Optimization of Machining Parameters in Electro Chemical Machining using Response Surface Method

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Abstract— Non-conventional machining is increasing in importance due to some of the specific advantages which can be exploited during machining operation. Electrochemical machining (ECM) appears to be a promising technique, since in many areas of application, it offers several special advantages including higher machining rate, better precision and control, and a wider range of materials that can be machined. The present work is, therefore, initiated to investigate the influence of some predominant electrochemical process parameters such as applied voltage, electrolyte concentration, electrolyte flow rate and tool feed rate on the metal removal rate (MRR), and radial overcut(ROC) to fulfill the effective utilization of electrochemical machining of copper produced through stir casting. The contour plots are generated to study the effect of process parameters as well as their interactions. The process parameters are optimized based on Response Surface Methodology (RSM).

Key words: Metal Matrix Composites (MMC'S), Electrochemical Machining (EMM), Radial Overcut (ROC), Metal Removal Rate (MRR), Contour Plot

I. INTRODUCTION

Today needs of the society such as handy cell phones, palmtops, painless injection and any modern products require Micro hole as one of the basic elements. Several manufacturing processes are capable of meeting the requirements. Among these electro chemical micro machining (EMM) is desired because of its advantages such as no tool wear, higher MRR, better surface finish and others A simple table top electrochemical micromachining tool with microcontroller based Inter Electrode Gap (IEG) is used for such applications. Material removal techniques have a pivotal role to play in component fabrication.

In recent years many high strength alloys such as Stainless Steel and titanium alloys are produced that are extremely difficult to machine using the traditional processes. These alloys were developed for a variety of industries ranging from aerospace to medical engineering. The tool size and geometry limit, the final component shapes that can be machined. Problem with these tools is that they leads to notch on the machined surface. These notch are objectionable. For example, in medical industry the presence of even very small notch leads to damage the living tissues where these parts are used as implants. In electronic devices where a number of components are in close contact, the notch may lead to short circuits. In mechanical components notch may result in misfits.

A. Metal removal rate (MRR)

It is a ratio between the material removed to machining time.

B. Radial OverCut (ROC)

It means that the extra machined of the part over than the planned measurement.

II. RESPONSE SURFACE METHODOLOGY

Response surface methodology (RSM) approach is the procedure for determining the relationship between various process parameters with the various machining criteria and exploring the effect of these process parameters on the coupled responses, i.e., the material removal rate and radial overcut. This is done using the MINITAB18 software. We are using this to find the optimized value from the given parameters of the electrochemical machining (ECM).

The value can be assigned according to our conditions and the parameters are also choosen accordingly.

III. EXPERIMENTAL WORK

The test specimens of copper alloy were produced through stir casting. The dimensions of the specimens were 50mm in length and 40 mm in breadth and 0.4mm thick. The experiments were conducted on ECM equipment. The tool was made up of stainless steel with a circular cross section. Electrolyte was axially fed to the cutting zone through a central hole of the tool. The electrolyte used for experiment was fresh NaCl solution, because of the fact that NaCl electrolyte has no passivation effect on the surface of the job the machining has been carried out for fixed time interval. The observations were made by varying predominant process parameters such as applied voltage, electrolyte concentration, and duty cycle. The machined samples were examined using SEM for micro structural observations. MRR was measured from the weight loss. The radial overcut of the machined test specimens was measured using the formula (needle radius – hole radius).

IV. MATHEMATICAL MODELING

The mathematical relationship for correlating the metal removal rate and the considered process variables has been obtained as follows

$$MRR=-0.07940 - 0.02283\,X1 + 0.005327\,X2 + 0.001063\,X3 + 0.000363\,X1*X1-0.000024\,X2*X2- 0.000129\,X3*X3 - 0.000067\,X1*X2 + 0.000777\,X1*X3 \quad (1)$$

The mathematical relationship for correlating the Radial over cut and the considered process variables has been obtained as follows:

$$Roc=-640.0 + 180.6\,X1 + 1.729\,X2 - 3.087\,X3 - 8.645\,X1*X1 - 0.06213\,X2*X2 + 0.6197\,X3*X3 + 0.6352\,X1*X2 - 3.208\,X1*X3 \quad (2)$$

x1 = Applied voltage(V)

x2= Duty cycle(%)
x3= Electrolyte concentration(g/l)

This are the entire regression model obtained from the "MINITAB 18" software in the Response surface method. In this we got a 100% closeness value.

