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EFFECT OF PROCESS PARAMETERS ON ELECTROCHEMICAL MACHINING OF AL/SiCp COMPOSITES

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ABSTRACT

Metal Matrix Composites (MMCs) have proved to be extremely difficult to machine using conventional machining processes due to certain amount of secondary reinforcement. Electrochemical machining (ECM) is a promising nontraditional machining technique that is used for machining such difficult-to-machine materials. This paper presents the effect of ECM process parameters such as applied voltage, electrolyte concentration, electrolyte flow rate and tool feed rate on the material removal rate (MRR) and surface roughness (Ra) of LM25Al/SiCp composites with 10% and 20% of SiC. This has been done by means of the technique of design of experiments (DOE), which allows us to carry out the above-mentioned analysis performing a relatively small number of experiments. Increase in volume percentage of SiC resulted in decrease in MRR and increase in Ra.

Keywords: *Electrochemical Machining (ECM), Material Removal Rate (MRR), Surface Roughness*

1. Introduction

Electrochemical machining (ECM) is among the well recognized non-traditional manufacturing processes in industry. An electrical current passes through an electrolyte solution between a cathode tool and an anode workpiece. The workpiece is eroded in accordance with Faraday's law of electrolysis. Since the introduction of ECM in 1929 by Gusseff, its industrial applications have been extended to electrochemical drilling, electrochemical deburring, electrochemical grinding and electrochemical polishing [1]. ECM was found particularly advantageous for high-strength alloys. It has been applied in diverse industries such as aerospace, automotive and electronics, to manufacture airfoils and turbine blades, die and mold, artillery projectiles, and surgical implants and prostheses [2]. ECM processes were also adopted in the aerospace and electronic industries for shaping and finishing operations of a variety of parts of the opening windows that are a few microns in diameter [3]. ECM is achieved by electrochemical reaction, hard and difficult-to-cut materials can be machined, and there is no residual stress in the workpiece.

Metal matrix composites (MMCs) are now beginning to make an important contribution to major industries such as transportation, electronics, sports, tooling, and machinery. Although the properties of MMCs, in many respects, are superior to those of their monolithic counterparts, the extremely hard, abrasive, low electrical conductivity, and high thermal resistance nature of the ceramic reinforcement phase remains a major obstacle in the shaping of these materials whether or not conventional or unconventional techniques are used [4]. It is accepted that ceramic reinforced metallic materials are in general much more difficult to machine than their unreinforced counterparts. The abrasive nature of the reinforcement, commonly a ceramic phase such as SiC or Al_2O_3 can cause rapid tool wear. To machine MMCs, using conventional means could be problematic and costly, and this, to a great extent, has slowed down the full commercial exploitation of these novel materials. Therefore, there is an obvious demand for the development of some efficient and precision machining techniques for MMCs [5]. Therefore, ECM is the best choice for machining of MMCs. This work explores the machinability of the two volume fractions of SiCp/ LM25aluminum alloy composites by ECM. The machining parameters such as electrolyte concentration, electrolyte flow rate, applied voltage, and tool feed rate were varied to investigate the effect of the metal removal rate (MRR) and surface roughness (Ra) of given different volume fractions of SiC particle composites.

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2. Objectives

- To study the Metal Removal Rate (MRR) and surface roughness (Ra) of LM 25Al/ 10% and 20%SiCp composites.
- To investigate the effect of Electrolyte concentration, Electrolyte flow rate, applied voltage, Tool feed rate on MRR and Ra.
- To investigate the effect of percentage volume of SiCp on ECM.

3. Experimental Details

LM25 Aluminium alloy (7 Si, 0.33 Mg, 0.3 Mn, 0.5 Fe, 0.1Cu, 0.1Ni, 0.2Ti) reinforced with silicon carbide particles of size 25 μm with 10% and 20% volume fractions manufactured through stir-casting route is used for experimentation. The dimensions of the specimens were 30mm diameter and 6mm height. The experiments were conducted on METATECH ECM equipment. The tool was made up of copper with a square cross section. Electrolyte was axially fed to the cutting zone through a central hole of the tool. The electrolyte used for experiment was NaCl solution [6], because of the fact that NaCl electrolyte has no passivation effect on the surface of the job. The level of parameters selected for the experiments were given in the Table.1. Thirty one experiments are carried out according to the central composite design (CCD). Initial and final weights of the workpiece were measured with a precision electronic weighing machine. Material removal rate (MRR) is expressed as the ratio of difference of weight of the work piece before and after machining to the machining time. The surface roughness (Ra) of the machined test specimens was measured using a Talysurf tester with a sampling length of 10mm.

