An Experimental study for Radial over cut and material removal rate in Electrochemical Drilling of Al-5%SiC composite

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ABSTRACT

Electrochemical machining (ECM) is one of nontraditional processes, in many applications; it display many advantages including better precision, higher operating rate, control, no tool wear and machining a wide range of materials. Metal matrix composites (MMCs) have been increasingly used in industries, aerospace, and automobiles due to their superior properties compared to other alloys and that is due to the tough and abrasive hard reinforced particles. It's complicated to machine materials by traditional processes methods the present study focused on the effect of electrolyte concentration, voltage, and Inter-electrode gap on radial over cut (ROC) and material removal rate (MRR) in electrochemical drilling of Al-5%SiC metal matrix composites. Based on Taguchi design the process parameters are optimized. Multiple Regression Model (MRM) was employed as model for radial over cut and material removal rate. The mathematical model was examined using analysis of variance (ANOVA).

KEYWORDS: *Electrochemical process, Metal matrix composites, ROC, MRR.*

INTRODUCTION

In recent years, the demand for composites materials has increased in various applications such as automobile industries, aerospace, and biomedical. Aluminum-based on composites materials importance their using due of the properties such as improved hardness, high wear resistance, good strength and a low thermal expansion coefficient, etc .. Because to possession of reinforcement strength and higher hardness, metal matrix composites are difficult to be machined by conventional machines [1, 2,3]. High-hardness aluminum oxide (Al_2O_3) or silicon carbide(SiC) abrasive particles are used as reinforcing materials for aluminum alloys although their operating costs are high for machining these types of materials. [4]. the machining of composite materials is receiving great attention due to the high tool wear associated with machining. Conventional processes, such as turning, drilling, milling, and broaching of composite materials reinforced with carbon nanotubes or alumina abrasive particles are Very hard due to its excessive abrasive characteristics [5,6]. There are several processes of non-conventional machines, such as chemical etching, electrochemical machining, abrasive water jet machining, electro-discharge machining, and magnetic abrasive finishing are widely used for the industrial processes. Due of its unique features, such as low cost, high machining efficiency, and no tool wear, hence the process of (ECM) becomes a more applicable method for machining in advanced manufacturing processes Figure 1. Electrochemical machining is depending on anodic dissolution of the work piece as the anode, with the tool as the cathode in the electrolyte [7]. The tool (cathode) moves towards the anode and approaching distance a so small inter-electrode gap (0.05–0.6 mm). Pulse voltage (10–40 volts) is applied across the anode and cathode. According to Faraday’s laws of electrolysis, and by the mechanism of anodic dissolution the material is removed from the workpiece. The electrolyte (NaCl or $NaNO_3$) flows at current density is usually (20–200 A/cm^2) and high speed (10–60 m/s), the reaction steady and remove the dissolution product, bubbles, and reaction heat.

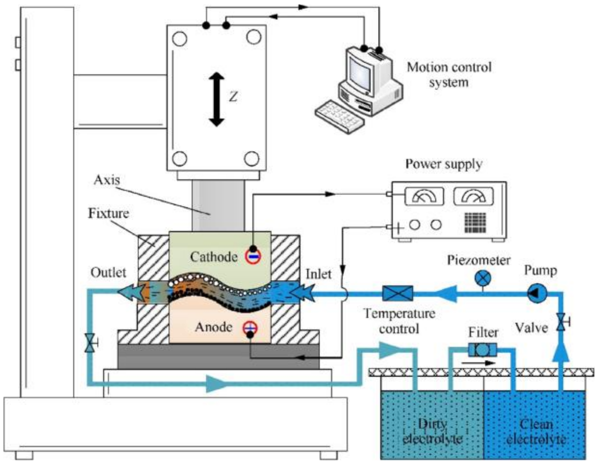

Fig. 1. Basic of ECM principle

The main benefits of using ECM, as shown in Fig. 2. it is appropriate for operating difficult and complex materials, regardless of their strength and hardness. In addition, high MRR can be obtained as well as good surface quality and high machining accuracy without happen of a residual stress, recast layer, deformation, heat affected zones, and micro cracks. No tool wear in this operation because only Bubbles of hydrogen is released on the tool surface. [9] Electrochemical machining is used in mass production to reduce the cost.