By using this regression equation (1) & (2) obtained in the Response surface methodology.

V. RELATIONS TO RESPONSE

A. *Parametric influence on MRR*

Based on the mathematical model given by Eq. (1), developed through experimental observations and response surface methodology, studies have been made to analyze the effect of the various process variables on the MRR. The contour plots were drawn for various combinations. Causing the enhancement of MRR. This conforms to the fundamental principles of metal removal in ECM. An increase in duty cycle increases the metal removal rate. This happens due to the reduction in inter-electrode gap that increases the current density in the gap with the consequent rapid anodic dissolution. The various combinations of the contour plots are drawn using the "MINITAB 18" software.

S.NO	X1	X2	X3	MRR(g/min)	ROC(µm)
1	6	70	25	0.0850	44.90
2	6	80	30	0.0910	65.85
3	6	90	35	0.0857	105.36
4	8	70	30	0.0800	119.32
5	8	80	35	0.0860	151.88
6	8	90	25	0.0970	30.03
7	10	70	35	0.0870	91.41
8	10	80	25	0.0860	58.85
9	10	90	30	0.100	28.62

Table 1: Input Parameters & Responses

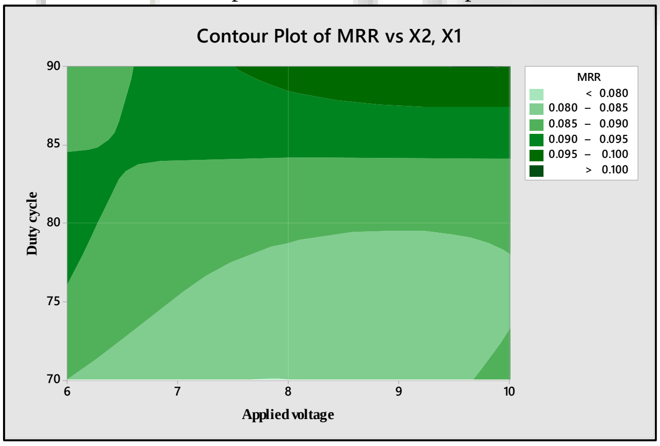

Fig. 1: Effect of applied voltage and duty cycle on MRR

Figure 1, depicts the influence of applied voltage and duty cycle on MRR. Increment of voltage and duty cycle causes more metal removal rate. Any increase in applied voltage results in corresponding increase in the machining current across the IEG, which leads to increase in the metal removal rate . The higher duty cycle removes hydrogen bubbles more effectively from the cathode grooves resulting in an increased ionic strength and therefore, more effective metal removal on the anode . Figure 2, exhibits influence of electrolyte concentration and applied voltage on MRR. It can be noted that the increase in electrolyte concentration increases the material removal rate. This can be attributed to the increase in the electrical conductivity of the electrolyte with increase in concentration as a result of which machining current in the IEG increases. Further, at higher concentration, a large number of ions accumulated in the IEG increase the machining current and thus enhances the material removal rate.

