Experimental Study on Parametric Optimization of Titanium based Alloy (Ti-6Al-4V) in Electrochemical Machining Process

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Abstract-Electrochemical machining (ECM) has inaugurated itself as one of the major other possible way to conventional methods for machining hard materials and complicated outlines not having the residual stresses and tool wear. Electrochemical machining has vast application in automotive, Aircrafts, petroleum, aerospace, textile, medical and electronic industries. Studies on Material Removal Rate (MRR) are of extremely important in ECM Use of optimal ECM process parameters can significantly reduce the ECM operating, tooling, and maintenance cost and will produce components of higher accuracy. This paper investigates the effect and parametric optimization of process parameters for Electrochemical machining of Titanium based alloy. The process parameters considered are electrolyte concentration, feed rate and applied voltage and are optimized in consideration of material removal rate. Analysis of variance is performed to get contribution of each parameter on the performance characteristics and it was observed that feed rate is the significant process parameter that affects the ECM robustness.

Keywords - Electrochemical machining; Material removal rate; Taguchi method; orthogonal array; process parameters; electrolyte; etc.

I. INTRODUCTION

Electrochemical machining is a nontraditional machining process which is used to machine hard materials which cannot be machined easily without causing any harm to tool. This can be used for mass production and can machine external and internal of any geometry. But use of it is limited only to electrically conductive materials. Unlike conventional processes ECM removes metal atom by atom. It can be regarded as a solution to a variety of metal removal problems such as cavity sinking, contouring machining and machining helices.

1.1 Principal of ECM

As ECM is controlled removal of metal by anode dissolution in an electrolyte. Removal of metal of work piece occurs which is anode and tool is cathode. This removal of metal happens on the principle of Faraday law of electrolysis. Let us consider iron alloy as work piece and copper as tool and brine solution as electrolyte. Electrolyte is mixture of NaCl and water. This breaks as $NaCl= Na^{+}+Cl^{-}$ and $H_2O = H^{+}+OH^{-}$

When potential is applied between work piece and tool negatively charged ions move towards anode and positively charged ions move towards cathode. At cathode hydrogen ions takes electron from cathode (tool) and becomes hydrogen gas. $2H^{+}+2e^{-} = H_2$

At anode iron ions comes out of work piece and loses two electrons and combines with chloride ions to form iron chloride which acts as precipitate. $Fe = Fe^{+\,+} + 2e^{-}$ and $Fe^{2+} + Cl^{-} =FeCl_2$

Similarly hydroxyl ions combine with sodium ions and form sodium hydroxide. $Na^{+} + OH^{-} = NaOH$

In this way material is machined and removed material is found as precipitate in electrolyte. Moreover there is not coating on the tool, only hydrogen gas evolves at the tool or cathode.