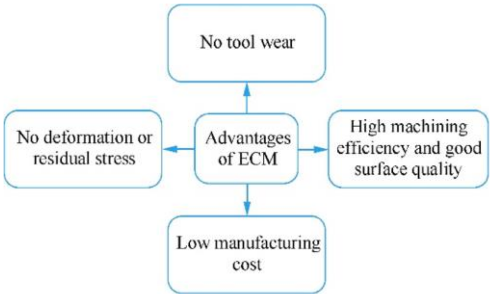

Fig. 2. The main benefits of using ECM

In addition, electrochemical machining also has some disadvantages. Manufacturing precision and operating stability are difficult to control since then. Applications of this process extend to electrochemical grinding (ECG), drilling and deburring. In modern researches, there have been three main areas of focus of electrochemical machining researchers. The first is the operational precision of electrochemical machinery, which focuses on improving surface quality and processing precision in the ECM. Such as parameter optimization and prediction, process calculation and simulation, instrument shape design and flow field are the major objectives of the work. The purpose is to enhance the conditions of electrolyte flow in the gap between the tool and the workpiece, maintain small and stable gaps to achieve higher fabrication precision, enhance the localization of anodic atomization, better process stability, and good surface finish. The second zone is the fine electrochemical machines in which surface structures and fine metallic parts can be achieved and by using an electrolyte solution and high-frequency pulsed energy to enhance the localization of the melt. [10.11] Finally, a hybrid electrochemical treatment in which electrochemical machines are combined with each other with different types of energy to improve the advantages of electrochemical machining and other processes and reduce the potential drawbacks of a single technology. Electrochemical discharge machines (ECDM) is a good example. [12,13] Figure 3 illustrates the three research areas of electrochemical machining. J. Muda et al. focused on the electrochemical micromachining by using (RSM) approach with taking radial over cut and material removal rate as separate objective measures [14]. G. Ganesan et al. used (RSM) to develop and enhancement mathematical models in ECM for LM25 Al -10% SiC composites materials [15]. Chakra dhar et al. the multi-objective optimization of the ECM examined by analyzing the gray relationship while EN31 steel as work piece with concentration of electrolyte, voltage, and feed rate as process parameters. [16]. T.Rajmohan Optimization in ECM etching of Al / SiC composites to reduce surface roughness, thrust, tool wear and ledge height using Taguchi Gray Relationship Analysis (TGRA) taking into account multiple performance characteristics [17]. Rama Rao et al. used evolutionary algorithms and Taguchi technique to model the electrochemical machining by considering electrolyte concentration, voltage, current, , gap and feed rate as dependent variables (surface roughness ,Radial over cut, and material removal rate) as independent variables for process [18,19]. Therefore, in this work deals with fabrication of Al-5%SiC composites. Process parameter optimization is depending on statistical methods with three independent input factors such as concentration of electrolyte, voltage, and inter-electrode gap (IEG) on radial over cut and material removal rate in electrochemical drilling (ECMD) on composite materials. ANOVA was used to develop an important model to examination the efficiency of the developed mathematical model.

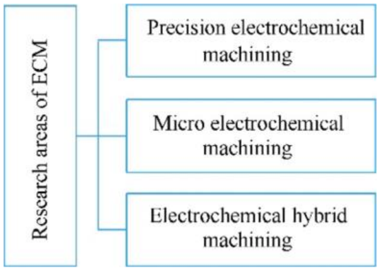

Fig. 3. Three research area of ECM

DESIGN OF EXPERIMENTAL(DOE)

Genichi Taguchi was suggested method is called Taguchi technique. The biggest advantage of this method is the reduction in number of tests, therefore reducing of conducting experimental time and cost of conduct it. It's widely used in statistical engineering analysis [20]. Design of Experiments (DOE) is used with a combination of the concept of the quality loss function so as to obtain strong designs for processes conditions and product [21]. The experimental results are converted into (S/N) ratio, which works to determine the quality characteristics deviated or close to the required values. Analysis of the quality characteristics include three categories nominal is the best, higher is the best, and smaller is the best [22].

