An Experimental Investigation Ecm of Titanium 6AL-4V-ELI Alloy With Different Electrolytes

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Abstract ECM can fabricate high surface quality and tranquil surface items. It is non-conventional machining methods that can effective use to work on hard to machine materials, for example, Composite steel, Ti alloys, super alloys etc. ECM process finds applicability in various industries like manufacturing of turbine blades, nozzles, components of fuel injection system, ordnance components etc. In this experimental study, electrochemical machining of Ti-6Al-4V ELI alloy with different electrolytes with Copper tool was conducted. The electrolytes used were NaCl, $NaNO_3$ and KCl. In view of astounding erosion opposition, high explicit efficiency and cryogenic properties, titanium alloy are widely used in marine construction, clinical and material projects. In various sectors such as aviation and automotive firms, titanium compound is commonly used as it has great solidarity with the proportion of weight. Due to the localization of chemical reactions in small areas, material removal rates are still high relative to other machining methods.

Keywords: Electrochemical machining (ECM), Material removal rate (MRR), Energy X-ray spectroscopy (EDX)

1. INTRODUCTION

Titanium metal is the ninth bountiful component on the earth. Ti-6Al-4V ELI (Grade 23) has additional low interstitial type of Titanium grade 5 (Ti-6Al-4V) amalgams which makes it harder. Ti-6Al-4V ELI composites are prevalently utilized in marine designing, clinical and substance businesses in light of its brilliant consumption obstruction, high explicit strength and cryogenic properties.[1-4] Electro Chemical Machining depends on the standard of electrolysis. The ECM device (cathode) is situated near the work piece (anode) and a low-voltage, highamperage direct current is passed between them by means of an electrolyte moving through the anode-cathode hole. Material is eliminated by anodic disintegration and is diverted by the electrolyte.[5-7] A charge trade happens between the cathode and the anode in a watery electrolyte arrangement which targets explicit territories of the work piece. This can be utilized to make shapes, ring conduits, depressions or chime hollows with no contact, however with exceptionally high accuracy[8]. The eliminated material is accelerated from the electrolyte arrangement as metal hydroxide. The machining can be done paying little mind to the primary state of the metal and both delicate and hard materials.

The ECM cycle depends on Faraday law which states, "If two conductive poles are put in a conductive electrolyte bath and energized by a current, metal removed from the positive pole (anode) and plated onto the negative post(cathode)"[9-10]. In another word, ECM eliminates material from a workpiece by anodic disintegration. It has been accounted for that in this process, no mechanical or nuclear power is utilized. **Rajurkar et al[11]**presented that a direct current (D.C.) voltage (10-25V) is usually applied across electrodes (between anode workpiece and cathode tool). Common electrolytes such as: NaCl/ KCl/ $NaNO_3$ etc. is allowed to flows at speed from 10- 60 m/s between the gap of 0.1-0.6 mm. Normally with current density of 20-200Acm^{-2}, the anode workpiece is dissolved. The shape of the workpiece is mirror image of the tool. The tool does not alter during ECM process because of difference in electrochemical equivalent of tool and workpiece. ECM has many advantages over traditional machining such as its applicability regardless of material hardness, no tool wear, high material removal rate, smooth and bright surface, and production of components of complex geometry **Manikanadan et al.[12]** the essential point of this work is to build up the working boundaries of electrochemical penetrating of titanium amalgam Ti-6Al-4V.It control of different boundaries like feed rate, electrolyte stream rate and convergence of electrolyte over material evacuation rate and overcut is examined. Taguchi's symmetrical exhibits, sign to commotion proportion, the examination of difference and dark social investigation are utilized to dissect the impact of these boundaries and locate the ideal cycle boundary level for multi target reaction. **Neto et al.[13]**This paper examination of the intervening elements in electrochemical machining (ECM) of SAE-XEV-F Valve-Steel. Material removal rate (MRR), brutality and over-cut were resolved and four limits changed during the examinations feed rate, electrolyte, stream movement of the electrolyte and voltage. Unmistakable electrolytic courses of action used sodium chloride (NaCl) and sodium nitrate ($NaNO_3$). The outcome show that feed rate was the rule limit impacting the material removal rate. The electrochemical machining with sodium nitride gets the best eventual outcomes of surface obnoxiousness and over-cut. Lopsided clearing of material is a ton of inclined to occur at low feed rates.

