Optimization Of ECM Parameters For Machining Ti-6Al-6V-2Sn

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Abstract: Electrochemical machining described as reversed electroplating process is a non-contact process wherein the formation of shape is look alike to the tool shape. Primacy of the ECM to machine conductive materials, over other processes lies in its ability to produce complicated shapes without stress, while requiring minimal finishing work. This research is concerned with ECM of Ti 6Al-6V-2Sn alloy using $NaNO_3$ electrolyte. Experimental design for Process parameters i.e. voltage, tool feed rate, electrolyte flow rate and electrolyte concentration is done using RSM and response parameters i.e. MRR, Overcut, Ra has been optimized by using the ANOVA. The regression models are developed to be used as predictive tools. Diagnosis plots are developed to validate the regression models. Research results can be realized in pragmatic sense while selecting parameters for machining in field work.

Index Terms: BBD, ECM, MRR, Ra, ROC

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1 INTRODUCTION

Electrochemical machining(ECM), a nontraditional machining process, used to machine difficult to machine materials like alloy steels, Ti alloys, super alloys etc. is characterized as reverse electroplating process. Faradays law of electrolysis forms the basis for this process. Due to its ability to machine difficult-to-cut materials and complicated shapes without distortion, scratches, burrs, and stress, ECM is presently applied in the manufacturing of a variety of components such as aircraft turbine blades, surgical implants and prostheses, bearing cages, moulds and dies, artillery projectiles.ECM is an important process for semiconductor devices and thin metallic films because a basic requirement of semiconductor industry is the machining of components of critical shape and high strength alloys. This process is also used for shaping and finishing operation in aerospace and electronics industries for different parts of the opening. ECM is a controlled anodic dissolution process wherein workpiece and tool are made cathode and anode respectively. Normally, a low voltage (7-25V DC continuous or pulsed) is applied between the electrodes with a small gap (about 0.25 mm) maintained between them. Electrolyte (such as NaCl or NaN03 aqueous solutions) flows between the electrodes with a high velocity (30-60 m/s) to maintain the anodic dissolution as well as to sweep away the reaction products. Current flowing between the tool and the workpiece through the electrode causes a depleting action to occur, which removes material from the workpiece. In this process workpiece and tool are immersed in an electrolyte solution, the most common electrolytic solutions are NaCl or $NaNO_3$ to provide with a better understanding a simple schematic diagram in fig. 1 has shown the workpiece and tool immersed in the electrolyte. The tool is connected to the negative terminal and workpiece is connected to the positive terminal, hence tool will be the cathode and the workpiece will be the anode. As the workpiece is anode this process is also known as controlled anodic dissolution process.

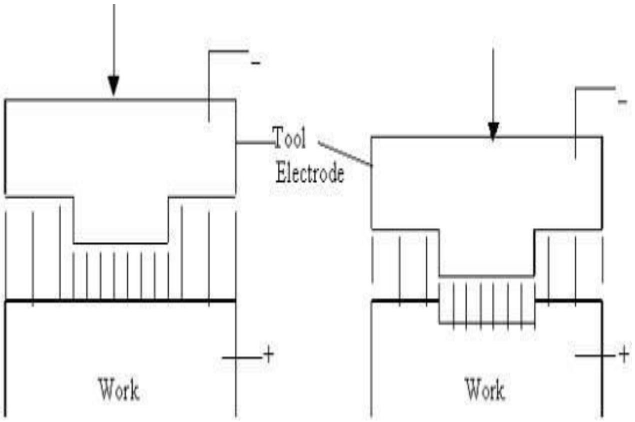

Fig.1. *Schematic Workpiece-Tool Diagram for ECM*

Not much data is available related to electrochemical machining of Ti 6Al-6V-2Sn alloy but electrochemical machining of many titanium alloys has been performed. B. Bhattacharyya et.al [1] investigated into controlled ECM through response surface methodology. The analysis of the experimental observations highlighted that the MRR in ECM Is greatly influenced by the various dominant process parameters such as electrolyte concentration, electrolyte flow rate applied voltage Inter-electrode gap considered inthe study. R V Rao et.al [2] studied that the selection of critical process parameters of ECM methods such as feed rate, flow velocity of electrolyte, and voltage play an important role in improving the measures of process performance. F. Klocke et.al [3] studied the electrochemical machining of some selected modern titanium- and nickel-

