Experimental Study of Electrochemical Micro Machining on Titanium (Ti-6Al-4V) Alloy

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Abstract

Electro Chemical Machining is an unconventional machining process where removal of material takes place by the action of electrochemical process. Electro Chemical Machining is used to machine extremely hard material or materials that are difficult to machine using conventional machining process. Titanium grade 5 has very good application in aerospace and medical industry. Performing micro machining operation on titanium is very difficult using conventional process. Therefore, Electro Chemical micro machining is done to perform machining operation with less external force thus avoiding tool wear.An attempt has been made in this project to optimize the parameters like voltage, electrolyte concentration, and frequency to achieve geometric accuracy and better surface finish (R_a). Machined material was scanned using microscopic system to measure Conicity and Overcut of the drilled hole and profilometer was used to measure surface roughness of the machined surface to determine the optimum machining parameter. Taguchi Analysis of Variance was performed to determine each parameter influence over Material removal rate, Circularity and Overcut of drilled hole.From the above experimental work, electrolyte concentration plays a vital role among the electrolyte concentration, voltage and frequency in material removal rate, as acidic nature of the electrolyte affects the machining/material removal rate. Voltage ranks first in affecting Conicity of the drilled hole among the three input parameters. Optimum input parameters were determined by carrying out S/N ratio analysis with respect to MRR and Conicity.

Keywords: Electro Chemical Machining, Surface Finish, Taguchi, Conicity

1 INTRODUCTION

Micromachining is the process of removing material in the form of chips or debris having size in the range of micron. There are various techniques which can be employed for the manufacturing of microproducts. Micro-Electro Mechanical Systems (MEMS) based manufacturing employs techniques such as photolithography, chemical-etching, plating, LIGA and laser fabrication. While non-MEMS-based manufacturing often implements techniques such as mechanical machining, Electro Discharge Machining (EDM), Electrochemical Machining (ECM), laser cutting, laser patterning, laser drilling, embossing, injection molding, forging, extrusion, and stamping [1]. Among the various capable techniques, electrochemical micromachining (EMM) is considered for its advantages such as high Material Removal Rate (MRR), small forces acting on the work piece are required as well as low stresses and better accuracy [2].Electrochemical machining (ECM) is a method of removing metal using electrochemical process. It is normally used for mass production and is used for machining extremely hard materials or materials that are difficult to machine using conventional methods. Its use is limited to electrically conductive materials. ECM can cut small or odd-shaped angles, intricate contours or cavities in hard and exotic metals, such as titanium aluminides, Inconel, Waspaloy, and high nickel, cobalt, and rhenium alloys. ECM is capable of machining both external and internal geometry.ECM is often characterized as "reverse electroplating", where removal of material takes place instead of adding it. ECM is similar in concept to electrical discharge machining (EDM) where current is passed between an electrode and the part, through an electrolytic material removal process having a negatively charged electrode (cathode), a dielectric fluid (electrolyte), and a conductive work piece (anode); however, in ECM there is no tool wear. Material removal rate (MRR) is animportant characteristicto evaluate efficiency of a non-traditional Machining process. In ECM, material removal takes place due to atomic dissolution of work material. Electrochemical dissolution is governed by Faraday's laws.

The first law states that the amount of electrochemical dissolution or deposition is proportional to amount of charge passed through the electrochemical cell, which may be expressed as:

$$m \propto Q, \qquad (1)$$

where m = mass of material dissolved or deposited
Q = amount of charge passed

The second law states that the amount of material deposited or dissolved further depends on Electrochemical Equivalence (ECE) of the material that is again the ratio atomic weigh and valency. Thus

$$m \propto ECE \propto \frac{A}{v} \qquad (2)$$

2 EXPERIMENTAL SETUP

2.1 Process parameter

The main process parameters governing the ECM process are electrolyte, current and voltage settings, frequency,electrode gap and flow velocity.

The electrolyte is one of the main components of the machining system. The electron movement from the cathode to the anode is dependent on the properties of the electrolyte. The preferred electrolyte for our material is given in table 1.

Table 1 Electrolyte and its composition ratio

Alloy	Electrolyte
Ti based	10% HF + 10% HCL + 10%HNO_3

The experimental setup of electrochemical machining is shown in Fig 1. The Specification of the ECM Machine is listed in Table 2.

