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Optimization of Abrasive Assisted Electrochemical Machining Using Response Surface Methodology

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ABSTRACT

Electrochemical Machining is one of the non-traditional machining process, which is used for generate complex profiles without inducing vibrations and tool wear. Presently it is used for producing of aerospace components, automotive products, fuel injection systems, semiconductors, dies and molds etc. The most important process parameters of ECM process are feed rate, electrolyte flow rate, voltage, inter-electrode gap, current, electrolyte concentration, tool material and type of electrolyte. The base material used in this study was Aluminium Silicon Carbide (Al-SiC) composite. The process parameters which affect the responses like surface finish, metal removal rate, radial over cut, and tool life. In the present study, responses also largely depend on the physical and electrical properties. Hence, in Metal Matrix Composite material the physical and electrical properties mainly depend on the percentage of reinforcement material. So, that the percentage of reinforcement material is considered as one of the input factor along with the feed rate, voltage and varied within the selected range to study the Material Removal Rate of ECM of Aluminium-silicon carbide composite fabricated through stir casting process. In this work, NaCl (sodium chloride) electrolyte, Copper tool, and silicon carbide (SiC) as abrasive were used. In order to enhance Metal Removal Rate, abrasive particles are added into the electrolyte solution. It is obtained that the added abrasive particles work along with anodic dissolution to enhance the Metal Removal Rate (MRR).

Keywords – Electro-chemical machining (ECM), Aluminum silicon carbide (Al-SiC), Material Removal Rate (MRR), Response Surface Methodology (RSM).

1. INTRODUCTION

Electro-chemical machining is one of the popularly known and widely used non-conventional machining processes belonging to electrochemical category wherein the metal removal takes place by anodic dissolution of work-piece in an electrolytic solution. ECM process is independent of hardness of work-piece material with very less tool wear and stress free surface generation. ECM finds its use into various fields such as automotive, defence, electronic industries, and aerospace etc. Machining parameters and other factors primarily decides the accuracy and precision of the machining. With regards to this, various researchers have carried out electrochemical machining of different materials and applied various optimization techniques to find optimal condition of machining process.

Senthilkumar et al. [1] used response surface methodology to investigate the characteristics of Electro-Chemical Machining of Aluminium metal matrix composites. Contour plots were plotted between the responses, such as Metal Removal Rate and Surface Roughness, and process parameters, namely feed rate, electrolyte flow rate, applied voltage, and electrolyte concentration. Rama Rao et al. [2] studied that Aluminium Metal Matrix Composites (MMC) fabricated through stir casting method. In this study, surface plots are constructed to study the input process parameters on the response of non-linear mathematical models. Material Removal Rate decreases with the increase in percentage of reinforcement and increases with increase in voltage, feed rate and electrolyte concentration. Sathiyamoorthy et al. [3] attempted to optimize the predominated machining parameters in Electro-Chemical Machining of AISI 202 Austenitic stainless steel using Response Surface Methodology. Senthilkumar et al. [4] have investigated the Electrochemical machining of Aluminium silicon carbide composites using non-dominated sorting genetic algorithm-II (NSGA II). They considered Material Removal Rate (MRR) and surface roughness (SR) as output responses and developed multiple regression analysis. Sankar et al. [5] studied electrochemical machining by adding abrasive material silicon carbide into the electrolyte to improve material removal rate and surface finish. Sadineni Rama Rao et al. [6] investigated Electrochemical Machining Process

Using Full Factorial Design of Experiments. Bhattacharya et al. [7] investigated that the maximization of Material Removal Rate and minimization of overcut during electrochemical machining of EN19 steel and developed mathematical model to study the effects of the various input process parameters. Ravikumar et al. [8] developed non-linear mathematical models by conducting experiments through rotatable central composite. In that study, the authors considered voltage, current, electrolyte flow rate and gap between the tool and workpiece as process parameters and metal removal rate (MRR) and surface roughness (SR) as responses. Sadineni Rama Rao et al. [9] investigated responses (MRR), Surface roughness (SR), and Radial over cut (ROC) are optimized simultaneously based on Response Surface Methodology.

Most of the researchers/engineers concentrated only on the process variables of ECM like, current, voltage, feed rate, electrolyte concentration, tool material, electrolyte flow rate, gap between electrodes and types of electrolyte solution etc. But in case of composite material, the responses such as Material Removal Rate and surface finish mainly depend on the percentage of reinforcement material. Hence, in this work percentage of silicon carbide particles has been considered as one of the input factors along with feed rate, voltage and optimization of the machining variables was done using Response Surface Methodology and the effect of these process parameters on Material Removal Rate was studied using ANOVA.