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based alloys for aero engine components. C. Senthil kumar et.al [4] highlighted that the electrochemical machining criteria like MRR, Ra in ECM are greatly influenced by the various predominant machining parameters considered in the study. Response surface methodology used in the research work has proved its adequacy to be an effective tool for analysis of the ECM process. Mathematical modelshad been developed based on RSM approach for correlating the MRR and Ra with predominant process parameters. Shirish D. Dhobe et. al [5] examined the surface characteristics of ECMed titanium work samples for biomedical applications and concluded that at higher flow velocity and applied voltage values, MRR increases, and surface finish quality also improves. P. Asokan et. al [6] developed multi-objective optimization models for the electrochemical machining process and presented a practical method of optimizing the cutting parameters for ECM based on multiple regression models. Current, voltage, flow rate and the gap had been considered as machining parameters. K. Mishra et. al [7] performed experimental investigation into electrochemical milling of Ti6Al4V. Study of comparative effects of different electrolytes on various performance characteristics on titanium alloy, was the soul of this paper.

2 SELECTION PROCESS

PARAMETERS:

Parameters that play substantial role in electrochemical machining are-,

- Voltage
- Current
- Inter-electrode gap
- Electrolyte concentration
- Tool feed rate
- Electrolyte feed rate

In this work voltage, electrolyte concentration, flow rate of electrolyte and tool feed rate were selected as the process parameters for optimizing electrochemical machining of Ti 6Al-6V-2Sn alloy. Three levels of each process parameters were considered as shown in table 1.

Table1 *Process Parameters and their levels*

	Factors	*Unit*	*L-1*	*L-2*	*L-3*
1	*Voltage*	*V*	*10*	*15*	*20*
2	*Tool Feed Rate*	*mm/min*	*0.096*	*0.120*	*0.144*
3	*Electrolyte Concentration*	*gm/litre*	*150*	*200*	*250*
4	*Flow rate of Electrolyte*	*m^3/sec*	*80*	*90*	*100*

Design of Experiments:

Response Surface Methodology (RSM)-based Box Behnken Design (BBD) technique was used for experimentation using Design Expert Software (version-12). Three levels of each process parameter were taken for experimentation. A total of 29 experiments were conducted to study the effect of process parameters on response parameters i.e. material removal rate, surface roughness (Ra) and radial over-cut ROC. The table 2 illustrates the experimental scheme according to RSM.

Table2
Design of Experiments for ECM of Ti 6Al-6V-2Sn Alloy

S.no.	*Factor 1*	*Factor 2*	*Factor 3*	*Factor 4*
	Voltage	*Tool Feed*	*Flow Rate*	*Electrolyte*
1	*10*	*0.120*	*80*	*200*
2	*15*	*0.096*	*100*	*200*
3	*15*	*0.120*	*100*	*250*
4	*20*	*0.120*	*80*	*200*
5	*15*	*0.144*	*90*	*150*
6	*15*	*0.120*	*90*	*200*
7	*15*	*0.096*	*90*	*250*
8	*20*	*0.144*	*90*	*200*
9	*15*	*0.120*	*90*	*200*
10	*15*	*0.096*	*80*	*200*
11	*10*	*0.120*	*90*	*250*
12	*20*	*0.120*	*90*	*250*
13	*15*	*0.096*	*90*	*150*
14	*20*	*0.120*	*90*	*150*
15	*15*	*0.144*	*90*	*250*
16	*20*	*0.120*	*100*	*200*
17	*10*	*0.120*	*90*	*150*
18	*20*	*0.096*	*90*	*200*
19	*15*	*0.120*	*100*	*150*
20	*15*	*0.120*	*90*	*200*
21	*15*	*0.120*	*90*	*200*
22	*15*	*0.120*	*80*	*150*
23	*15*	*0.144*	*100*	*200*
24	*15*	*0.120*	*90*	*200*
25	*15*	*0.120*	*80*	*250*
26	*15*	*0.144*	*80*	*200*
27	*10*	*0.096*	*90*	*200*
28	*10*	*0.120*	*100*	*200*
29	*10*	*0.144*	*90*	*200*