2. SELECTION OF WORK MATERIAL AND TOOL MATERIAL

The fundamental goal of examination is to consider the conduct of titanium based combination by utilizing various electrolytes. The determination of work piece and device for electrochemical machining is totally needy upon the electrical conductivity of the material.

2.1 WORK PIECE MATERIAL

Ti-6Al-4V ELI was selected as the workpiece material providing high yield and ultimate strengths for the research work that has been discussed. The Ti-6Al-4V ELI alloy has outstanding strength, strong resistance to corrosion and medium fabricability. For airframes, jet engines, rocket engine cases, nuclear reactor components, Ordnance components. It has better ductility and fracture toughness. The material is readily available in the open market.It can also be ordered online. The work piece ordered was a plate of dimensions 200 mm length, 150 width and 6mm thickness as shown in Fig.2

Fig.1 Work piece Titanium plate

The chemical composition of Ti-6Al-4V ELI alloy is outlined in the table 4.1 and physical properties of the material is given in the table 4.2 and mechanical properties in table 4.3

Table 1 Chemical Composition of Titanium grade 23 Ti 6Al 4V ELI Alloy

Elements	Percentage value
Titanium, Ti	88.09-90
Aluminum, Al	5.4-6.5
Vanadium, V	3.5-4.6
Iron, Fe	≤ 0.25
Carbon, C	≤ 0.070
Nitrogen, N	≤ 0.020
Hydrogen, H	≤ 0.0125

2.2 TOOL MATERIAL

As there is negligible tool wear in the ECM phase, any good conductor can be used satisfactorily as a tool material. Due to its easy availability and most common used tool material in ECM, copper is selected as the tool material, in addition they are easily machined, they are conductive materials and they will not corrode. It consists of a circular cross section of copper rod, there was a hole through middle hole. The tool used was provided with the ECM machine tool METATECH industries, Pune.

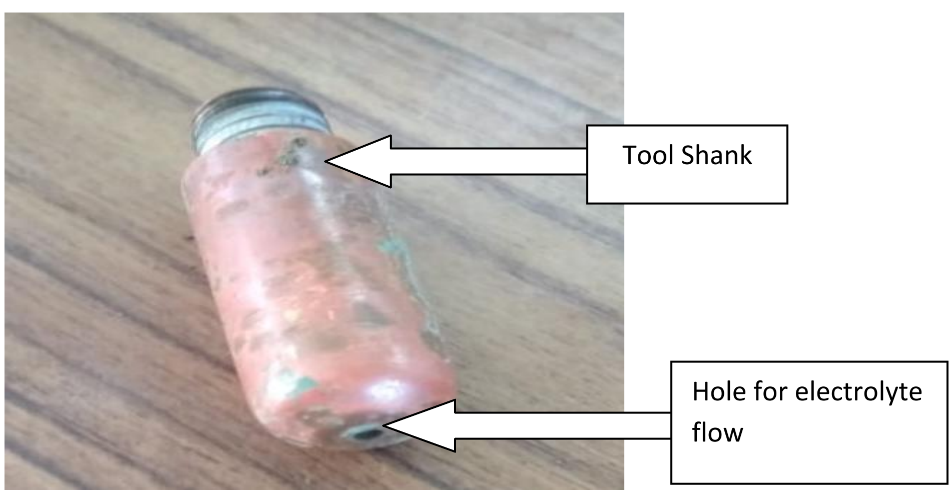


Fig. 2.Copper tool used for machining

2.3 SELECTION OF ELECTROLYTE

In electrochemical machining, the solution making process plays a critical role in the pace of material removal. By adding $NaNO_3$, NaCl and KCl to water, electrolytes are prepared while preserving water conductivity. So, we need to find a salt solution. We have to maintain conductivity until the end of the experiment in order to maintain the substance removal rate correctly**.**For this experiment we have taken 200 gm of sample in 1000 ml of water at room temperature.