2. FABRICATION OF MMC

The base material used in these experiments was Aluminium silicon carbide composite produced through stir-casting technique. It has excellent mechanical properties such as low weight with high strength, high stiffness, high wear resistance, good corrosion resistance and also it can withstand high temperature. Due to possession of higher hardness and toughness, composite materials are difficult to machine by conventional machining. Hence Electrochemical machining process becomes a most suitable method for machining of metal matrix composites.

In this work percentage of silicon carbide (SiC) is considered as one of the input factors. In order to achieve different composition, SiC particles of 12 to 20 micron size are added to the base material Al6061 in the proportion of 5%, 10% and 15% by weight.

The reason for choosing Aluminium 6061 as the matrix metal is because of its excellent properties like good corrosion resistance, medium fatigue strength, very good weldability and convincing machinability.

2.1 Composite Preparation

For fabricating MMC's, a number of techniques are available such as powder metallurgy, stir casting technique, squeeze casting and pressure infiltration etc. In this study fabrication of Aluminium silicon carbide composite were carried out through stir casting technique due to its simple set-up and minimum cost. The stir casting set up used for making this composite is shown in fig. 1. In stir casting technique, the reinforcement material SiC added into the molten material Al 6061 and it's stirred through mechanical stirrer to achieve uniform distribution. In order to distribute the reinforcement material uniformly in the matrix metal. Hence, the silicon carbide particles is preheated separately while Al6061alloy is gets heated in a graphite crucible in an electrical furnace at a melting temperature of 800°C. The preheated SiC particles are added with the molten Aluminium metal and mechanical stirring is done and then different composition of composite material is poured in a mild steel die with dimension of 100mm Length *100mm Breadth*10mm Thickness as shown in Fig. 2 and an allowed to solidify. The Composition of matrix Al6061 and reinforcement SiC is given in Table1.

Fig. 1 Stir casting set up

Table 1 Composition of matrix and reinforcement

Samples	Al6061 in %	SiC in %
1	95	5
2	90	10
3	85	15

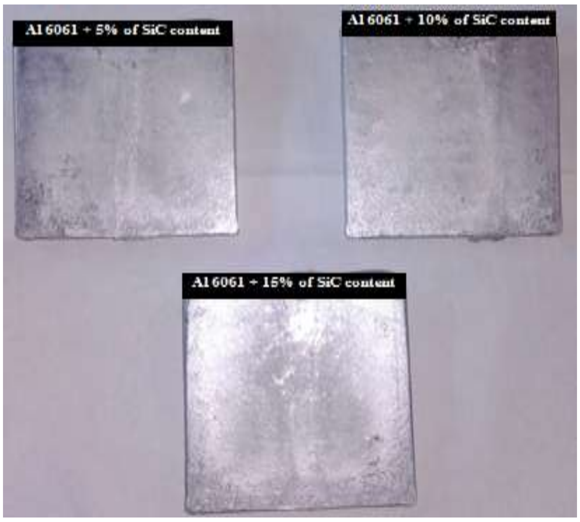

Fig. 2 Prepared specimens

3. DESIGN OF EXPERIMENTS

In this work an attempt is to build the input (factors) - output (response) relationship of ECM of aluminium silicon carbide composite. A pilot study has been conducted to determine the working ranges of the input factors. The levels of each parameters selected are given in Table 2.

Table 2 Electrochemical machining parameters and their levels

Process Parameters	Units	Level 1 [-1]	Level 2 [0]	Level 3 [+1]
% of Reinforcement	Weight %	5	10	15
Feed rate	mm/min	0.4	0.5	0.6
Voltage	Volts	8	11	14

In the present work the experiments runs or combinations were designed based on the Face centered central composite design (CCF). For the three factors the design required 20 combinations with 8 factorial points, six axial points to form Face centered central composite design with ($\alpha = 1$) and six centre points are use to investigates the experimental error. The twenty experimental runs was generated and analysed using MINITAB17 statistical software. The levels of each parameter were chosen as −1, 0, and 1 in coded variables to have a face centered central composite design.