Table 2 ECM Machine Specifications

Specification	
Pump	Magnetic type
Discharge	16 -18 Lit / min
Motor	Stepper motor
Filter	5 micron cartridge
Acrylic tank size	200 X 100 X 80 mm
Tank Capacity (max)	1.6 litres
Tool movement per revolution of motor	0.8467 mm
Maximum tool movement	75 mm

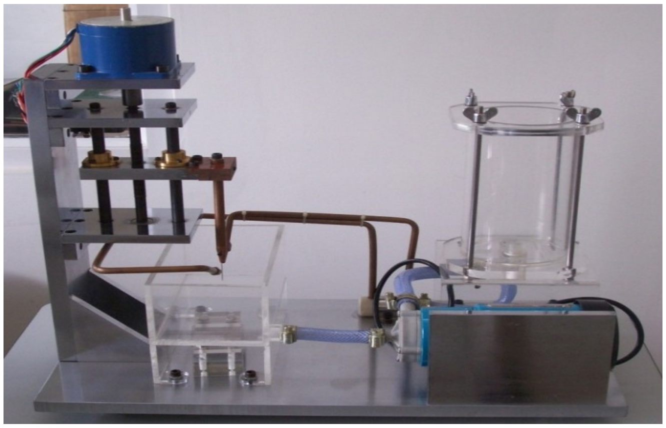

Fig.1. ECMM setup

3 DESIGN OF EXPERIMENTS

Taguchi's L9 orthogonal array was used to carry out in machining, which helps to determine the optimum and best responsive factor in less number of trials.

3.1 Design of Experiment for ECMM

The design of an experiment involves the following steps,

- Selection of independent variables
- Selection of orthogonal array
- Assigning the independent variables to each column
- Conducting the experiments
- Analysing the data
- Inference

3.2 Process Parameter and its Level

Before selecting the orthogonal array, the minimum number of experiments to be conducted shall be fixed based on the total number of degrees of freedom. The minimum number of experiments that must be run to study the factors shall be more than the total degrees of freedom available. In counting the total degrees of freedom, the investigator commits 1 degree of freedom to the overall mean of the response under study. The number of degrees of freedom associated with each factor under study equals one less than the number of levels available for that factor. Hence the total degree of freedom without interaction effect is 1 + as shown in the equation3.

Table 3 Process Parameters and its level

S.No	Level	Process Parameters		
		A (Voltage)	B (Concentration)	C (frequency)
1	1	18	0.050	40
2	2	19	0.075	60
3	3	20	0.100	80

Table 3tabulates the three study parameters and its levels of experiments that are carried out in this project to determine the high response factor and also the optimum value.

3.3 Selection of an Orthogonal Array

Orthogonal arrays are special standard experimental design that requires only a small number of experimental trials to find the main factors effects on output. Before selecting an orthogonal array, the minimum number of experiments to be conducted is to be fixed based on the Taguchi's equation (3)

$$N\ Taguchi = 1 + \sum_{i=1}^{NV}(Li - 1) \qquad (3)$$

N Taguchi = Number of experiments to be conducted
NV = Number of parameters
L = Number of levels
In this work,
NV = 3 and
L = 3
Hence,

$$N\ Taguchi = 1 + 4\ (3-1) = 9 \qquad (4)$$

Hence at least 9 experiments are to be conducted. Based on this orthogonal array (OA) is to be selected which has at least 9 rows i.e.,9 experimental runs.
The following standard orthogonal arrays are commonly used to design experiments:

- 2-Level Arrays: L4, L8, L12, L16, L32
- 3-Level Arrays: L9, L18, L27
- 4-Level Arrays: L16, L32

1.4 Input Parameter

Electro Chemical Micro Machining was carried out, followingL9orthogonal array. By, which 9 experiments where carried as shown in the Table 4.

Voltage and concentration range are varied based on the experiments that are studied over other materials [3]. But, frequency (Hz), duty cycle and pulse on and off time[4,8] are inter related, whose relations are expressed in equation (5 & 6)

$$Frequency\ (Hz) = \frac{1}{Total\ time} \qquad (5)$$

$$Duty\ cycle = T_{on}/(T_{on} + T_{off}) \qquad (6)$$

Other major and influencing input parameter that is varied in this experiment was Electrolyte concentration.