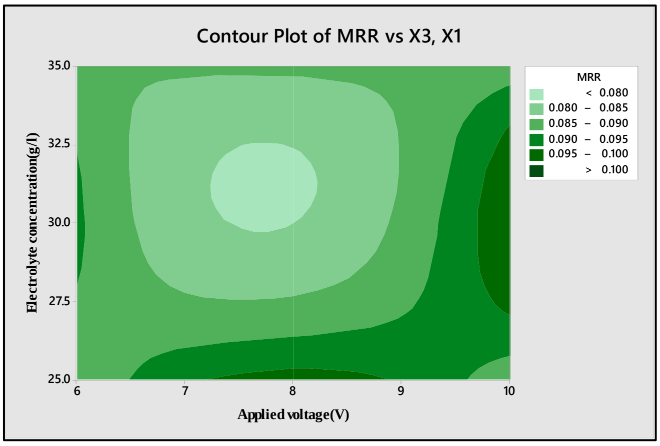

Fig. 2: Effect of applied voltage and electrolyte concentration on MRR

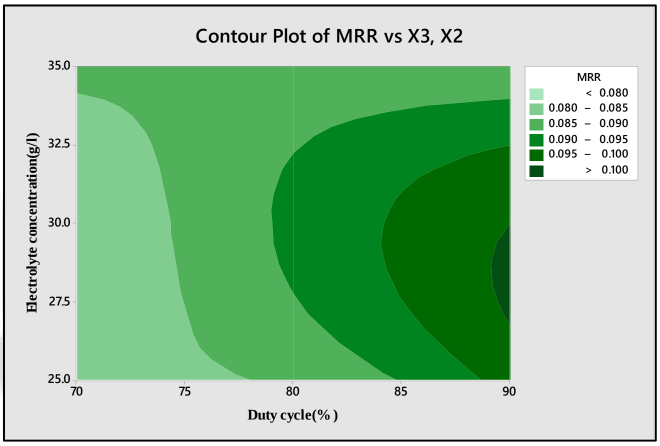

Fig. 3: Effect of duty cycle and electrolyte concentration on MRR

B. *Parametric Influence on Radial Overcut*

Based on the mathematical model given by Eq. (2). The study of the effects of various machining parameters on radial overcut has been made so as to analyze the suitable parametric combinations that can be made for achieving controlled overcut. The contour plots were drawn for various combinations. The numbers represent in the contour plot is surface roughness. Figure 4, illustrates the influence of applied voltage and duty cycle on radial overcut. It shows that the increase in duty cycle increases the overcut radially.so we need to maintain a medium duty cycle leads to overcome the radial overcut . Figure 5, shows the influence of applied voltage and the electrolyte concentration on the radial overcut. In that we can understand that the maximum overcut occurs at the maximum electrolyte concentration. So we need to maintain the lower electrolyte concentration to reduce the overcut. Figure 6, depicts the influence of duty cycle and electrolyte concentration on radial overcut of the composite material. If both increases the radial overcut also increases. However the increase in the electrolyte concentration increases

