Experimental Investigation on Performance Characteristics of Aluminium Electrode using a developed µ-ECM Method

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Abstract
Over the last few decades, due to the market demands for miniaturized features and intricate components with high surface quality characteristics and closed dimensional tolerances industries are focusing on the advanced machining methods. Traditional machining methods are not suitable to achieve the same as they are unreachable to the required size of the machining tool, exhibit high setup cost, tool wear and involve more energy consumption with high unit removal of material. However, the quest for a chemical based advanced micromachining method has become considerably important to overcome the shortcomings of the traditional methods. Therefore, in the present article, Micro Electrochemical Machining (µ-ECM) method has indigenously developed to study the performance characteristics of the electrodes. The work piece electrode is taken as aluminum, tool electrode as stainless steel and NaCl as the electrolyte. Machining of micro holes has carried out on the work piece with 30% electrolyte concentration using the µ-ECM method by controlling the voltage and feed rate. The affect of these parameters on the material removal rate (MRR) has studied. The experimental results show that by increasing the voltage, workpiece MRR increases with negligible tool wear, and found to be maximum at 30 volts and 0.64 A.

Keywords: Micro Electrochemical machining, Aluminum electrode, Voltage, Feed rate, Material removal rate

INTRODUCTION

In the present century products were made from the most durable and un-machinable materials. In an effort to meet the manufacturing challenges created by these materials, tools such as alloy steel, carbide, diamond and ceramics have evolved. Since the power of water, wind, steam and electricity were harnessed, mankind was able to extend manufacturing capabilities with conventional machines having greater accuracy and faster machining rates. In these machines, metal removal takes place by cutting toolin contact with work piece.However, a contactless electrochemical machining process has emerged over the last couple of decades. In today's high technology industries, with the growing demand towards miniaturization of features/components, especially the development of MEMS, advanced micromachining process has become increasingly important. Among these, recently Electrochemical machining (ECMM) has seen a resurgence of industrial interest due to its many advantages such as no tool wear, stress free and smooth surfaces of machined product and ability to machine complex shape in electrically conductive materials, regardless of their hardness. It has been applied in diverse industries such as aerospace, automotive and electronics, to manufacture airfoils and turbine blades, die and mould, artillery projectiles, surgical implants and prostheses, etc. Moreover with recent advances in machining accuracy and precision, based on the development of advanced electrochemical metal-removal processes, demonstrate that the ECMM can be effectively used for micromachining components in the electronics and precision industries.The material removal mechanism in ECMM is controlled anodic dissolution at atomic level of the work piece by a shaped tool due to flow of high current at relatively low potential difference through an electrolyte which is quite often water based neutral salt solution.

In this as a literature survey few selected research papers related to ECMM and RSM is reported on surface roughness (Ra), metal removal rate (MRR), overcut and other responses.

B. Bhattacharyya, S. Mitra, A.K. Boro: This journal provides us the betterunderstanding of high rate anodic dissolution processes like electrochemical machining (ECMM) and electrochemical micromachining (ECMM) as these processes are become a widelyemployed manufacturing process in the electronic and precision manufacturing industries particularly in the micro manufacturing domain. A successful attempt has been made to develop an ECMM setup for carrying out in depth independent research for achieving satisfactory control of electrochemical machining process parameters to meet the micromachining requirements. The developed ECMM setup mainly consists of various sub-components and systems, e.g., mechanical machining unit, micro tooling system, electrical power and controlling system and controlled electrolyte flow system,etc.

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Jagannath Munda & Bijoy Bhattacharyya: They reported that when ECMM is used inthe micron range, it is called electrochemical micromachining (ECMM) and it is used as one of the best micromachining technique for machining electrically conductive ,tough and difficult to machine material with appropriate machining parameters combination. This paper attempts to establish a comprehensive mathematical model for correlating the interactive and higher-order influences of various machining parameters, i.e. machining voltage pulse on/off ratio, machining voltage, electrolyte concentration, voltage frequency and tool vibration frequency on the predominant micromachining criteria, i.e. the material removal rate and the radial overcut through response surface methodology (RSM), utilizing relevant experimental data as obtained through experimentation. Optimization of this parameters using mathematical model of RSM gives higher accuracy of the response parameter during machining.