3. RESULT AND DISCUSSION

Response parameters were measured after performing the experiments and the values obtained were then further used for optimization in order to obtain the optimized value of process parameters. Three response parameters which were measured during the experimentation were surface roughness, material removal rate and radial overcut. The Table3 experimental values obtained for Material Removal Rate and Surface Roughness are given in table 3.

Experimental Results

Run	A:Voltage(V)	B:Feed Rate(mm/min)	C:Flow Rate of Electrolyte(m^3/sec)	D:Electrolyte Concentration(gm/l)	MRR(gm/min)	Radial Overcut(mm)	Surface Roughness(µm)
1	10	0.120	80	200	0.16	0.895	0.589
2	15	0.096	100	200	0.2	1.052	0.785
3	15	0.120	100	250	0.13	1.21	1.12
4	20	0.120	80	200	0.1	1.439	1.2
5	15	0.144	90	150	0.17	0.8595	0.865
6	15	0.120	90	200	0.15	1.005	1.025
7	15	0.096	90	250	0.14	0.985	0.997
8	20	0.144	90	200	0.1	1.12	1.58
9	15	0.120	90	200	0.16	1.112	0.985
10	15	0.096	80	200	0.17	1.12	0.875
11	10	0.120	90	250	0.14	0.954	0.605
12	20	0.120	90	250	0.09	1.328	1.35
13	15	0.096	90	150	0.18	1.11	0.852
14	20	0.120	90	150	0.14	1.221	1.112
15	15	0.144	90	250	0.16	1.002	1.105
16	20	0.120	100	200	0.1	1.435	1.125
17	10	0.120	90	150	0.16	0.895	0.496
18	20	0.096	90	200	0.11	1.32	1.105
19	15	0.120	100	150	0.16	1.025	0.941
20	15	0.120	90	200	0.15	1.121	0.984
21	15	0.120	90	200	0.14	1.115	0.885
22	15	0.120	80	150	0.16	1.194	0.859
23	15	0.144	100	200	0.16	1.145	0.959
24	15	0.120	90	200	0.15	1.025	0.852
25	15	0.120	80	250	0.13	1.115	0.993
26	15	0.144	80	200	0.14	0.909	0.857
27	10	0.096	90	200	0.23	0.855	0.596
28	10	0.120	100	200	0.19	0.9456	0.52
29	10	0.144	90	200	0.17	0.9963	0.496

A) Material Removal Rate Multiple regression models were developed for material removal rate. Mathematical Sqrt (material removal rate + 1.00)= 1.44449- (0.0190119 *Voltage) – (3.87993 *Feed Rate) + (0.423365* Voltage*Feed Rate) – (0.0587125*Concentration * Feed

equation obtained for removal is:

Rate) + (36.8132 * Feed Rate^2) - (1.56756 * Voltage * Feed rate^2) ……. (1)

The results were represented in the form of multi-dimensional curves representing varied slopes, thus indicating variation in influence on material removal rate. The perturbation plot is shown in figure 2.

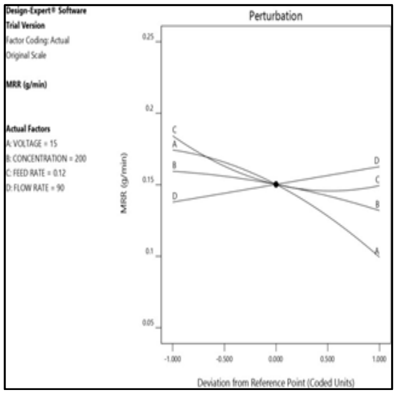

Fig. 2. *Perturbation Plot of MRR*

The optimized process parameters so obtained from machining are shown in Table 4 below:

Table 4
Optimized Solution for MRR

Voltage	*Concentration*	*Feed Rate*	*Flow Rate*	*MRR*
10.000	*164.905*	*0.097*	*100.000*	*0.230*

The perturbation plot is shown in figure 3

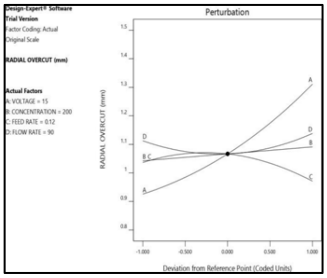

Fig.3*.Perturbation Plot of ROC*

The optimized process parameters so obtained from machining are shown in Table 6

Table 6
Optimized Solution for Surface Roughness

Voltage	*Concentration*	*Feed Rate*	*Flow Rate*	*Radial Overcut*
10.000	*162.926*	*0.096*	*99.981*	*0.803*

(C) Surface Roughness

Multiple regression models were developed for surface roughness. The mathematical equation obtained for surface roughness is:

(B) Radial Overcut

Multiple regression models were developed for radial over cut. The mathematical equation obtained for radial overcut is:
Sqrt(Radial Overcut) = 5.28109 + (0.034382 * VOLTAGE) - (2.23896 * FEED RATE) - (0.0810248 * FLOW RATE) - (0.341871 * VOLTAGE * FEED RATE) + (0.0281252 * CONCENTRATION * FEED RATE) + (0.155481 * FEED RATE * FLOW RATE) – (53.8767 * FEED RATE^2)
The results were represented in the form of multi-dimensional curves representing varied slopes, thus indicating variation in influence on material removal rate.

Sqrt(Surface Roughness) = 1.16644 + (0.00643295 * VOLTAGE) - (0.0034915*CONCENTRATION) - (16.8163 * FEED RATE) + (0.0150661 * FLOW RATE) + (0.569851 * VOLTAGE * FEED RATE)+ (0.107244 * FEED RATE * FLOW RATE)
–(9.62358 * FEED RATE^2)

The results were represented in the form of multi-dimensional curves representing varied slopes, thus indicating variation in influence on material removal rate. The perturbation plot is shown in figure 4

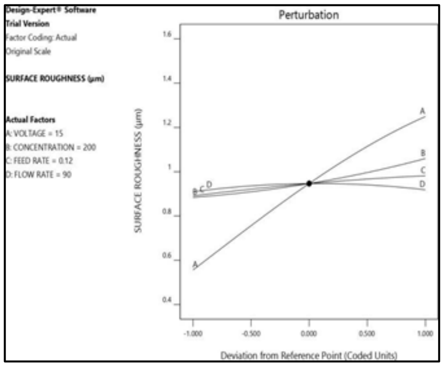

Fig. 4. *Perturbation Plot of Surface Roughness*

The optimized process parameters so obtained from machining are shown in Table 5 below:

Table 5

Optimized solution for ROC

Voltage	Concentration	Feed Rate	Flow Rate	Surface Roughness
10.000	169.601	0.098	100.000	0.527

4. CONCLUSION

The machining of Ti 6Al-6V-2Sn was successfully done with copper tool by the optimizing the process parameters viz. voltage, tool feed rate, flow rate of electrolyte and electrolyte concentration. The following conclusions are drawn on the basis of experimental work and analysis of the result.

- Optimal value of MRR of 0.230 gm/min was obtained at a voltage 10 volts, feed rate of 0.097 mm/min, electrolyte concentration of 164.905 gm/liter and at a flow rate of 100m^3/sec.
- Voltage was most influencing factor for MRR followed by concentration, feed rate and flow rate respectively.
- The Optimised value of ROC of 0.803 mm was obtained at a voltage value of 10 volts, feed rate of 0.096 mm/min electrolyte concentration of 162.926 gm/litre and at a flow rate of 99.981m^3/sec.
- The variation in plots shows that better surface quality is obtained at lower value of voltage and concentration.

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