The equation employed to calculate the S / N ratio to obtain the smallest ROC is:

$$S/N = -10log_{10}\left[\frac{1}{n}\sum_{i=1}^{n}(y^2)\right] \qquad (1)$$

The equation employed to calculate the S / N ratio to obtain the largest MRR is:

$$S/N = -10log_{10}\left[\frac{1}{n}\sum_{i=1}^{n}(1/y_i^2)\right]; i = 1,2, \ldots \ldots . n \qquad (2)$$

Where n: represents the number of iterations.

y_i: represent value of observed response.

For the purpose of monitor the degree of effect of the processing parameters in electrochemical machines, three factors was using in this paper, each at three levels, are taken into consideration, as shown in Table 1.

Table 1. Machining parameters of electrochemical drilling

No.	Process parameters	Code	Level 1	Level 2	Level 3
1	Electrolyte concentration (g/l)	A	50	75	100
2	Voltage (V)	B	8	10	12
3	Inter-electrode gap (mm)	C	0.1	0.2	0.3

EXPERIMENTAL PROCEDUR

The experimental setup procedure includes an electrochemical machining unit and electrolyte tank. The tool used in the tests was brass tool with a circular cross section, the chemical compositions of tool material was presented in Table 2. NaCl was used as the electrolye solution for experiment, due to the fact that the electrolyte sodium chloride is inexpensive, available and has no passivation influence on the surface of the workpiece [23]. The tank of electrolyte is filled with the NaCl and supplied to the machining unit by pump with flowrate 10L/min. The test specimens of aluminum alloy were the chemical composition as shown in Table 3 which have been tested in the Central Organization for Standardization and Quality Control, the specimens reinforced with 5 weight percent of silicon carbide was fabricated by stir casting technique. Metal Matrix Composites (MMC) is composed of a metallic matrix (Aluminium) and a dispersed silcon carbide phase. In this work Al 6061 is used as a matrix and SiC as a filler material. In Stir Casting liquid state MMC manufacturing method, discontinuous reinforcement is stirred into molten metal which is allowed to solidify. By mechanical stirring a dispersed phase is mixed with a molten matrix metal. Figure 4 shows a stir casting process. Powder reinforcement is distributed into molten metal by means of mechanical stirring process. The production of MMC using this process can affect by process variables such as holding temperature, stirring speed, size of impeller and position of impeller in the melt which has impact on mechanical properties. The properties of MMC are strongly depending on the interfacial bonding strength of reinforcement and matrix phase [6]. The specimens for experiments with dimensions were 50mm in length and 40 mm in breadth and 0.4mm thick.

Table 2. Composition of Brass cathode

Element	Zn	Pb	Sn	P	Si	S	As	Ag	Bi	Cd	Sb	Cu
Weight%	35.5	1.7	0.157	0.006	0.002	0.009	0.008	0.004	0.006	0.004	0.03	remain

Table 3. Chemical Composition of Aluminum alloy

Metal	Si%	Fe%	Cu%	Mn%	Mg%	Cr%	Ni%	Zn%	AL%
Aluminum alloy	0.059	0.206	1.84	0.206	2.17	0.190	0.001	5.57	remain

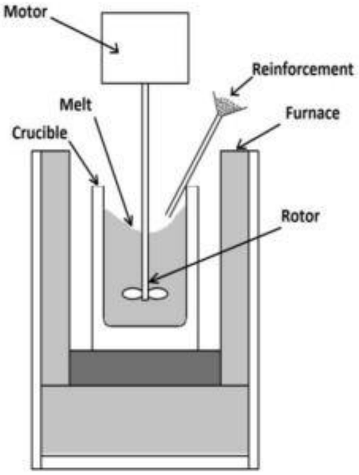

Fig. 4. Stir casting principle

By varying predominant variables the Perceptions were made such as, electrolyte concentration, applied voltage, and Inter-electrode gap. By using vernier caliper is measured the diameter of drilled hole and the ROC is determined as the formula

$$\text{Radial Over Cut} = (D_h - D_t) / 2 \quad (3)$$

Where D_h: Diameter of hole (mm)

D_t: Diameter of tool (mm)

MRR was measured from by the difference between the weight:

$$MRR = (W_i - W_f) / T \quad (4)$$

Where W_i: Initial weight (gm) , Wf: Final weight(gm) , T: Machining time (min)

Electrochemical machining was used for the experiments work as shown in Figure 5.