Table 4 Input parameters for machining

S.No	Voltage	Concentration (Molar)	Frequency (Hz)	Duty cycle	Pulse		Current (Amps)
					ON	OFF	
1	18	0.05	40	50	12.5	12.5	4
2	19	0.05	60	60	10	6.67	4
3	20	0.05	80	70	8.75	3.75	4
4	18	0.1	60	70	11.66	4.99	4
5	19	0.1	80	50	6.25	6.25	4
6	20	0.1	40	60	15	10	4
7	18	0.075	80	60	7.5	5	4
8	19	0.075	40	70	17.5	7.5	4
9	20	0.075	60	50	8.33	8.33	4

2. RESULTS AND DISCUSSIONS

4.1 Inference from the Experiment

Electrochemical chemical micro machining was performed and base material was observed under micro scope to measure diameter to determine the Conicity and overcuts. Difference in weight of the base material was measure to calculate the MRR and analysis was carried out using Taguchi to determine the influencing parameter.

4.2 Material Removal Rate

MRR is defined as the rate at which material is removed from the work piece during machining.

Material removal rate is calculated based on the equation (7)

$$MRR = \frac{Intial\ weight - final\ weight}{time}\ (gm/sec) \qquad (7)$$

Above equation (7) was substituted in the 9 experiments to get material removal rate as shown in the Table5.

Table 5MRR values

Exp. No	Time (sec)	Initial weight (I)	Final Weight (F)	(I)–(F) wt	MRR(gm/sec)
1	1224	3.7311	3.5942	0.137	0.000112
2	1083.6	3.4633	3.3108	0.153	0.000141
3	965.4	3.4867	3.4427	0.044	4.56E-05
4	241.2	3.5215	3.4783	0.043	0.000179
5	456.6	3.5789	3.5036	0.075	0.000165
6	223.2	3.5680	3.5300	0.038	0.00017
7	578.4	2.9341	2.9024	0.032	5.49E-05
8	514.8	3.2036	3.1758	0.028	5.41E-05
9	631.8	3.2907	3.2690	0.022	3.45E-05

Time denotes the time taken to machine or drill single work piece. From overall observation of Table 5 is clear that MRR moves in increasing trend when concentration is increased [5].

4.3 Conicity

Conicity is defined as the degree of straightness of the through hole that was machined. Conicity is preferred to be zero for effective and straight through hole [6,7]. Conicity is explained as shown in Fig2.

4.4 Overcut

Overcut is defined as the difference between the size of the electrode and the size of the cavity created during machining. Overcut is preferred to zero for any process for accurate hole size. Overcut is calculated by measuring the tool radius (µm) and hole radius (µm) and using the below equation (8)

$$Overcut = tool\ radius \sim Hole\ radius \qquad (8)$$

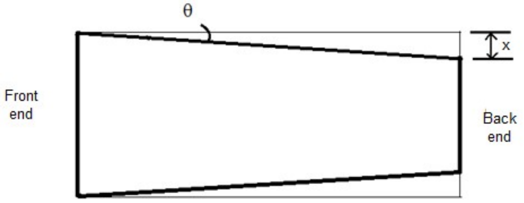

Fig.2.Angle (θ) of Conicity

The base material was observed under microscope, to measure Conicity. The ECMM was done at 0.05, 0.075, 0.01 molar concentrations and the microscopic images of the base material was shown below in Fig. 3, 4 and 5. The distance between the front end and back end is the thickness of the material which is of 500 µm. The calculated values of conicity for the material are listed in table 6.

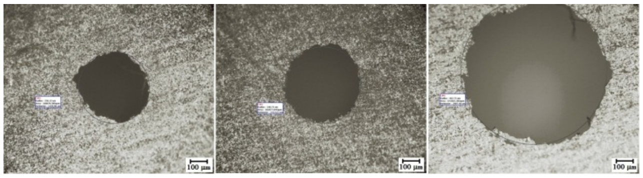

Fig.3 Microscopic image (0.05 molar concentration)

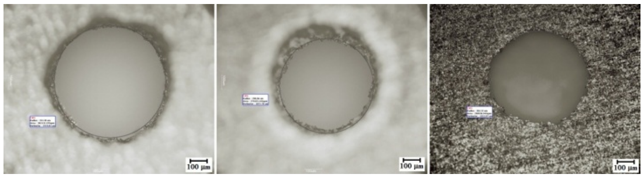

Fig. 4 Microscopic image (0.075 molar concentration)