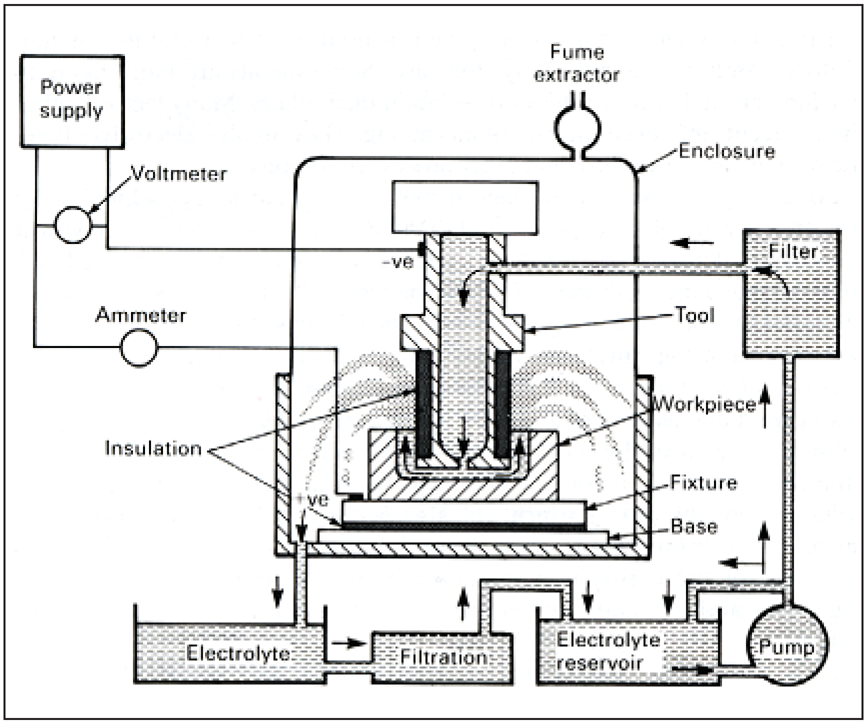


Figure 1: Schematically the experimental set-up ECM

II. DESIGN OF EXPERIMENTS

Design of experiment is a powerful analysis tool for modeling and analyzing the influence of control factors on performance output. The initial step in the Taguchi model development is to build up an input- output database required for the optimization through the turning experiments. In order to have a complete knowledge of turning process over the range of parameters selected, a proper planning of experimentation is essential to reduce the cost and time. Hence an experimental plan based on Taguchi orthogonal array (L_9) was chosen.

The machining tests are conducted on Electrochemical machining (ECM). The materials selected for the experimentation was Ti-6Al-4V.The machining parameters selected for the experimentation are NaCl concentration, voltage, feed rate. The Gap voltage is kept as a constant parameter. The gap maintained in between the tool and the work piece is 0.3 mm. The various input parameters and output parameters (response variables) selected for the experimentation are as follows:

Table 1 shows the input factors with their levels

Factor/level	Notation	Units	1	2	3
NaCl concentration	C	%	10	15	20
Voltage	V	Volt	10	15	20
feed rate	F	mm/min	0.1	0.21	0.32

Experimental layout plan of L_9 Taguchi orthogonal array is shown in the following table.

Table 2 Experimental layout plan of L9 Orthogonal Array

Exp.No.	**NaCl Concentration**	**Voltage**	**feed rate**
1	10	10	0.1
2	10	15	0.21
3	10	20	0.32
4	15	15	0.1
5	15	20	0.21

6	15	10	0.32
7	20	20	0.1
8	20	10	0.21
9	20	15	0.32

2.2 Selection of work piece

The material used for experimentation is Titanium based alloy (Ti-6Al-4V). Typical applications of this alloy include aircraft, jet –engine, racing car, chemical, petrochemical, and marine components, submarine hulls, and biomedical materials.

2.3 selection of tool electrode: A pure copper electrode is used for experimentation.

III. EXPERIMENTAL RESULTS FOR MATERIAL REMOVAL RATE FOR MATERIAL TI-6AL-4V

Table 3 Experimental results for Material removal rate for Material Ti-6Al-4V

Exp. No.	**NaCl Concentration (%)**	**Voltage (volts)**	**feed rate (mm/min)**	**W 1 (gm)**	**W 2 (gm)**	**Time (min)**	**MRR (gm/min)**
4	10	10	0.1	326	325	10	0.1
5	10	15	0.21	325	322	10	0.3
6	10	20	0.32	322	317	10	0.5
1	15	15	0.1	333	331	10	0.2
2	15	20	0.21	331	328	10	0.3
3	15	10	0.32	328	326	10	0.2
7	20	20	0.1	317	314.5	10	0.25
8	20	10	0.21	314.5	313.5	10	0.1
9	20	15	0.32	313.5	312.5	10	0.1