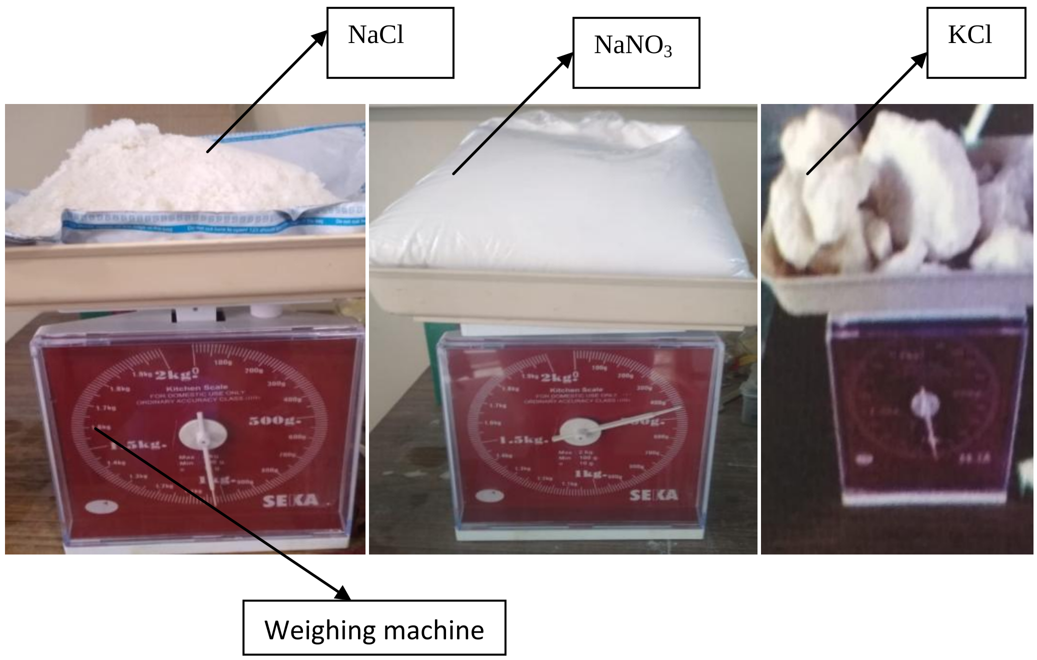


Fig.3. Selection of different electrolyte

3. EXPERIMENTATION SET UP

The material of work piece was tested for the original composition with the help of energy X-ray spectroscopy (EDX) machine available at material testing lab of department of mechanical Engineering, National Institute of technical Teachers Training and research , Chandigarh. The EDX machine is shown in the Fig. below.

Fig. 4. Scanning Electron Microscope used for EDX

In the workshop of the Department of Mechanical Engineering, experiments were carried out to calculate the material removal rate, and radial overcut on METATECH ECM machines. National Institute of Technical Teachers Training and Research, Chandigarh Figure below displays the machining setup used for experimentation.

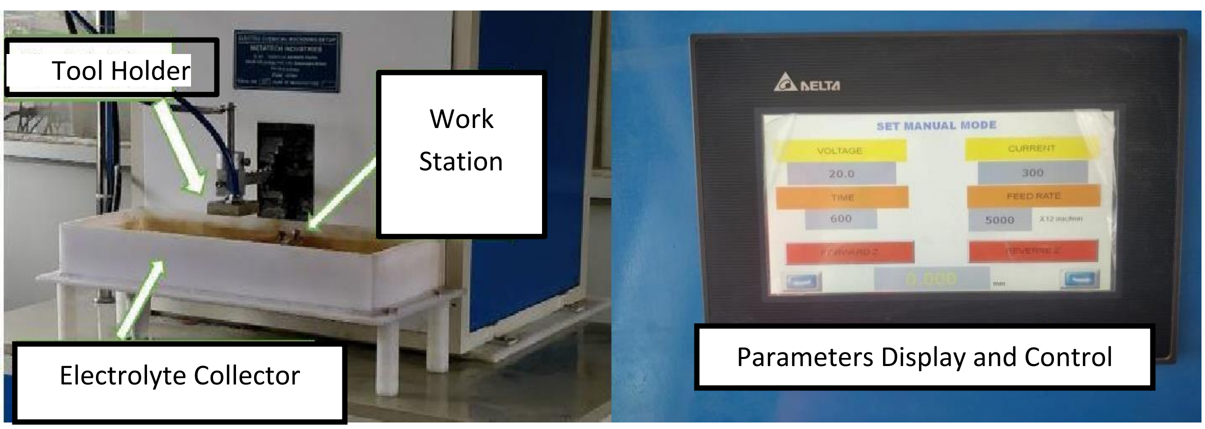


Fig.5. Machining Setup for Electrochemical Machining of Ti-6Al-4V ELI

4. RESULT AND DISCUSSION

On the basis of previous investigations and the pilot experiment conducted on the workpiece, cutting parameters were chosen. A general range of input parameters was chosen. The different voltage combination was 10 to 20 V, the feed rate of the tool was 12 to 16 mm/min, and the inter-electrode gap was 0.1 to 0.5 mm. Three levels of each parameters were selected for experimentation and one categorical factor electrolyte concentration same for all different electrolytes.