3.1 Response Surface Methodology

Response surface methodology (RSM) is a collection of mathematical and statistical techniques which explores the relationships between several independent variables and dependent variables (Response) and the main objective of the RSM is to optimize the optimum operating condition. In the present study, Response surface methodology is used for empirical model building between input factors and output responses. The concept of a response surface method involves a dependent variable y called the response variable and several independent variables x_1, x_2…., x_k. In the present study, in order to determine the influence of the input variables on the MRR, a second-order regression model can be fitted into the following equation (1).

$$Y_u = b_o + \sum_{i=1}^{k} b_i X_i + \sum_{i=1}^{k} b_{ii} X_i^2 + \sum_{i<j=2}^{k} b_{ij} X_i X_j ------(1)$$

Where Y_u is the output response and $X_{i\ (1,2,\ldots,k)}$ are levels of k independent quantitative variables. The coefficient b_o is the constant term and the coefficients b_i, b_{ii}, b_{ij} are the linear, quadratic and interaction terms.

4. EXPERIMENTAL WORK

The experiments tests for the twenty different combinations were conducted on the prepared specimens using METATECH ECM. The experimental set-up for electrochemical machining as shown in Fig. 3. The set up consists of machining chamber, control panel, electrolyte tank, electrolyte circulation, tool feed mechanism, pump etc. The cathode (TOOL) was made of copper material with hexagonal cross-section and with central hole as shown in fig. 4. The electrolyte solution was fed to the cutting area through the central hole of the tool. Sodium chloride (NaCl) is used as electrolyte solution for both with and without abrasive Electro-chemical Machining. Experiments for 20 different runs were carried out for a fixed time interval (5 minutes for each run). Experiments were conducted by varying predominant process parameters such as feed rate, voltage and reinforcement content and the Material Removal Rate was measured from the weight loss technique. The material removal rate observed for various sets of experiments with different combinations of process variables based on Face centered central composite design of response surface methodology is presented in Table 3.

Fig. 3 Electro-chemical machining set up

Fig. 4 Copper tool with hexagonal cross section

Once the experiments are conducted, Material Removal Rate is calculated for twenty runs. Based on the data observed from the (CCF) face centered central composite design, the mathematical model was developed.

4.1 Mathematical Model of MRR

Equation (2) shows the developed mathematical model for Material Removal Rate (MRR).

Material Removal Rate (MRR) = 26.510 - 2.452 A + 3.541 B + 3.830 C - 0.165 A*A - 0.498 B*B - 0.239 C*C + 1.667 A*B - 0.537 A*C + 0.685 B*C (2)

Table 3 Design matrix and measured responses (ECM with abrasive assistance)

Run	A	B	C	MRR (mm^3/min)
1	5	0.4	8	21.925
2	15	0.4	8	15.185
3	5	0.6	8	25.111
4	15	0.6	8	23.851
5	5	0.4	14	30.074
6	15	0.4	14	20.000
7	5	0.6	14	34.814
8	15	0.6	14	32.592
9	15	0.5	11	24.888
10	5	0.5	11	29.111
11	10	0.6	11	29.777
12	10	0.4	11	23.555
13	10	0.5	14	30.370
14	10	0.5	8	23.481
15	10	0.5	11	27.333
16	10	0.5	11	26.370
17	10	0.5	11	24.814
18	10	0.5	11	26.888
19	10	0.5	11	25.111
20	10	0.5	11	25.925

5. RESULTS AND DISCUSSION

5.1 Analysis Of Variance

The analysis of variance (ANOVA) has been performed to verify the goodness of fit of the developed mathematical models presented in Table 4.

The value of the R^2 for Material Removal Rate is over 97.16%, which denotes that the developed mathematical model reveals that the better relationship between the input process factors and output response at a 95 % confidence level. The probability 'P' value of the model is lesser than 0.05(i.e. 95% confidence), which shows that the developed mathematical model is significant at a 95% confidence level. The values which are greater than 0.1 which indicates that the model terms are not significant at a 95% confidence level. The results show that all the input variables, i.e. percentage of reinforcement, feed rate and voltage have their influence on the material removal rate. In table 4 from the probability p values, for the response (Material Removal rate) linear effect A (% of Reinforcement), B (Feed rate), and C (Voltage) are significant. Moreover, the interaction effect and square effect are insignificant for the response (Material Removal Rate).