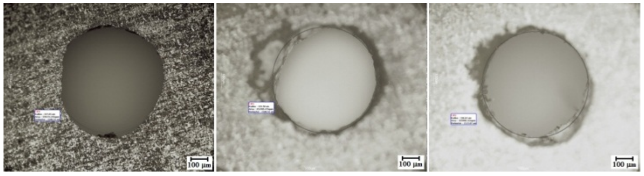

Fig.5 Microscopic image (0.1 molar concentration)

4.5 Optimum input for MRR

Where n is the number of measurements in a trial/row, in this case, n=1 and y is the measured value in a run/row. The S/N ratio values are calculated by considering equation9.

$$S/N = -10\log_{10}\left(\frac{1}{n}\Sigma\left(\frac{1}{y*y}\right)\right) \quad (9)$$

The S/N ratio for smaller the better is used for Conicity

$$S/N = -10\log_{10}\left(\left(\frac{1}{n}\right) * \Sigma(y * y)\right) \quad (10)$$

The MRR values measured from the experiments and their corresponding S/N ratio values are listed in table7.

The plot for S/N curve is plotted between mean of S/N ratio and data means of voltage, concentration and frequency is shown in figure

Table 6 Conicity values

Exp. No	Front diameter (µm)	Backside diameter (µm)	opposite side (differnce in dia /2)	Conicity
1	453.20	460.64	-3.72	-0.019
2	481.30	479.40	0.95	0.0048
3	925.46	898.36	13.55	0.0676465
4	706.40	696.18	5.11	0.0255444
5	596.12	583.62	6.25	0.0312398
6	608.64	623.22	-7.29	-0.0364339
7	694.10	698.26	-2.08	-0.0103996
8	671.16	652.40	9.38	0.0468656
9	673.24	658.66	7.29	0.0364339

Table 7S/N Ratio for MRR

S.No	Voltage (volts)	Concentration (Molar)	Frequency (Hz)	MRR (gm/sec)	S/N ratio
1	18	0.05	40	0.000112	-79.02
2	19	0.05	60	0.000141	-77.03
3	20	0.05	80	4.56E-05	-86.83
4	18	0.1	60	0.000179	-74.93
5	19	0.1	80	0.000165	-75.66
6	20	0.1	40	0.00017	-75.40
7	18	0.075	80	5.49E-05	-85.20
8	19	0.075	40	5.41E-05	-85.34
9	20	0.075	60	3.45E-05	-89.25

5 CONCLUSION

The micro hole was produced using various parameters, from the results it is found that

1. The concentration of the electrolyte was influence by about 87% for the MRR. The remaining 13% of MRR is influenced by the parameters like voltage, frequency and current.
2. The conicity factor was influenced voltage and frequency about 40%.
3. Similarly, for overcut the concentration plays a major role and contributing about 78%. By which it is suggested that concentration selection is most important in electro chemical machining of titanium grade-5.
4. S/N ratio manipulation was carried and the optimum input parameters with respect to output performance characteristic was suggested.
5. This process of developing a model was simulated using a developer software tool for L9 orthogonal array with 3-level inputs.

Electrolyte concentration is the most influencing parameter among the study parameters, while Voltage and Frequency contribute almost equal impact on the quality of the hole. Also that ECMM is well suited method to machine titanium in micro level with desired accuracy on output characteristics.

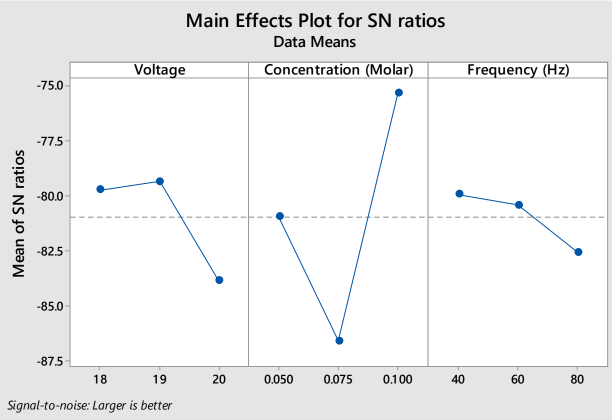

Fig. 6Graph plotted between S/N ratios (MRR) against each input parameter)

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