Table 2 Levels of Machining Parameters for Experimentation

S. No.	FACTOR	LEVEL 1	LEVEL 2	LEVEL 3
1	Voltage (volt)	10	15	20
2	Feed rate (mm/min)	12	14	16
3	Inter electrode gap(mm)	0.1	0.3	0.5

The experimental design dataset for RSM was generated using trial version of Design expert software (Version-12). Three levels of each input parameters (i.e. voltage, feed rate, electrolyte concentration and inter electrode gap) were taken for experimentation and results were tabulated as shown in Table 3.

Run	Factor 1	Factor 2	Factor 3	Factor 4	Response 1
	A:voltage	B:feed rate	C:inter electrode gap	D:electrolyte conc.	MRR
	V	mm/min	Mm		gm/min
1	10	16	0.3	NaCl	0.050
2	10	14	0.1	NaCl	0.025
4	15	16	0.1	NaCl	0.025
13	10	14	0.5	NaCl	0.075
15	15	12	0.5	NaCl	0.050
16	15	12	0.1	NaCl	0.050
19	20	16	0.3	NaCl	0.075
24	10	12	0.3	NaCl	0.025
29	20	14	0.1	NaCl	0.075
31	20	12	0.3	NaCl	0.025
35	15	14	0.3	NaCl	0.075
36	15	14	0.3	NaCl	0.100
40	15	14	0.3	NaCl	0.100
43	15	16	0.5	NaCl	0.050
44	15	14	0.3	NaCl	0.050
47	20	14	0.5	NaCl	0.050
49	15	14	0.3	NaCl	0.075
3	15	16	0.5	$NaNO_3$	0.100
5	20	14	0.1	$NaNO_3$	0.075
6	15	14	0.3	$NaNO_3$	0.075
10	10	14	0.1	$NaNO_3$	0.075
11	15	14	0.3	$NaNO_3$	0.075
14	15	14	0.3	$NaNO_3$	0.075
20	15	12	0.5	$NaNO_3$	0.050

22	15	14	0.3	$NaNO_3$	0.075
26	20	12	0.3	$NaNO_3$	0.050
27	15	14	0.3	$NaNO_3$	0.050
28	20	14	0.5	$NaNO_3$	0.075
34	10	12	0.3	$NaNO_3$	0.050
38	20	16	0.3	$NaNO_3$	0.075
39	15	16	0.1	$NaNO_3$	0.100
42	10	14	0.5	$NaNO_3$	0.025
45	10	16	0.3	$NaNO_3$	0.050
50	15	12	0.1	$NaNO_3$	0.050
7	15	12	0.5	KCl	0.100
8	15	16	0.5	KCl	0.100
9	10	14	0.5	KCl	0.075
12	10	16	0.3	KCl	0.075
17	10	12	0.3	KCl	0.050
18	20	12	0.3	KCl	0.050
21	20	14	0.5	KCl	0.075
23	15	14	0.3	KCl	0.050
25	15	14	0.3	KCl	0.075
30	15	16	0.1	KCl	0.125
32	15	14	0.3	KCl	0.100
33	15	12	0.1	KCl	0.100
37	20	16	0.3	KCl	0.050
41	15	14	0.3	KCl	0.075
46	15	14	0.3	KCl	0.125
48	20	14	0.1	KCl	0.050
51	10	14	0.1	KCl	0.075

4.1 EFFECTS OF INTERACTION ON OUTPUT PARAMETERS

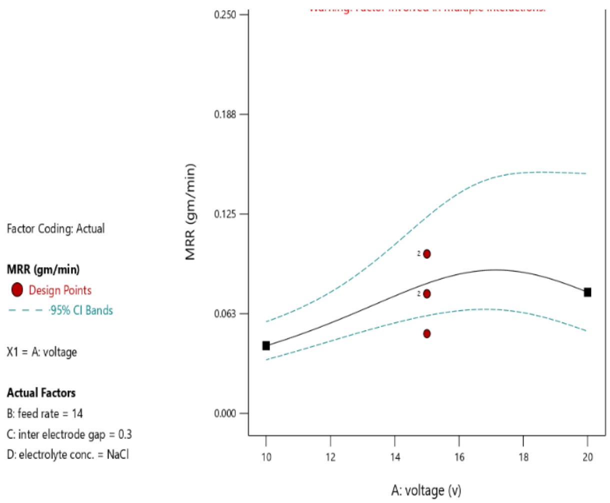
Interaction of voltage, feed rate and inter electrode gap in case of material removal rate values for electrochemical machining of Ti-6AL-4V ELI material is discussed below.