The optimum value of different parameters are obtained as : pulse on/off time -1.0,machining voltage -3V ,electrolyte concentration- 15g/l, voltage frequency – 42.118 Hz and tool vibration as 300 Hz. The nature of machined micro-hole is depicted through the different SEM micrographs. The results and discussions are analyzed from the different graphs like machining voltage v/s electrolyte concentration on ROC; machining voltage v/s tool vibration frequency on MRR and pulse on/off ratio v/s voltage frequency on MRR. All the graphs and planning of the experimental design are obtained using the software called MINITAB.

Taha Ali El-Taweel& S. A. Gouda: Wire electrochemical machining (WECMM) is acutting process in which the workpiece acts as anode and the wire is the cathode (tool).In this paper Taha and Gouda discusses the feasibility of using a wire as a tool in electrochemical turning process (WECT). They measured the performance criteria of the WECT process through investigating the effect of working parameter namely voltage, wire feed rate, wire diameter, workpiece rotational speed,and overlap distance on the response parameter which is metal removal rate,surface roughness and roundness error. Using the Response Surface Methodology (RSM) the regression model and analysis of variance were studied based on the experimental result. From the results and discussion the conclusions were obtained :

1. More effective micro-size turned parts can be produced using wire as an electrode in electrochemical turning instead of using a profiled tool.
2. The increase of the wire feed rate increases the surface roughness while improving the roundness error.
3. The increase of rotational speed of the work piece improves both the productivity of the process and geometrical error of the produced parts.
4. The optimum combination of parameters value was obtained as :

applied voltage of 32.5 V, wire feed rate of 0.4 mm/min, wire diameter of 1.3 mm, overlap distance of 0.03 mm, and rotational speed of 750 rpm for maximizing metal removal rate and minimizing both surface roughness and roundness error.

B. Bhattacharyya, S.K. Sorkhel: In this journal, researchers performed a experimentin a microprocessor-based ECMM system having DC power supply with controlled electrolyte flow and automatic tool feeding. They developed a comprehensive mathematical model for correlating the interactive and higher-order influences of various machining parameters on the dominant machining criteria, i.e. the metal removal rate and the overcut phenomena, through response surface methodology (RSM), utilising relevant experimental data as obtained through the experimentation. The analysis of the experimental observations highlight that the MRR in ECMM increases non-linearly with increase in the electrolyte flow rate and concentration and with the applied voltage. The observations and analysis carried out for over cut (OC) confirmed that an optimal control of the OC effect could be found for various process parameters to secure effective dimensional control of electrochemically-machined work piece.

Based on the exhaustive literature survey, it has been found machining of aluminum using ECMM not been addressed properly. Therefore the present paper has focused on the machining of aluminium holes using a developed ECMM method and to study the performance characteristics of the process. Optimal quality of the work piece in ECMM can be generated through combinational control of various parameters.

EXPERIMENTAL STUDY AND RESULTS

Figure 1and Figure 2 shows the schematic diagram and photographic view of the developed setup.

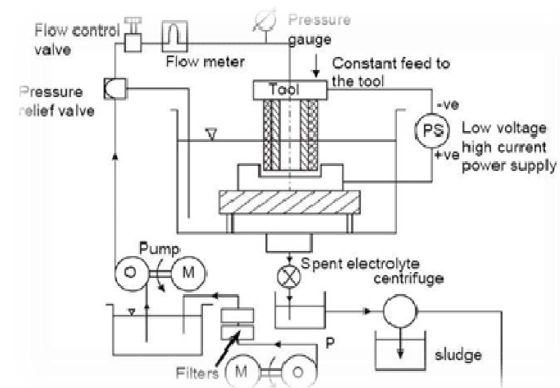

Figure 1. Schematic of developed ECMM setup

The setup consists of workpiece tank holding the workpiece, tool holder, electrolyte tank, flow controlled valve, pump to deliver the electrolyte, rack and pinion mechanism for tool feed control, temperature control system, filtering arrangement and electrical accessories.