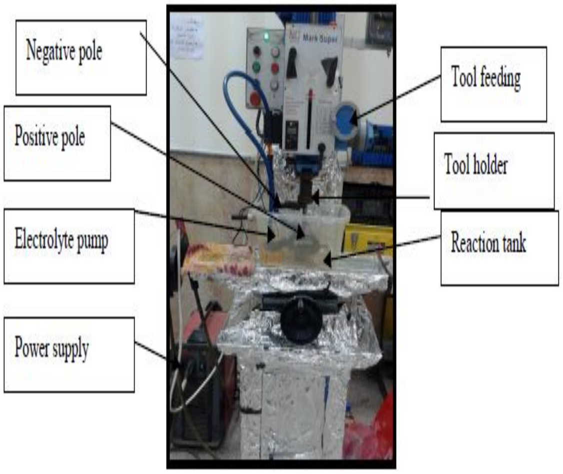

Fig.5. Electrochemical machining

By the digital weighing machine, the weights of the workpieces were measured by the weight losses after each experiment. Taguchi standard set orthogonal from L9 (3^4) was used. This array was used with machine conditions here in this paper and their level set for each test as shown in Table 4.

Table 4. Experimental results for response parameters

No.	Parameters Coded			Parameters of ECM			ROC (mm)	MRR (gm/min)	S/N For ROC	S/N For MRR
	A	B	C	Electrolyte Con(g/L)	Voltage (volt)	IEG (mm)				
1	1	1	1	50	8	0.1	0.853	0.682	1.38102	-3.32431
2	1	2	2	50	10	0.2	1.230	0.621	-1.79810	-4.52427
3	1	3	3	50	12	0.3	1.291	0.538	-2.21179	-4.71648

4	2	1	2	75	8	0.2	0.984	0.618	0.14010	-4.46598
5	2	2	3	75	10	0.3	1.218	0.644	-1.71295	-3.99941
6	2	3	1	75	12	0.1	1.269	0.626	-2.06923	-4.49507
7	3	1	3	100	8	0.3	1.287	0.698	-2.19157	-3.66192
8	3	2	1	100	10	0.1	1.422	0.663	-3.05799	-4.09631
9	3	3	2	100	12	0.2	1.392	0.810	-2.87278	-3.26087

ANALYSIS OF VARIANCE (ANOVA)

Tables 5 and 6 indicate the information of ANOVA for the ROC and MRR of ECM process. It’s represented that the developed model is important and their own mathematical model is also indicated in the equations 5 and 6. The value of F ratio represents the mean square error to the residual error ratio. It is used to measure the statistical indication of a given factor for the experiment as a whole. The indication or no indication parameter on the responses is representing by P-value. While percent contribution for each machining parameters can be defined as the contribution rate on the radial over cut and material removal rate.

Table 5. ANOVA for ROC

Source	DF	Seq. SS	Adj. SS	Adj.MS	F	P
Concentration%	2	0.10405	0.10405	0.052027	9.13	0.099
Volt	2	0.13856	0.13856	0.069278	12.16	0.076
Gap	2	0.01852	0.01852	0.009262	1.63	0.381
Residual Error	2	0.01140	0.01140	0.005698	/	/
Total	8	0.27253	/	/	/	/

$$\text{ROC} = -3.040 + 0.00017\ \text{concentration\%} + 0.748\ \text{volt} + 0.000142\ \text{concentration\%*concentration\%} - 0.02771\ \text{volt*volt} - 0.001660\ \text{concentration\%*volt} \quad (5)$$

Table 6. ANOVA for MRR

Source	DF	Seq. SS	Adj. SS	Adj.MS	F	P
Concentration%	2	0.003699	0.003699	0.001849	18.43	0.051
Volt	2	0.001442	0.001442	0.000721	7.19	0.122
Gap	2	0.007153	0.007153	0.003576	35.64	0.027
Residual Error	2	0.000201	0.000201	0.000100	/	/
Total	8	0.012494	/	/	/	/

$$\text{MRR} = 0.880 - 0.00623\ \text{concentration\%} - 0.3283\ \text{gap} + 0.000046(\text{concentration\%})^2 \quad (6)$$

Where: SS is sum of squares, and MS is mean of squares.