3.1 EVALUATION OF OPTIMAL SETTINGS FOR MRR FOR MATERIAL Ti-6Al-4V

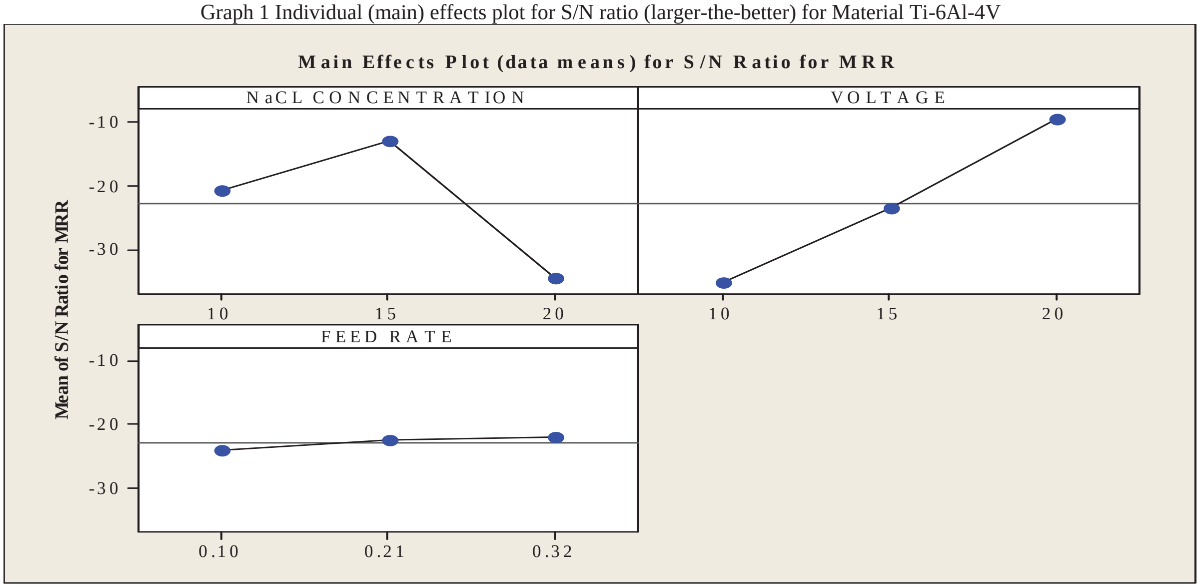
From the experimental results, the effects of process parameters on MRR are plotted by using MINITAB software as shown below. The signal to noise ratio for this material is calculated as follows.

Table 4 S/N ratio for Material Ti-6Al-4V

Exp. No.	**NaCl Concentration (%)**	**Voltage (volts)**	**feed rate (mm/min)**	**MRR (mg/min) (Yi)**	**S/N ratio** $\eta = 10\, ln_{10}\, \frac{1}{n}\left(\sum_{i=1}^{n}\frac{1}{y_i^2}\right)$
1	10	10	0.1	0.1	-46.05
2	10	15	0.21	0.3	-10.457
3	10	20	0.32	0.5	-6.021
4	15	15	0.1	0.2	-13.979

5	15	20	0.21	0.3	-10.457
6	15	10	0.32	0.2	-13.979
7	20	20	0.1	0.25	-12.041
8	20	10	0.21	0.1	-46.05
9	20	15	0.32	0.1	-46.05

Graph 1 Individual (main) effects plot for S/N ratio (larger-the-better) for Material Ti-6Al-4V



Optimal values of process parameters: From this graph we can predict the optimum values of process parameters

Table 5 optimal values of process parameters

Process parameters	units	Optimum values
NaCl Concentration (C)	%	15
Voltage (V)	Volt	20
Feed rate (F)	(mm/min)	0.32

Mathematical regression equation for material Ti-6Al-4V

It is possible to obtain regression equation correlating the dependent response with the independent variables using MINITAB software as listed below. The calculated mathematical regression equation of MRR for material Ti-6Al-4V is as follows.