Table 4 Analysis of Variance for Material Removal Rate (MRR)

Source of variation	DOF	Sum of squares	Mean sum of squares	F value	P value	
Regression	9	363.529	40.392	38.02	< 0.000	Significant
A	1	60.118	60.118	56.58	< 0.000	Significant
B	1	125.358	125.358	117.98	< 0.000	Significant
C	1	146.666	146.666	138.04	< 0.000	Significant
A*A	1	0.075	0.075	0.07	0.796	
B*B	1	0.683	0.683	0.64	0.441	
C*C	1	0.157	0.157	0.15	0.709	
A*B	1	22.218	22.218	20.91	< 0.001	Significant
A*C	1	2.307	2.307	2.17	0.171	
B*C	1	3.754	3.754	3.53	0.090	
Error	10	10.625	1.063			
Lack-of-Fit	5	5.753	1.151	1.18	0.430	
Pure Error	5	4.872	0.974			
Total	19	374.154				

5.2 Main Effect Plot

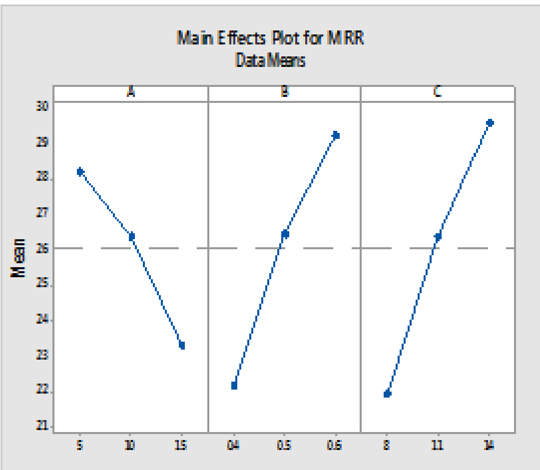

Fig. 5 Main effects plot for the Material Removal Rate

The main effects of the input parameters, such as percentage of reinforcement content (A), feed rate (B), and Voltage (C) on the response Material Removal Rate is shown in Fig .5.

From that figure, we can be observed that with increase in feed rate, voltage the Material Removal Rate increases. With increase in voltage, the machining current in the inter-electrode gap increases, this leads to the enhancement of Material Removal Rate. It is also interesting to note that increased feed rate reduces the inter-electrode gap that leads to increase in the current density. This effect causes rapid anodic dissolution which increases the MRR and with decreases in percentage of reinforcement the MRR increases. This may be due to the fact that by increasing the percentage of Reinforcement particles, the electrical conductivity of the work piece decreases, because the reinforced particles are poor conductors than the base material. Thus the increase in the percentage of reinforcement added into the matrix material leads to decrease the metal removal rate.

5.3 Analysis Of Response Surface Graph

Response surface graph were developed for the empirical relationship, taking two input variables in the 'X' and 'Y' axis and output response in 'Z' axis. The response surface graphs clearly show the location of the optimum response point. The relationship between independent variables and dependent variables was graphically shown by three dimensional response surface graph as shown in (Figures 6- 8).

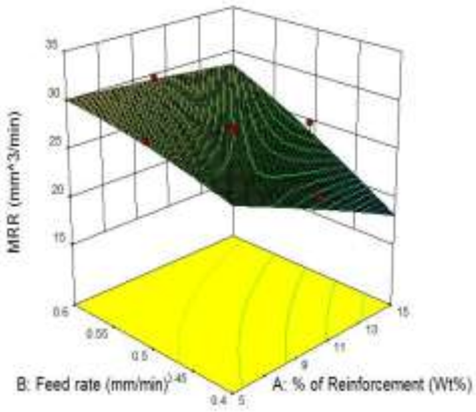

Fig. 6 Response surface graph due to interaction of percentage of reinforcement and Feed rate on material removal rate

Fig.6 shows that the response surface graph for the Material Removal Rate between percentage of reinforcement and feed rate, it can be seen from this figure that material removal rate increases with increase of feed rate and decreasing of percentage of reinforcement material.

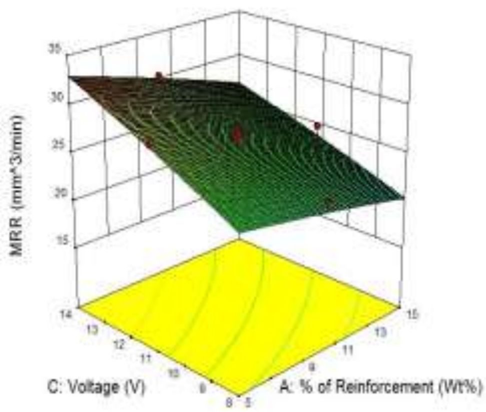

Fig. 7 Response surface graph due to interaction of percentage of reinforcement and voltage on material removal rate

Fig.7 shows that the response surface graph for the Material Removal Rate between percentage of reinforcement and voltage, it can be seen from this figure display that material removal rate increases with increase of voltage and decreasing of percentage of reinforcement material.

