Overcut and Material Removal Rate on Electrochemical Machining of Aluminum and Stainless Steel using Isolated Brass Electrode

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***Abstract*—The electrochemical machining has been developed as an alternative for conventional techniques of machining very hard materials and complex shape without any harm to tool and residual stresses. This paper addresses the influence of processing parameters on the overcut (OC) and Material Removal Rate (MRR) of a custome-built electrochemical machine. In addition, the angle of overcut for the workpieces were also examined. Stainless steel and aluminium plate with thickness of 0.4 mm as workpieces were machined using ECM equiped with a 3-mm isolated brass rod as electrode in sodium chloride as electrolityc solution. Experiments were conducted with the developed setup by varying the machining voltage and initial workpiece-to-electrode gap with a constant tool movement. MRR in ECM was obtained from weight loss measurement while image analysis using open source sofware (ImageJ) was applied to assist OC determination. The result shows that increase in machining voltage and gap enhances ion's mobility and conductivity for conduction, so that it results MRR, overcut and angle of overcut getting higher.**

Keywords— Electrochemical machining, overcut, material removal rate, electrolyte, flow rate

I. INTRODUCTION

Electrochemical machining (ECM) is categorized as a non conventional machining process which is a contactless and non-thermal process. Electrochemical method is based on anodic dissolution of the workpiece as anode, using the tool as the cathode, in the electrolytic solution during electrolysis [1]. The electrolytic solution flows between electrodes and flushes away the dissolved metal. Hence, this technique is suitable for the machining of very hard and electrically conductive materials without causing any harm to the tool. The tool electrode as its negative mirror image determines the final shape of the workpiece. The tool movement toward to workpiece allowing to fabricate complex parts without any residual stress and tool wear. Recently many industries use a number of variants of ECM such as electrochemical sinking, electrochemical deburring, electrochemical polishing, pulse ECM, ECM with orbiting tool electrode and ECM with numerically controlled tool-electrode movement [2].

A wide range of parts can be produced for various industrial applications such as aerospace, automotive and medical [3]. Recent study in biomanufacturing reported the development of microfilter system consisting of micro chamber made of stainless steel and nanoporous membrane [4]. The smoth surface microchamber is dificult to be fabricated using conventional machine due to cutting force being generated on the thin metal [5]. Chemical etching and electropolishing have been carried out to fabricate the chamber. However, generally hazardous chemicals are used in chemical etching technique, such as sulfuric acid and hydrofluoric acid. Although electropolishing technique is considered as enviroment friendly process and apply non toxic electolyte solution, such as sodium chloride, this process need a longer time. In addition, the electrolyte solution become thicker and darker due to material disolution. For a long periode it may affect the effectiveness of the removing material process. ECM, which posses its own controllable electrolyte circulation system and gap width and also using non toxic solution offers the advantages to overcome the problems. MRR and OC in ECM are important factors and have drawn attention for improving quality of the process [10-12] [6-8]. Those are significantly affected by the various process parameters considered in the previous studies, such as electrolyte flow rate, electrolyte concentration, current, voltage and gap width.

Regarding those, a custom built ECM laboratory scale has been developed in our department. The design and its fabrication was reported elsewhere and current research is carried out in order to characterize the ECM being developed. In the future the ECM will be used to fabricate the microchamber. In this paper, the material removal rate and overcut of electrochemically machined stainless teel and aluminum plate were examined. Two parameters were varied during the experiments, *i.e.* voltage and initial gap width.

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II. EXPERIMENTAL METHOD

A. Workpieces and Electrodes

Stainless steel of grade AISI 304 plate and aluminum plate with thickness of 0.4 mm were selected as workpieces for ECM machining, while the tool electrode is an isolated brass rod with the diameter of 3 mm. The workpiece blank was weighed before a flexible mask with a 3-diameter hole was applied on the surface of each workpiece (Fig 1).