MRR = 0.048 - 0.0150 C + 0.0217 V + 0.379 F

Predicator	Coefficient	SE Coefficient	T	P
Constant	0.0482	0.1249	0.39	0.715
NaCl Concentration (C)	-0.015	0.005288	-2.84	0.036
Voltage (V)	0.021667	0.005288	4.1	0.009
Feed rate (F)	0.3788	0.2404	1.58	0.176

S = 0.0647645 R-Sq = 84.5% R-Sq (adj) = 75.2%

IV. ANALYSIS OF VARIANCE

Source	DF	SS	MS	F	P
Regression	3	0.114583	0.038194	9.11	0.018
Residual error	5	0.020972	0.004194		
Total	8	0.135556			

Table 6 ANOVA for Material Ti-6Al-4V

Source	DF	Seq. SS
NaCl Concentration (C)	1	0.03375
Voltage (V)	1	0.070417
Feed rate (F)	1	0.010417

The calculated F-ratio values (9.11) are higher than the tabulated F-ratio values (5.41) for 95 % confidence. The factors which have an F ratio larger than the criterion (F ratio from the tables) are believed to influence the average value for the population, and factors which have an F ratio less than the criterion are believed to have no effect on the average. The machining parameters which have p-value less than 0.05 are considered most significant (shown in bold). In this study it is observed that Voltage is the most significant parameter and then the NaCl Concentration, and Feed rate. R^2 is the percentage of total variation in the response which depends on the factors in the model. The higher the value of R^2, the better the model fits the data. The adjusted R^2 accounts for the number of predicators or factors in the model. It is useful for comparing models with different number of predicators or factors. It may decrease when another predicator or factor is added to the model. The sequential sum of squares in the analysis of variance table indicates the relative importance of each factor. The factor with the biggest sum of squares has the greatest impact. Here Voltage and NaCl Concentration are the most important factors.

V. CONCLUSION

In this study it is observed that Voltage is the most significant parameter and then the NaCl Concentration, and Feed rate. The material removal rate increases with the increase in voltage and NaCl Concentration. The mathematical model for MRR fits the data as R^2 is 84.5%.

REFERENCES

[1] D.Chakradhar, A.Venu Gopal, "Multi-Objective Optimization of Electrochemical machining of EN31 steel by Grey Relational Analysis", International Journal of Modeling and Optimization, Vol. 1, No. 2, June 2011.

[2] R.Goswami R. Chouhan V. Chaturvedi, "THE IMPLEMENTATION OF TAGUCHI APPROACH ON ECM PROCESS PARAMETERS FOR MILD STEEL AND ALUMINUM", International Journal of Research in Engineering & Applied Sciences; Volume 3, Issue 2 (February 2013) ISSN: 2249-3905.

[3] C. SENTHILKUMAR, G. GANESAN, R. KARTHIKEYAN, "Parametric optimization of electrochemical machining of Al/15% SiCp composites using NSGA-II", Received 8 November 2010; accepted 12 April 2011.

[4] Suresh H. Surekar, Sudhir G. Bhatwadekar, Wasudev G. Kharche, Dayanand S. Bilgi, "DETERMINATION OF PRINCIPLE COMPONENT AFFETING MATERIAL REMOVAL RATE IN ELECTROCHEMICAL MACHINING PROCESS", International Journal of Engineering Science and Technology (IJEST).

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

[6] Sekar T., Marappan R., "Improving Material Removal Rate of Electrochemical Machining by Using Rotating Tool".

[7] H. S. Beravala, R. S. Barot, A. B. Pandey, G. D. Karhadkar, "Development of Predictive Mathematical model of process parameters in Electro Chemical Machining Process", National Conference on Recent Trends in Engineering & Technology.

[8] R Thanigaivelan and Ramanathan Arunachalam, " optimization of process parameters on machining rate and over cut in electrochemical micromachining using grey relational analysis method", journal of scientific and industrial research; vol 72 Jan.2013

[9] Kanhu Charan Nayak, Rajesh Kumar Tripathy, "Taguchi integrated Least Square Support Vector Machine an alternative to Artificial Neural Network analysis of electrochemical machining process", IOSR Journal of Mechanical and Civil Engineering (IOSRJMCE) ISSN : 2278-1684 Volume 1, Issue 3 (July-Aug 2012), PP 01-10.