The larger (S / N) ratio matches the best performance. Thus, the optimum level for a parameter is the highest level (S / N) ratio and it always gives the best characteristics quality with low variance. The response table for means of ROC obtained for varying processing levels of parameter as shown in Table 7, and it can be seen that A1 B1 C1 represents the best level combination of low ROC and voltage has larger effect on ROC followed by electrolyte concentration and Inter-electrode gap .As well can be observed in Table 8 that A3B1C1 is the optimal level combination for maximum material removal rate and Inter-electrode gap has the greater influence on MRR then electrolyte concentration and voltage.

Table 7. Response for means of ROC

Level	Concentration%	Volt	Gap
1	1.124	1.041	1.154
2	1.157	1.290	1.262
3	1.367	1.317	1.232
Delta	0.243	0.276	0.108
Rank	2	1	3

Table 8. Response for means of MRR

Level	Concentration%	Volt	Gap
1	0.6190	0.6453	0.6667
2	0.6083	0.6163	0.6153
3	0.6557	0.6213	0.6010
Delta	0.0473	0.0290	0.0657
Rank	2	3	1

RESULTS AND DISCUSSION

The obtained experimental results are shown in the tables 4. ROC and MRR were analyzed in accordance with the input parameters i.e. electrolyte concentration, voltage and inter electrode gap. Nine experiments were conducted according to the Taguchi design.

Analysis of ECM parameters on radial over cut

Influence of different machining parameters on ROC in ECMD of Al-5%SiC composites as shown in Figure 6, and depend on the mathematical model in equation (5) the effects of different processing parameters were performed on the radial over cut for the purpose of achieving the controlled it.

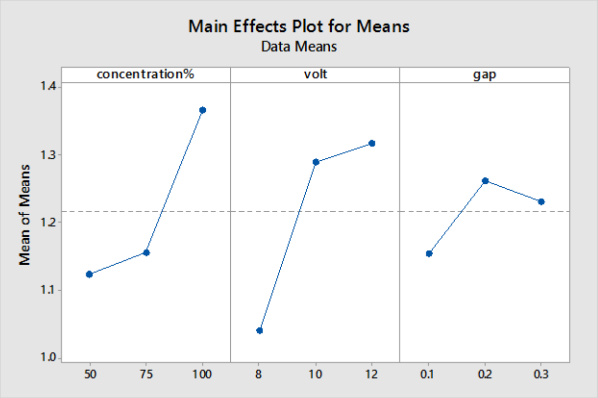

Fig.6. Influence of electrolyte concentration, voltage, and IEG on ROC

Increase in electrolyte concentration cause increasing in ROC. Increases in electrolyte concentration lead to precipitation at a higher from concentration electrolyte and leads to the forming bubbles of gas, e.g. O_2, H_2, etc. These influences causes to the increasing flow of stray current to the periphery of machining process thereby increase the radial over cut [1]. An increase in the voltage value leads to an increase in the electrolytic current in the IEG and an increase in the intensity of the stray current, resulting to higher radial over cut. A great number of in the IEG lead to increases the current and thus causes an increase in ROC.

Figure 7, shows the relationship between electrolyte concentration and voltage on the radial over cut. ROC is increasing with increasing electrolyte concentration and voltage. The minimum value of ROC occurs at 50g/l of electrolyte concentration and 8 volt, while maximum value occurs at 100g/l and 10 volt.

From figure 8, the effect of electrolyte concentration and inter electrode gap on the ROC indicate the minimum value of ROC at 50g/l and 0.1mm IEG, while the maximum value at 100g/l and 0.1mm .