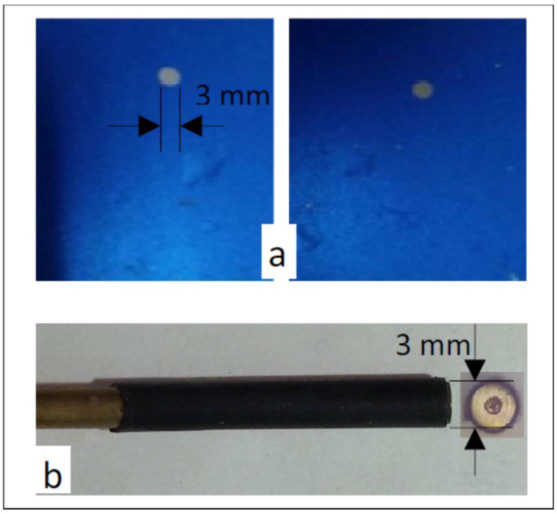


Fig. 1. (a) Masked workpieces with 3 mm diameter hole and (b) 3 mm diameter isolated brass rod tool electrode

B. Experimental Set-Up and Its Procedure

The operation being observed was an electrochemical drilling process using a 3 mm diameter isolated tool brass. It utilized sodium chloride at concentration of 150 g/l as electrolytic solutions. The machining parameters being used in the experiment are presented by Table 1.

TABLE 1. ELECTROCHEMICAL MACHINING PARAMETER

No	Parameter			Current being measured (x 10^{-1}A)		
	Voltage (V) / Initial Gap (mm)			7	10	13
1	Stainless Steel	0.5	range	7-8	7-14	12-17
		0.75	range	5-8	6-13	8-15
		1.0	range	5-9	5-13	6-13
2	Aluminum	0.5	range	4-8	3-9	6-16
		0.75	range	5-.9	8-12	10-15
		1.0	range	6-10	7-10	10-14
3	Salt solution	Concent - ration (%)		15		
		Flow rate (l/m)		3		
4	Tool speed (mm/s)			$2{,}0\times10^{-2}$		

A masked workpiece was loaded on the holder in the workpiece container. The machining proces is started by setting the gap width of 0.5, 0.75 or 1.0 mm. Electrolyte circulation was activated and the valve was set up to produce electrolyte flow rate of 3 l/m at machining area. Following this, the electochemical machining proces was conducted by employing voltage of either 7, 10 or 13 volt between workpiece and the tool electrode for 371 s (for stainless steel) or for 93 s (for aluminum) at tool speed of 0.12 mm/minute. When the machining process has been completed, the applied voltage was terminated and the tool was pulled back from the machining area.

The machined workpieces were then weighed followed by determining the MRR using Eq. (1), where m_{bm} = mass before machining and m_{am} mass after machining , ρ= specific mass and t_m = machining time [9]

$$MRR = (m_{bm}-m_{am})/(\rho.t_m) \qquad (1)$$

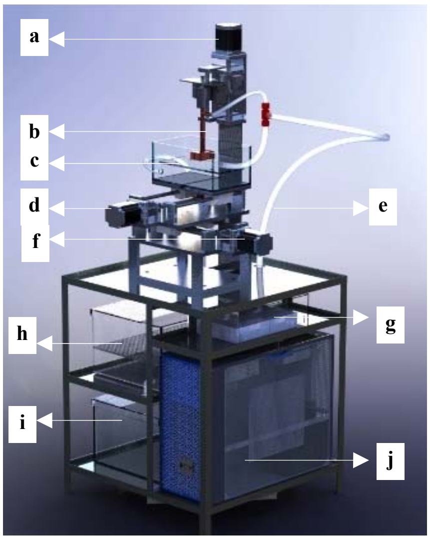
An optical microscope was used to capture the image of machined workpiece profile. Diameters of the holes were measured by image analysis using open source software (ImageJ). Eq. (2) was employed to calculate the over-cut, where D_t is the external tool diameter and D_i, is the largest internal diameter of the workpiece.

$$Over\text{-}cut = (D_i\text{-}D_t)/2 \qquad (2)$$

Some of the machined workpieces were cut and mounted into resin for capturing images by using the optical microscope to obtain the angle of the over-cut (α).

