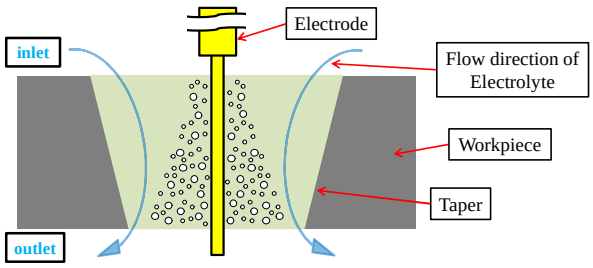

Figure 1. Schematic of principle of taper shape machining by utilizing by electrolyte flow

Figure 2 shows the schematic of machining setup especially designed and developed. This device can be used for three machining process; ECM, EDM, and drilling. In addition, since the machining process can be switched without removing the workpiece, the workpiece can be machined with different processing methods continuously, for example, ECM after drilling. In this research, a pre-machined through hole was machined by drilling, and then it was enlarged and shaped by ECM. In the ECM process, electrolyte was sucked or compressed from the lower side of the through hole using a pump.

Since the diameter and the depth of the machined hole are about 500µm and 1000µm, it is difficult to measure the hole inner surface directly. Therefore, an indirect measurement method using replicating resin [6] (Provil novo lite) was employed. After the resin was inserted into the machined hole, it hardened to a hardness about 52hs under condition of atmosphere and the hole shape was replicated. The hole shape was then obtained by measuring the pulled out resin. Through verification experiments it was found the resin replicates the inner shape quite well, since the shrinkage percentage is very low.

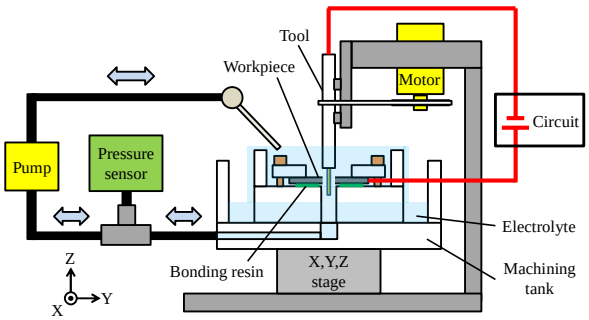

Figure 2. Schematic of machining equipment in ECM mode

3. Experimentas results of tapered hole machining

The ECM experiments were conducted under various machining conditions and hole shapes were measured and evaluated in order to verify the proposed principle. Main experimental conditions are shown in Table1. Machining was carried out under three kind of electrolyte flow; a) suction mode: the electrolyte flows downwards in the inter-electrode area with the suction of the pump, b) compression mode: the electrolyte flows upwards with the pump pressure, and c) intermit mode: the electrolyte flow stops during the period of voltage application. One typical photo of the resin which replicated a hole machined in the suction mode is shown in Figure 3. It is found that the hole diameter is bigger in the upper part where exist less gas bubbles as shown in Figure 1. From this result, we can say that the proposed machining method works well as expected.

Table 1 Main experimental conditions

Workpiece	t1 mm SUS 304 plate
Pre-machined hole	φ300 μm (by drilling)
Eletctrode	φ200 μm W
Electrolyte	20 wt% NaCl aq
Power supply mode	Constant Voltage
Applied voltage	10 V
Pulse width	10 ms
Pulse period	100 ms
Machining time	30 s

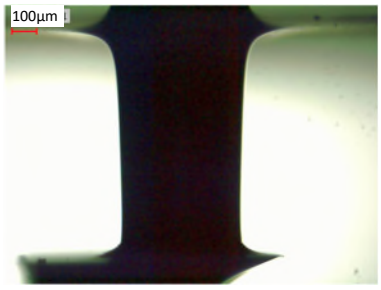

Figure 3. Picture of replicated resin of machined hole in suction mode

To evaluate the machining characteristics of proposed method, the diameter difference and the taper angle were measured for different machining modes. The diameter difference was obtained from the diameter in the middle position before and after machining, while the taper angle was obtained from the diameters in the in-mid and the out-mid positions and the distance between these two positions as shown in Figure 4. The hole diameter in different positions was measured with the pulled-out replicated resin with optical an microscope, while the uncertainty of the measurement was about 2μm. The Figure 5 shows the results of the diameter difference and measured machining current, while Figure 6 shows the taper angle obtained under three modes. It is found from the figures that tapered hole were succeflully obtained in the suction and compression modes, although the diameter difference and taper angle are little different in two modes. In addition, the result that no taper appears in the intermit mode without electrolyte flow proves the fact that the taper is generated by the gas bubble distribution in the electrolyte flow.

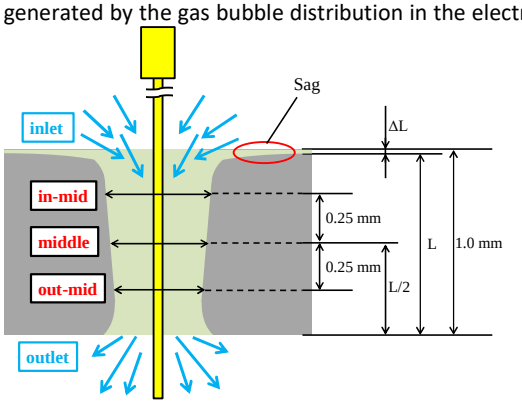

Figure 4. Schematic of measured positions

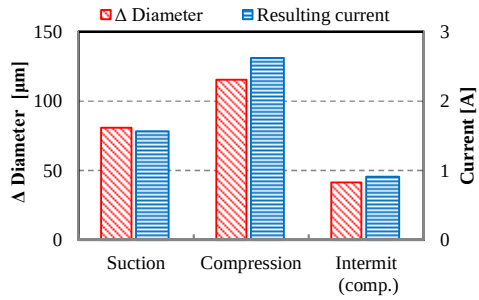

Figure 5. Processed diameter and resulting current

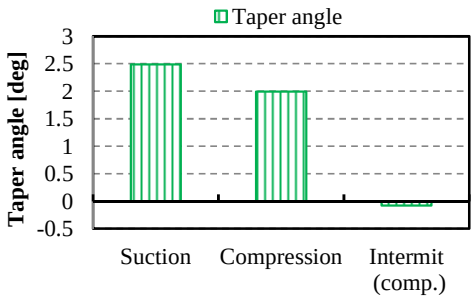

Figure 6. Taper angle of holes processed in different modes

4. Conclusions

In this research, a method was proposed to form a tapered hole by utilizing the change in the electric resistance caused by the bubble flow with the electrolyte, and the effectiveness of the method was experimentally verified.

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