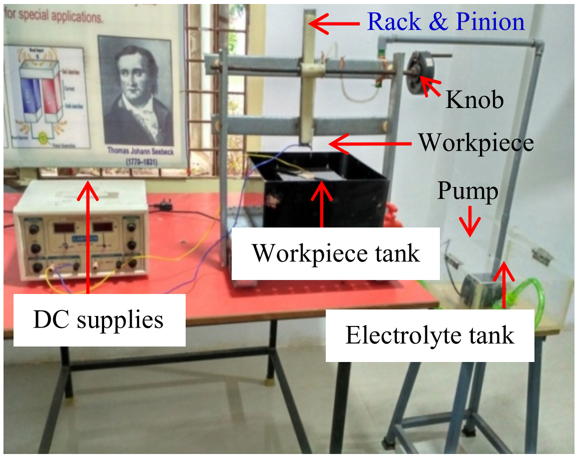

Figure 2. Photographic view of developed ECMM setup

The process parameters used for the experimentation is provided in the Table 1. The detailed description of removal of material is presented beneath.

Table-1 Process parameters used for expermentation

Tool	Stainless steel
Workpiece	Aluminium
Supply voltage	20-30 volts
Current	1 amp
Tool Feed Rate	0.5mm/min - 15mm/min
Electrolyte	NaCl solution
Environment	Room temperature

In the present study, workpiece(aluminium) is connected to positive terminal (anode) and tool(stainless steel) is connected to negative terminal(cathode).The tool workpiece are held close each other with a very small gap between them by using Rack and pinion.The electrolyte from the reservoir is pumped at high pressure and flows through the gap between the workpiece and tool at a velocity of 30 to 60m/s.A mild voltage about 5 to 30 volts is applied between the tool and workpiece.Due to applied voltage, the Current flows through the electrolyte with positive charged ions and negative charged ions. The positive ions move towards the tool(cathode) while negative ions move towards workpiece(anode) as shown in Figure 3.The electrochemical reaction takes place due to this flow of ions and it causes the removal of metal from the workpiece in the form of sludge.

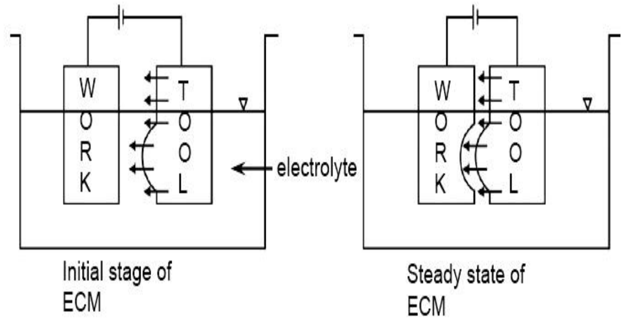

Figure 3. Mechanism of material removal in ECMM

When the current is switched on, the electrolyte ($NaCl+H_2O$) gets ionised according to the following relationship,

$$NaCl \longrightarrow Na^+ + Cl^-$$

$$H_2O \longrightarrow H^+ + OH^-$$

As hydrogen ions reach the cathode (tool), they combine with free electrons resulting into evolution of H_2 gas.

$$2H^+ + 2e^- \rightarrow H_2$$

Assume that pure iron is being machined by this process, reactions that would occur are

$$2Na+ + 2OH^- = 2NaOH$$

$$Al^{2+} + 2\,Cl^- = AlCl2$$

$$2NaOH+AlCl_2=2NaCl+Al\,(OH)_2$$

Thus using NaCl as the electrolyte, aluminium is removed as Al $(OH)_2$ and sodium chloride is recovered back. The aluminium hydroxide produced during the process must be removed continuously from the electrolyte by filtration before it is recirculated.It is to be noted that during ECMM process, the machining gap size increases as the metal is removed. The larger gap leads to a decrease in the metal removal rate. Therefore to maintain a constant gap between the tool and the work piece, the cathode (tool) should be advanced towards the anode (work) at the same rate at which the metal is remove. This is achieved by rack and pinion arrangement so that machining could continue without any interruption.

Table 2 shows the material removal rate of aluminium electrode machined during ECMM process. Figure 4 shows the photographic view of holes machined on aluminium workpiece.