C. ECM

The experiment used laboratory scale ECM machine which is shown in Fig. 2. The ECM machine consists of an electrical system (g & j), a mechanical system (a,b,c,d & f) and an electrolyte circulating system (e, h & i). The mechanical system posseses 3 axes which are able to be controlled independently using a computer.



a. Z axis stepper motor
b. Tool electrode
c. Workpiece container
d. X axis stepper motor
e. Electrolyte hose
f. Y axis motor stepper
g. Controller
h. Filter in 1st reservoar
i. 2nd Electrolyte reservoir
j. Power Supply

Fig 2. Drawing of the ECM machine used in the experiment

III. RESULT AND DISCUSSION

The experiments have been conducted on the developed ECM set-up to analyze the effect of the machining voltage and the gap width on MRR and overcut. The experimental results are presented on the figures and the graphs.

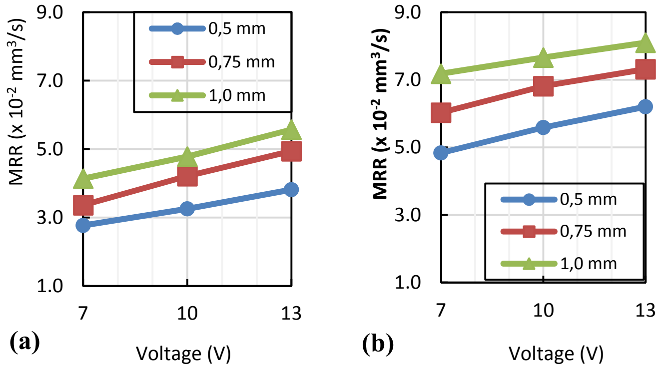
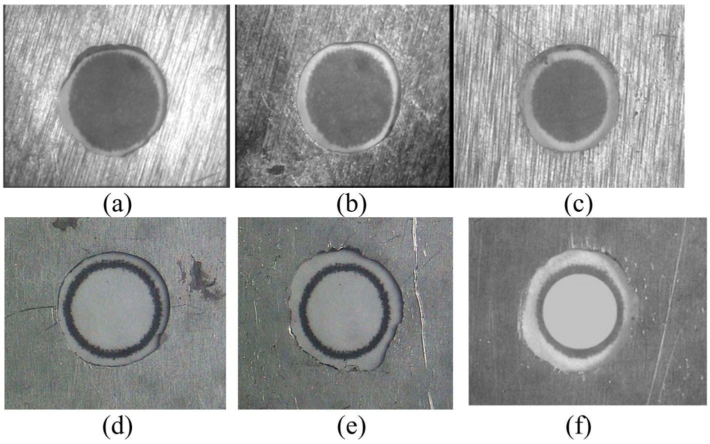


Fig 3. Variation of MRR with voltage and gap width for (a) stainless steel and (b) aluminum

From Fig.3 it can be seen that the MRR of the both metals increase with an increase of the voltage and the gap width at electrolyte concentration of 150 g/l. As seen in table 1, the machining current goes up with an increase of the applied voltage. Mobility and avalability of ions are enhanced resulting in a higher value of MRR. The value of MRR of aluminum is higher than that of stainless steel due to its higher electric conductivity. However increase in gap width of electrode-workspiece was observed to reduce this increase. Those results are inline with Faraday's rule that MRR is proportionally affected by the machining current. Similar results have also been stated by Bhattacharyya and Sorkhel [12]


(a) (b) (c)

(d) (e) (f)

Fig 4. Photograph of the holes being electrochemically machined on workpieces of (a-c) aluminum with gap width of 0,5mm and voltage of 7, 10 and 13 V and (d-f) stainless steel with gap width of 0,5 mm and voltage of 7, 10 and 13 V

Figure.4 demonstrated some macrographs of hole being machined in ECM at a combination of machining voltage and gap width parameter. Irregularities in the shape of the electrochemically machined hole have been found in the photograph of ECM work piece, especialy for higher machining voltage parameter. This may be caused by the improper flushing out of the burr from the hole and excesive material removal .