MRR Vs Voltage

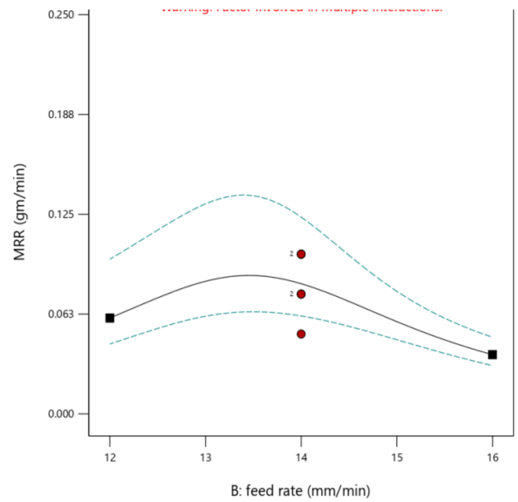
From Fig.6 (a) it is found that a for a change in value of voltage from 10 volts to 20 volts the corresponding changes in value of MRR range from 0.042 gm/min. to 0.076 gm/min i.e. increase in value of voltage is accompanied by increase in MRR.

MRR Vs Feed Rate

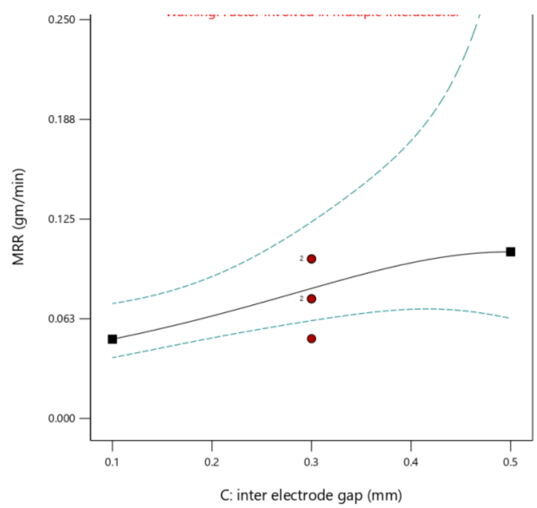
From Fig.6(b) it is found that a change in feed rate from 12 mm/min to 16 mm/min results in a change in MRR from 0.060 gm/min to 0.037gm/min i.e. an increase of feed rate leads to a decrease in MRR at the middle range of feed rate maximum MRR.



(a) MRR Vs Voltage



(b) MRR Vs Feed Rate



(c) MRR Vs Inter electrode gap

Fig.6 Variation of MRR with respect to each individual machining parameter

MRR Vs Inter electrode gap

From Fig.6 (c) it is found that a change in Inter electrode gap from 0.1 mm to 0.5 mm results in a change in MRR from 0.050 gm/min to 0.104 gm/min i.e**.** an increase of Inter electrode gap leads to increase in MRR.