Table 1: Experimental Parameters and their Levels

Parameters	Levels				
	-2	-1	0	+1	+2
Electrolyte Concentration (X_1), g/lit	10	15	20	25	30
Electrolyte flow rate (X_2), lit/min	5	6	7	8	9
Applied Voltage (X_3), (volts)	12	13	14	15	16
Feed rate (X_4), (mm/min)	0.2	0.4	0.6	0.8	1

4. Experimental Results and Discussions

Experiments have been carried out using the ECM machine on LM25Al-10% SiC and LM25Al-20% SiC to study the influence of some of the predominant process parameters such as electrolyte concentration, electrolyte flow rate, applied voltage and tool feed rate on MRR and Ra.

The mathematical relationship for correlating the MRR and the considered process variables for Al/10%SiCp and Al/20%SiCp has been obtained as follows:

MRR ***(Al/10%SiCp)*** $= 1.5882 - (0.0732\,X_1) - (0.5312\,X_2) + (0.2778\,X_3) - (5.3882\,X_4) + (0.00112\,X_1^2) + (0.0267X_2^2) - (0.0121\,X_3^2) + (2.3520X_4^2) + (0.0043\,X_1\,X_2) + (0.0003\,X_1\,X_3) + (0.0064\,X_1X_4) + (0.0048\,X_2\,X_3) + (0.0865\,X_2\,X_4) + (0.1728\,X_3\,X_4)$ *(1)*

MRR ***(Al/20%SiCp)*** $= -0.1321 + (0.0021X_1) - (0.0162\,X_2) + (0.0325X_3) - (0.3944\,X_4) + (0.000061\,X_1^2) + (0.0023X_2^2) - (0.0007\,X_3^2) + (0.3147\,X_4^2) + (0.0001X_1\,X_2) - (0.0002\,X_1\,X_3) - (0.0001\,X_1X_4) - (0.0009\,X_2\,X_3) - (0.0048\,X_2\,X_4) + (0.01056\,X_3\,X_4)$ *(2)*

The mathematical relationship, obtained for analyzing the influences of the various dominant machining parameters on the Ra the considered process variables for Al/10%SiCp and Al/20%SiCp has been obtained as follows:

Ra ***(Al/10%SiCp)*** $=170.155 - (1.233X_1) - (8.36\,X_2) - (17.013\,X_3) - (10.737\,X_4) + (0.017\,X_1^2) + (0.0385\,X_2^2) + (0.548X_3^2) + (3.788X_4^2) + (0.005X1\;X2) + (0.028Xx\;X3) + (0.094X1\;X4) + (0.170\,X_2\,X_3) + (0.501\,X_2\,X_4) - (0.039\,X_3\,X_4)$ *(3)*

Ra ***(Al/20%SiCp)*** $= 110.966 - (1.052\,X_1) - (6.355X_2) - (9.292X_3) + (7.308X_4) + (0.036\,X_1^2) + (0.244\,X_2^2) + (0.313\,X_3^2) + (10.341\,X_4^2) - (0.012\,X_1\,X_2) - (0.027X_2\,X_3) + (0.071X_1\,X_4) + (0.211X_2\,X_3) + (0.169\,X_2\,X_4) - (1.772\,X_3\,X_4)$ *(4)*

The contour plots were drawn for various process parameters for Al/10%SiCp and Al/20%SiCp on MRR and Ra. The number represent in the contour plot was MRR and Ra.

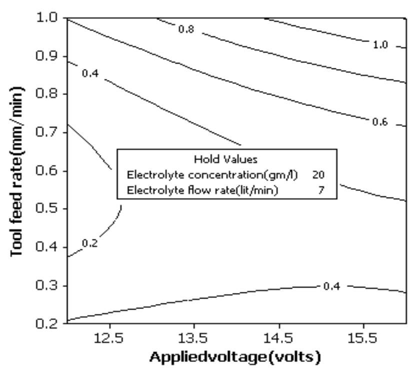

Fig. 1 (a) Effect of Applied Voltage and Tool Feed Rate on MRR for Al/10%SiC.