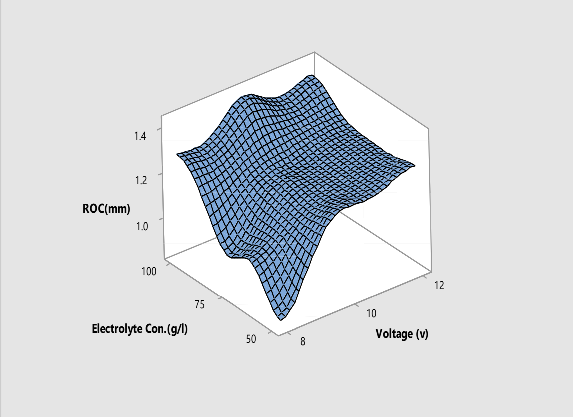

Fig. 7. Relationship between radial over cut, electrolyte con. and voltage

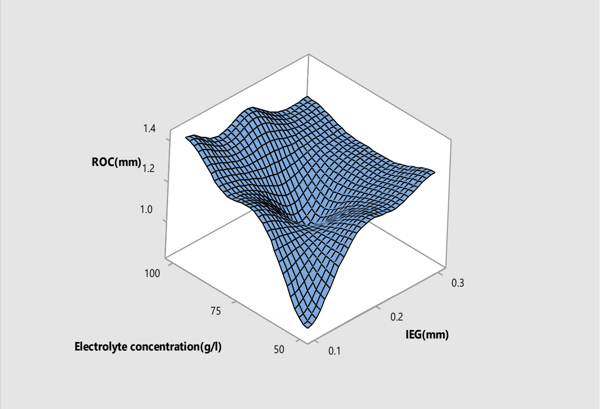

Fig. 8. Relationship between radial over cut, electrolyte concentration and inter electrode gap.

The minimum ROC value occurs at the lowest value of IEG and voltage, while the maximum ROC value occurs at 0.1mm of IEG and 10volt Figure 9.

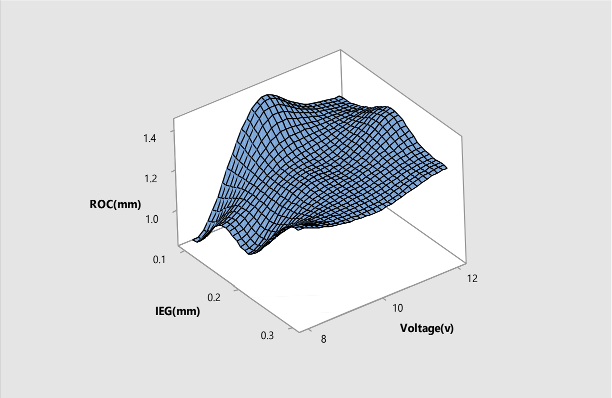

Fig. 9. Relationship between radial over cut, inter electrode gap and voltage.

Analysis of ECM parameters on material removal rate

From Figure 10 shows the effect of various machining parameters on the material removal rate, and based on the mathematical model in equation (6) in order to achieve control MRR the influences of different machining variables on MRR has been made. It can be seen that an increase in the electrolyte concentration causes an increase in the material removal rate. This result could indicate an increase in the electrical conductivity of the electrolyte solution as the concentration increased due to the increase in the machining current in IEG. Any increase in the voltage value results from the stability of the process at high voltage and the decrease in the MRR in the lateral direction of the hole. As well when increase in IEG causes decrease in MRR. Due to the stabilization of the process upon increased IEG and reduced MRR in the lateral direction of the hole.

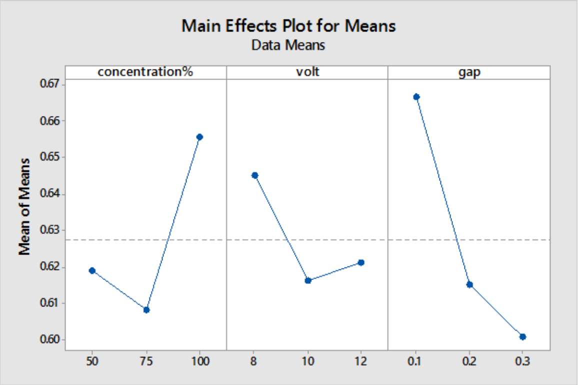

Fig. 10. Influence of electrolyte concentration, voltage, and IEG on MRR

The effect of the voltage and the concentration of the electrolyte on the MRR is shown in Figure 11, with increasing the voltage, the value of the MRR decreases, while when increasing the concentration of electrolyte the value of the MRR increases, and the highest MRR is at the highest voltage value (12 volt)and the highest electrolyte concentration (100 g/l) While the lowest value of the MRR is at the highest voltage value (12 volt) and the lowest electrolyte concentration (50g/l).