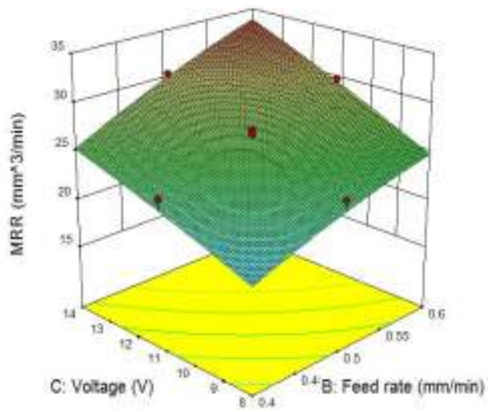

Fig. 8 Response surface graph due to interaction of Feed rate and voltage on material removal rate

Fig.8 shows that the response surface graph for the Material Removal Rate between feed rate and voltage, it can seen from this figure shows that Material Removal Rate increases with both the feed rate and voltage simultaneously increasing.

5.4 Comparison of MRR with and without Abrasive Assisted ECM

Table 5 ECM with abrasive assistance

A	B	C	MRR mm^3/min
5%	0.6	14	34.814

Table 6 ECM without abrasive assistance

A	B	C	MRR mm^3/min
5%	0.6	14	26.666

6. CONCLUSION

[1] In the present study, aluminium MMC was fabricated through stir casting method. It is interesting to note that percentage of reinforcement material has been considered as one of the input process parameter that

influences the quality of the parts produced using electrochemical machining.

[2] The analysis of the experimental observations shows that MRR in Electrochemical Machining is greatly influenced by the various input process parameters.

[3] The following results are obtained from this study as follows:

a) Mathematical model was developed for the response (MRR) using Response Surface Methodology and model was analysed using (ANOVA).

b) From the main effect plot graph, the optimum value of Material Removal Rate is obtained at 5% of reinforcement content, feed rate of 0.6 mm/min and voltage of 14 V.

c) In order to enhance the Material Removal Rate, fine abrasive SiC particles are mixed added into the electrolyte solution, which remove the remove material due to abrasion. During abrasive flow through the electrolyte solution, the reinforcement material is removed effectively due to abrasion which results in higher MRR.

d) From the above table 5 and 6 it is inferred that 1.3 times higher MRR is achievable in Abrasive assisted Electrochemical Machining than that of the Simple Electrochemical Machining.

REFERENCE

[1] C. Senthilkumar, G. Ganesan and R. Karthikeyan, Influence of Input Parameters on Characteristics of Electrochemical Machining Process, *International Journal of Applied Science and Engineering*, 11, 2013, 13-24.

[2] S. Rama Rao and G. Padmanabhan, Effect of process variables on metal removal rate in electrochemical machining of Al-B4C composites, *Archives of Applied Science Research*, 4(4), 2012, 1844-1849.

[3] V. Sathiyamoorthy, T. Sekar, P. Suresh, Optimization of processing parameters in electrochemical machining of AISI 202 using Response Surface Methodology, *Journal of Engineering Science and Technology*, 10, 2015, 780 – 789.

[4] C. Senthilkumar, G. Ganesan, R. Karthikeyan, Parametric optimization of electrochemical machining of Al/15% SiC Composites using NSGA-II, *Trans Nonferrous Met. Soc.*, 21, 2011, 2294-2300.

[5] M. Sankar, A. Gnanavelbabu, K. Rajkumar, and Effect of reinforcement particles on the abrasive assisted electrochemical machining of Aluminium-Boroncarbide-Graphite composite, *Procedia Engineering*, 97, 2014, 381 – 389.

[6] Sadineni Rama Rao and G. Padmanabhan, Linear Modeling of the Electrochemical Machining Process Using Full Factorial Design of Experiments, *Journal of Advanced Mechanical Engineering*, 2013, 13-23.

[7] Bhattacharya B and Sorkhel, Investigation for controlled electrochemical machining through response surface methodology-based approach, *Journal of Materials Processing Technology*, 86, 2006, 200– 207.

[8] R. Ravikumar, P. Ashokan, P.N. Singh, Modelling the machining parameters for electrochemical machining of aluminium composites using RSM, *Journal of Manufacturing Engineering*, 3(2), 2008, 104-114.

[9] Sadineni Rama Rao and G. Padmanabhan, Optimization of multiple-machining criteria in electrochemical machining of aluminium composites using design of experiments, *Journal of Scientific & Industrial Research*, 73, 2014, 251-257.