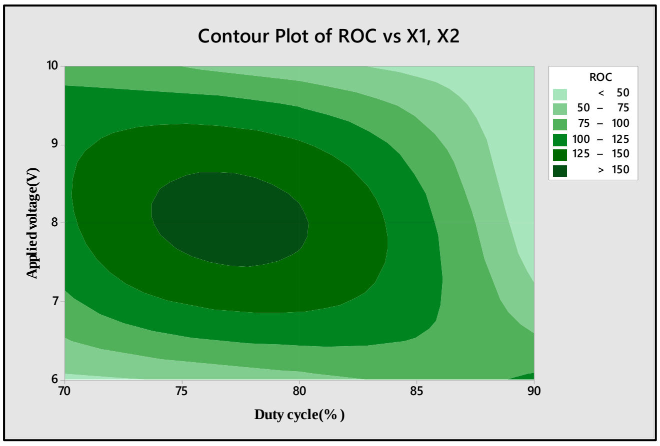

Fig. 4: Effect of applied voltage and duty cycle on ROC

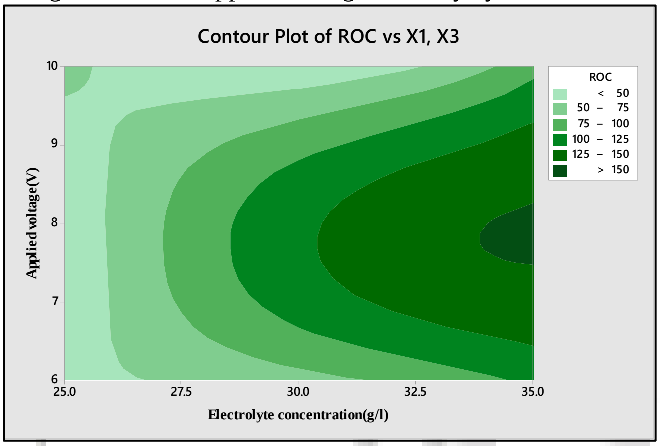

Fig. 5: Effect of applied voltage and electrolyte concentration on ROC

Combinations that can be made for achieving controlled overcut. The contour plots were drawn for various combinations. The numbers represent in the contour plot is surface roughness. Figure 4, illustrates the influence of applied voltage and duty cycle on radial overcut. It shows that the increase in duty cycle increases the overcut radially.so we need to maintain a medium duty cycle leads to overcome the radial overcut . Figure 5, shows the influence of applied voltage and the electrolyte concentration on the radial overcut. In that we can understand that the maximum overcut occurs at the maximum electrolyte concentration. So we need to maintain the lower electrolyte concentration to reduce the overcut. Figure 6, depicts the influence of duty cycle and electrolyte concentration on radial overcut of the composite material. If both increases the radial overcut also increases. However the increase in the electrolyte concentration increases the radial overcut. This overcut happens due to the over working of the tool and they also occurs due to varying the various parameters. And the critical combination in the applied parameters also leads to the overcut. The various reasons for the radial overcut is understood and changes made accordingly to reduce the radial overcut.

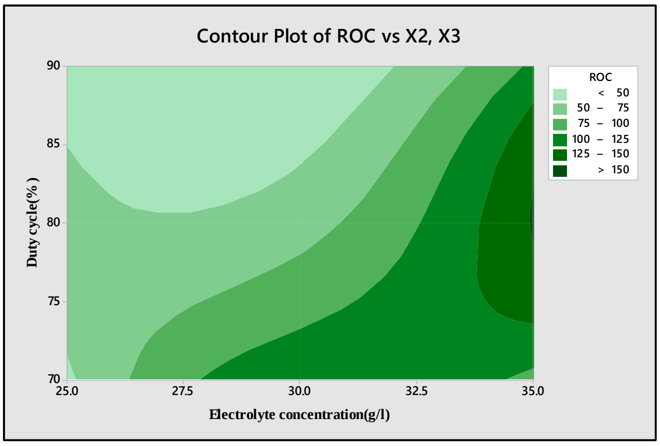

Fig. 6: Effect of duty cycle and electrolyte concentration on ROC

VI. ANALYSIS FOR OPTIMIZATION

Based on the developed second-order response surface equations, i.e., Equations.(1) and (2) for correlating the various process variable effects with the MRR and ROC optimality searches can be obtained. This is carried out to determine the optimal combination of the machining parameters and their combine effects on the desired response criteria. The optimality search model for the various process variable conditions for maximizing the MRR, minimizing the ROC value of various machined workpiece was formulated based on the methodology as described. The various parameters are optimized using "MATLAB 13" software. Table 2 exhibits a parametric combination, i.e., electrolyte concentration 25.013 g/l, duty cycle 70.005 %, applied voltage 9.743 V. Optimum values of machining process parameters for different machining criteria are also shown in Table 2. Machining with optimum parametric combination, MRR can be achieved as high as 0.077µm and Ra can be achieved as low as 77.463mm.

VII. CONCLUSION

The experimental analysis highlights that the electrochemical micro machining criteria like MRR, Roc in ECM are greatly influenced by the various predominant machining parameters considered in the present study. Response surface methodology used in the present research work has proved its adequacy to be an effective tool for analysis of the ECM process

S.no	Parameter	Optimum values	MRR (gm/min)	ROC (µm)
1	Applied voltage(V)	9.743	0.077	77.47
2	Duty cycle (%)	70.005		
3	Electrolyte concentration (g/l)	25.013		

Table 2: Optimum Values of the Machining Parameters Considering MRR & ROC

From the investigation, the following conclusions can be drawn: Mathematical models have been developed based on RSM approach for correlating the MRR and Roc with predominant process parameters. The adequacy of the developed mathematical model has also been tested through the analysis of variance (ANOVA).The results of the analysis justifying the closeness of fit of the mathematical model at 99% confidence level and 99% confidence level.

The influence of different process parameters on machining performance criteria are exhibited though contour plots. It is clear from the response contour plot of MRR, the MRR increases with an increase in any of the machining parameters. However, at higher level of machining parameters, except applied voltage, gives high Roc as shown in the contour plots of radial overcut. It is due to increase in voltage causes the excessive heating of electrolyte and a corresponding deterioration of the workpiece surface which will increase the Radial overcut. From the developed mathematical model, the optimal machining parametric combination, i.e., applied voltage, 9.743 V, duty cycle, 70%, Electrolyte concentration, 25 g/l, was found out to achieve the maximum metal removal rate as 0.077 g/min and minimum surface roughness as 77.47 µm. The effective utilization of ECM for copper composites for achieving the optimal combination of enhanced metal removal rate and generation of less radial overcut has been attempted.

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