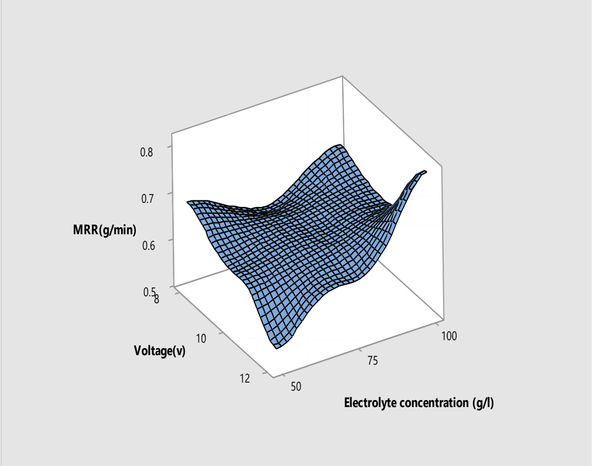

Fig. 11. Relationship between material removal rate, Voltage and electrolyte concentration.

From Figure 12, when the inter electrode gap value increases, the MRR decreases, and that the highest value of the MRR occurs at the gap value (0.2mm) and the electrolyte concentration (100 g/l), and the lowest value for the MRR is at the highest gap (0.3mm) and the lowest electrolyte concentration (50 g/l).

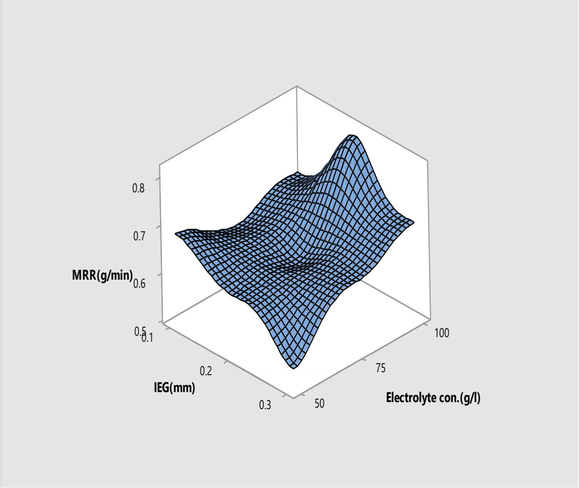

Fig. 12. Relationship between material removal rate, inter electrode gap and electrolyte concentration.

From Figure 13, the highest MRR is at the highest voltage value (12 volt) and at a gap value (0.2mm), and the lowest MRR is at the highest voltage value (12 volt) and the highest gap value (0.3mm).

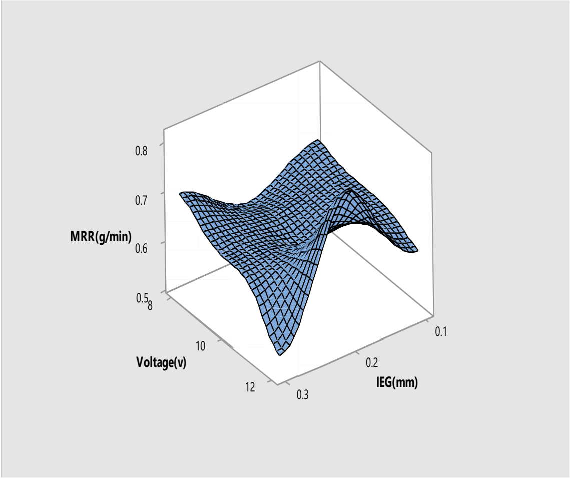

Fig. 13. Relationship between material removal rate, inter electrode gap and electrolyte concentration.

CONCLUSIONS

1. Development of a mathematical model to predict ROC and MRR in electrochemical etching of Al-5% SiC composite

2. Based on the Taguchi technique the experiments were designed to analysis optimum processing conditions of the radial over cut and material removal rate in the electrochemical drilling and it is obtained that electrolyte concentration 50 g/L, voltage 8 V, and IEG 0.1 mm the optimal parametric combination for ROC, as well electrolyte concentration 100 g/L, voltage 8 V, and IEG 0.1 mm the optimal parametric combination for MRR.

3. The increased ROC with increasing the electrolyte concentration, voltage and IEG value. The rate of material removal increases with raising concentration of electrolyte and decreases with increasing voltage and IEG value.

4. The models of the radial cut and material removal rate in this work may be used to improve the quality of the hole as the processing conditions are improved.

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