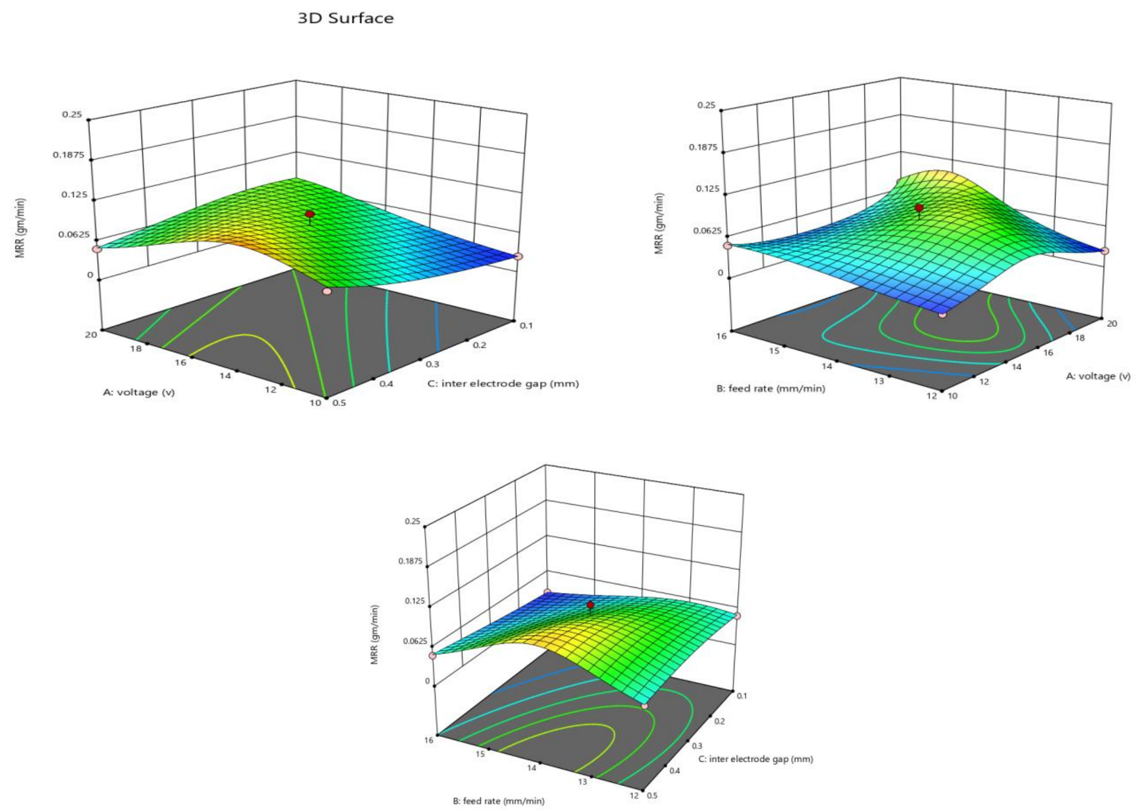


Fig.7 3D Surface plot of material Removal rate for Interaction between voltage, Feed rate and Inter electrode gap

4.2 PERTURBATION PLOT FORMRR NaCl

At a given point in the design space, the perturbation plot helps to examine the effects of all the variables. By changing only one factor over its range while holding all the other factors constant, the response parameter is plotted. A steep slope or curvature in a factor suggests that that factor is sensitive to the response.In that specific factor, a relatively flat line demonstrates insensitivity to transition. The disturbance plot may be used to find certain factors that influence the response most if there are more than two factors. The perturbation plot for the MRR is shown in Fig.7

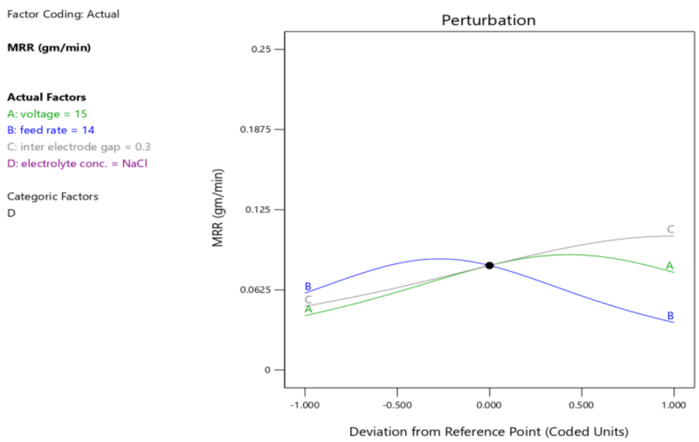


Fig.8.Effects of input factors on MRR

Figure 5 shows the effects of voltage (coded-A), feed rate (coded-B), inter electrode gap(coded-c) and electrolyte concentration (coded-D) on MRR. It is clearly indicated that the inter electrode gap is the most influential factor in controlling the MRR, as the slope found maximum. In this case voltage and feed rate are next influence factor respectively.

CONCLUSION

The present study was an attempt to predict the RSM model using NaCl,$NaNO_3$ and KCl as the electrolyte solution for electrochemical machining of Ti-6Al-4V ELI Alloy. For each response parameter, a mathematical regression technique that strings the response parameters in mathematical equations was used to generate dedicated individual mathematical equation. Design of experiments based on Box Behnken Design of Response Surface Methodology was used for designing experiments and analysis of results.

The machining of Ti-6Al-4V ELI Alloy was successfully done with copper tool by the optimizing of process parameters voltage, tool feed rate, inter electrode gap and electrolyte concentration. The optimum combination for machining was found to be voltage =20V, tool feed rate =12 mm/min, inter electrode gap = 0.1mm and electrolyte concentration = 200 gm/l constant for all electrolyte used.

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