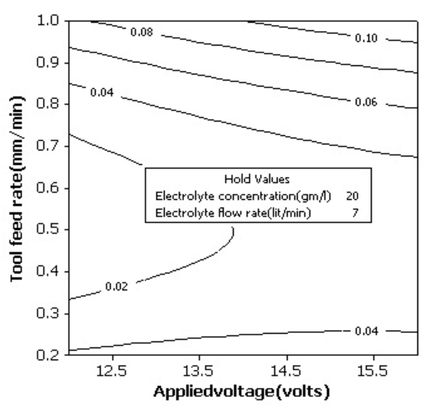

Fig. 1 (b) Effect of Applied Voltage and Tool Feed Rate on MRR for Al/20%SiC

4.1 Metal removal rate

Fig. 1(a) and (b) shows the effect of applied voltage and tool feed rate on MRR for both 10% and 20% SiC. The experimental results reveal that the MRR increases with increasing applied voltage. An increase in applied voltage causes a greater machining current available in the machining gap, thereby causing the enhancement of the MRR. Faraday's law states that the metal removal rate is proportional to the machining current [7]. While machining 10% SiC, current density at the matrix/particle interface is high. This enhances the dissolution of matrix material and results in loosening the particles, thus facilitating the removal of the ceramic particles. MRR decreases with 20%SiC contents. It is due to electrical conductivity of the aluminium matrix decreases due to the presence of the ceramic reinforcement [8]. Because, SiC is inert in nature. Higher percentage of SiC resulted in decrease in MRR. It is due to debris of 20% SiC comprises more reinforcing SiC than 10%SiC. This impedes the dissolution of workpiece. At low feed rates, the flow of electric current was low and the resistance in the

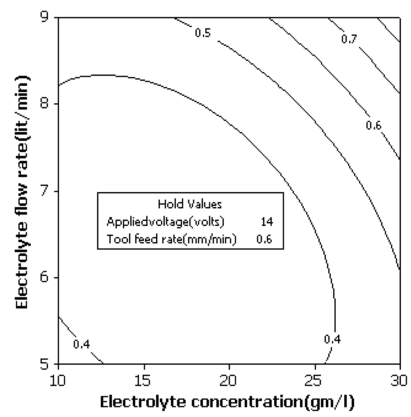

Fig. 2 (a) Effect of Electrolyte Concentration and Electrolyte Flow Rate on MRR for Al/10%SiC.

current flow path increases as a result of the widening inter electrode gap (IEG) [9]. Initially increase in MRR is very minimal due to lower feed rate. When the tool feed rate is high (0.8- 1 mm/min) the MRR increases linearly for both 10% and 20% SiC. This is because an increase in the tool feed rate shorten the inter-electrode gap that increases the current density in the gap with the consequent rapid anodic dissolution [10]. Fig.2 (a) and (b) illustrates the effect of electrolyte concentration and electrolyte flow rate on MRR for both 10% and 20% SiC. It was inferred that the increase in electrolyte concentration resulted in an increase in MRR. The increase in MRR is due to the larger number of ions associated in the machining process increases the machining current and thus results in higher MRR [7].

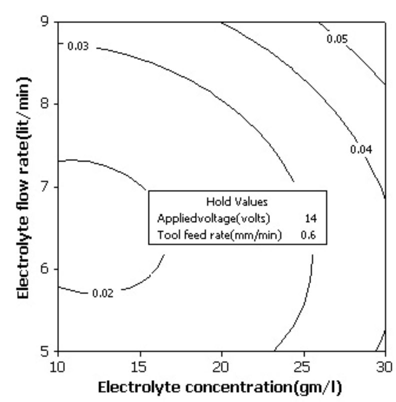

Fig. 2 (b) Effect of Electrolyte Concentration and Electrolyte Flow Rate on MRR for Al/20%SiC.

MRR found decrease with increase in volume fraction of SiC. The surface area of the matrix phase in 20% SiC composite exposed to the electrolyte is less than that of the 10% SiC composite. So the matrix material is slowly eroded, and it takes some time before the SiC particles can be totally exposed to the surface. As a result, a low MRR is obtained [5]. In 10%SiC MMC the surface area of the matrix phase is more, which take part effectively in electrochemical reaction than 20% SiC. Hence more MRR obtained in 10%SiC. MRR increases with increase in flow rate. This is because the increased flow rate causes not only a greater number of electrolytic negative ions to be produced in electrochemical reactions with the positive metal ions, but also the electrolyte conductivity is increased due to the higher ionic mobility, as well as quicker and greater removal of the reaction products formed in the machining gap [11].