Table-2 MRR obtained during ECMM process

As the tool advances towards work, gap decreases and Current increases which increases more metal at a rate corresponding to tool advance. A stable spacing between tool and work is thus established. It may be noted that high feed rate not only is industrious but also produces best quality of surface finish.

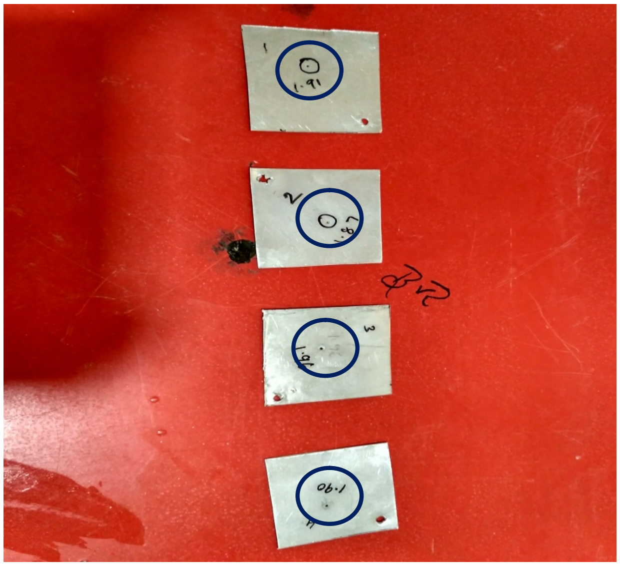

Figure 4. Photographic view of holes machined on aluminium workpiece

However feed rate is restricted by removal of hydrogen gas and products of machining. Metalremoval rate is lower with low voltage, low electrolyte concentration and low temperature. Figure 5 shows the plot of MRR with respect to voltage applied. The voltage is kept relatively low to minimize arcing across the gap. ECMM technique removes material by atomic level dissolution of the same by electrochemical action. Thus the material removal rate or machining is not dependent on the mechanical or physical properties of the work material. It only depends on the atomic weight and valency of the work material and the condition that it should be electrically conductive. Thus ECMM can machine any electrically conductive work material irrespective of their hardness, strength or even thermal properties.

Moreover as ECMM leads to atomic level dissolution, the surface finish is excellent with almost stress free machined surface and without any thermal damage.

W/P	Initial wt.of w/p Before Exp.	Time taken to prepare hole(sec)	Material thickness (mm)	Final wt.of w/p After Exp.	Electrolyte velocity (lt/min)	MRR g/min
1	1.87	38.65	1	1.86	1.5	0.0002
2	1.9	21.45	1	1.89	1.5	0.0004
3	1.91	40.22	1	1.89	1.5	0.0004
4	1.96	32.70	1	1.94	1.5	0.0006

CONCLUSIONS

In this work, Electro-chemical micromachining (ECMM) setup has been indigenously developed. Holes are machined using the ECMM setup in Aluminum work piece with Electrolyte concentration30%of NaCl.

Experiment conducted at various voltages and recorded time taken to prepare the holes. Metal removal rate was find out based on the initial weight of the work piece andfinal weight of the work piece. Maximum Metal removal Rate at 30 volts, 0.64amp based on conducted Experiment. It is observed that MRR of aluminum plate is gradually increased with increase in voltage.

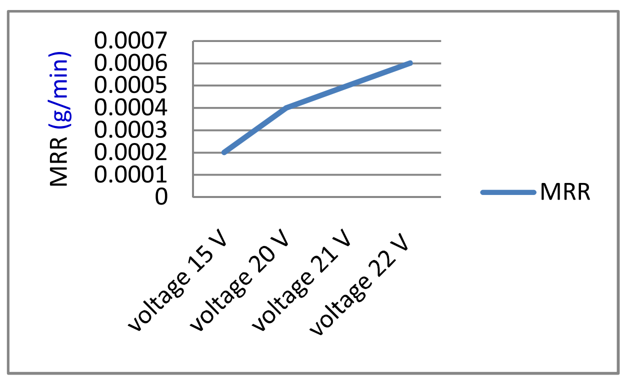

Figure 5. MRR with respect to applied voltage

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