The occurrence of the overcut has been examined in order to obtain machining precision. Fig.5 shows that the increase of machining voltage enlarge the value of over cut on the both workpieces. The localization cause of current flux flow decreases because of excess of machining voltage. Due to less localization cause, in fact the stray current flow enhances in the machining region, during turn touching, more material removal from the bigger area of workpiece which causes rise in over cut [10].

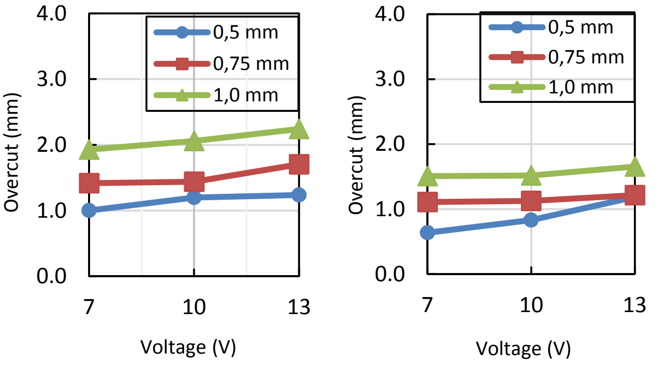


Fig 5. Variation of overcut with voltage and gap width for (a) stainless steel and (b) aluminum.

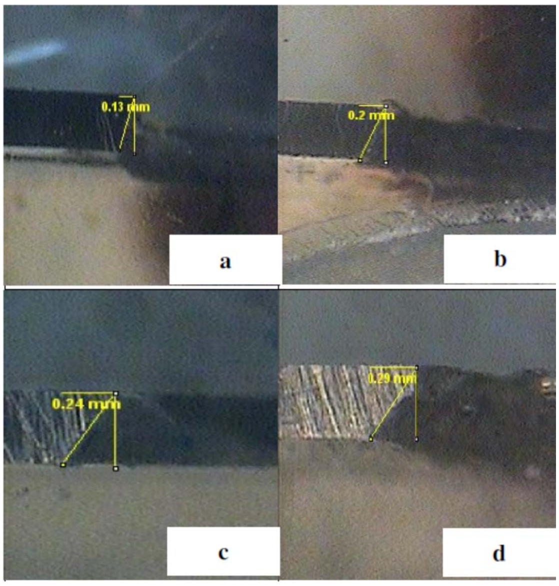


Fig 6. The angle of overcut for (a-b) aluminum and (c-d) stainless steel

Fig. 5 shows typical angle of overcut for each material. The stainless steel brass demonstrated considerably larger angle of overcut than that of aluminum. The angle of overut is associated to the overcut being produced. It shows a strong correlation bertwen the overcut and its angle in a positive way as studied by Sudiarso *et al* [11]. The higher overcut during machining resulted in the higher angle of overcut.

Conclusion

The work succesfully presents the effect of two process parameters of ECM *i.e.* machining voltage (7, 10 and 13 volt) and gap width (0.5, 0.75 and 1.0 mm) on the MRR and overcut. The MRR and overcut increase considerably with the increase of machining voltage and gap width. Yet, increase in gap width proceed to reduce the increase. The MRR of aluminum is found higher than that of stainless steel due to its conductivity and vice verca for its overcut and its angle of overcut. The precision of the ECM machining dereases with the increase of the machining voltage.

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