4.2 Surface roughness (Ra)

Fig. 3 (a) and (b) illustrates the influence of applied voltage and tool feed rate on surface roughness for both volume percentage of SiC. Ra decreases with increase in applied voltage and tool feed rate.

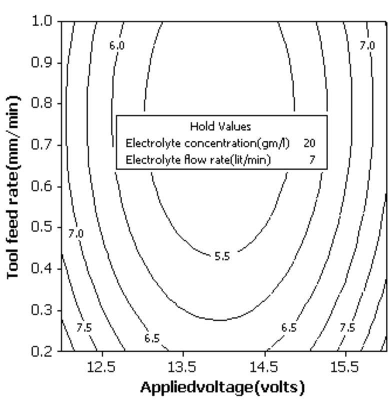

Fig. 3 (a) Effect of Applied Voltage and Tool Feed Rate on Ra for Al/10%SiC

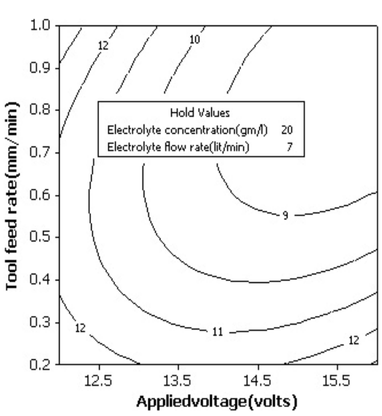

Fig. 3 (b) Effect of Applied Voltage and Tool Feed Rate on Ra. for Al/20%SiC

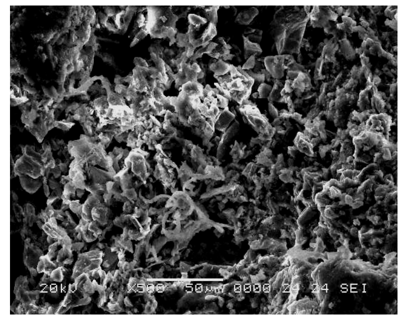

Fig. 4 Etch Pits occurs at Low Voltages

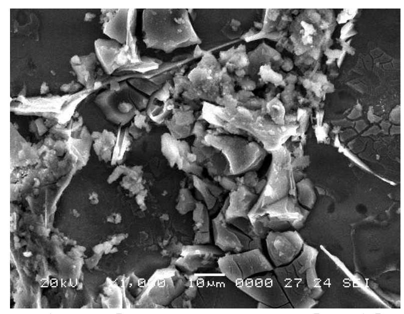

Fig. 5 Sharp Corners and Voids

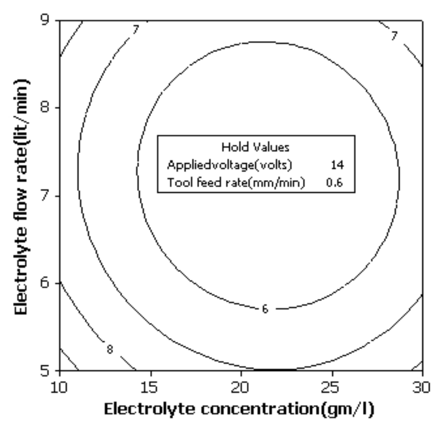

Fig. 6 (a) Effect of Electrolyte Concentration and Electrolyte Flow Rate on Ra for Al/10%SiC

It is due at low applied voltage and tool feed rate current density is low. Low current density in the IEG leads to etch pits and preferred grain boundary attack leading to extremely rough surface shown in Fig .4. Also at lower feed rate, greater roughness was attributed to the non-uniformity in anodic dissolution. Increase in applied voltage leads to increase current density in the inter-electrode gap. At high current densities, mass transport is controlled that suppresses the influence of crystallographic orientation and surface defects on the dissolution process thus yielding good finished surfaces [10].

The surface roughness is high at 20% SiC compared to 10 % SiC. It was due to that SiC particle does not take part in the electrochemical reactions. Since their full size and sharp corners are still visible after machining and some point's ceramic reinforcement particles became detached to left voids on the surface of the workpiece [8] shown in Fig .5. High tool feed rate decreases the surface roughness of the machined surface. This could be due to the decrease of the frontal gap at higher feed rates, which would result in increase of conductivity and flow speed of electrolyte [10].

Fig. 6 (a) and (b) illustrates the effect of electrolyte concentration and electrolyte flow rate on Ra for both 10% and 20% SiC. It can be seen that Ra decreases with increase in electrolyte concentration. The surface finish was poor at the electrolyte concentration of 10 gm/lit. Low concentration leads to poor surface finish due to depletion of ions. A reasonably good surface finish was achieved at the modest electrolyte concentration of 20 gm/lit, where as the surface finish was not so good at the maximum electrolyte concentration of 25 gm/lit used in the study.

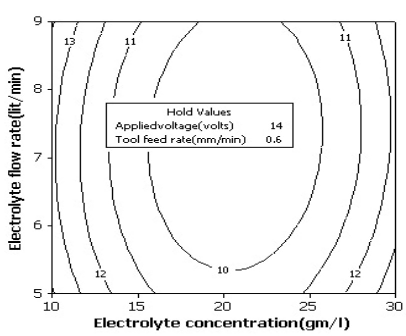

Fig. 6 (b) Effect of Electrolyte Concentration and Electrolyte Flow Rate on Ra for Al/20%SiC

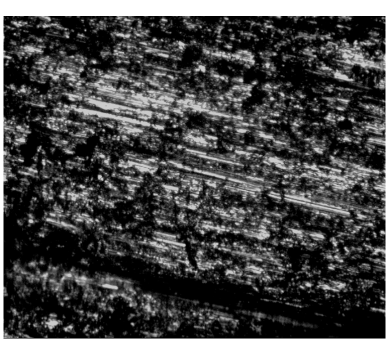

Fig. 7 Flow Streaks Occurs at Low Flow Rates

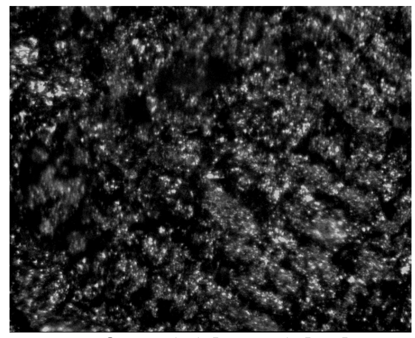

Fig. 8 Better Surface Finish at High Flow Rates

The reason for this could be attributed to the differential dissolution of the phases of the work material, particularly at the higher electrolyte concentration [10]. At lower flow rate the surface roughness is high for both volume percentage of SiC. The turbulence is being low in low flow rates. So the transported material moves slowly in a stratified form producing a streak on the surface as shown in Fig.7. Increase in electrolyte flow rate the metal ions on the upstream side of the valley will be picked up by the eddy current and are transported away by the flow and also a direct result of increasing the flow rate will be an increase in the level of turbulence. As a consequence to this, the effect of rotating eddies may be reduced resulting in a better surface finish and no flow streak appears on the surface [12] shown in Fig.8. Ra increases with increase in volume percentage of SiC. This is due to the debonding of SiC particles during electrochemical reaction that leaves voids on the surface of the work piece [5].The machined surface is better in 10% SiC than in 20% SiC. In 20%SiC the dissolution of matrix phase is less compared to 10%SiC. So the ECM effect causes the ceramic particle to emerge gradually into the electrolyte, and the removed ceramic particles is more in conductive path between the electrodes, this leads to decrease in current density.

5. Conclusion

The effects of Electrolyte concentration, applied voltage, Electrolyte flow rate and tool feed rate on metal removal rate and surface roughness of electrochemical machining of 10% and 20% SiC particle reinforced with LM 25 aluminum composites have been studied. Within the limits of the experimental conditions, the following major conclusions are drawn:

- Electrolyte concentration and tool feed rate significantly affects the MRR and Ra. Increase in electrolyte concentration and tool feed rate leads to high current density in the IEG. This promotes the electrochemical reaction at the interface between the ceramic particles and the matrix, and results in loosening of the particles.
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- The increase in volume percentage of SiC has resulted in a decrease in MRR. Because electrical conductivity of the aluminium matrix decreases due to the presence of the SiC reinforcement.
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- The increase in volume percentage of SiC has resulted in decrease increase in Ra. Ra value was increased with increase in volume percentage of SiC. It was observed that SiC particles do not take part in electrochemical reactions. After machining the SiC particles were detached from the workpiece left voids on the surface.

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