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# Effect of Process Variables on Electrochemical Micromachining of Titanium Alloy (Ti-3Al-2.5V)

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**Abstract.** Electro-chemical Machining (ECM) is mainly used for shaping, deburring, milling and finishing operations in various precision industries and its use in micron level machining is called Electro-Chemical Micro Machining (EMM). EMM and ECM are receiving considerable attention from high-tech industries. It is because it allows to manufacture structures of complex shapes, it has high precision and accuracy, it is simpler and eco-friendly manufacturing technique and it can be used for different conducting materials. Different industry working with water which is saline, needs heat exchanger for the process. Titanium Alloy (Ti-3Al-2.5V) due to its high corrosion resistance under saline conditions is preferred by these industries. This present work is mainly concentrated on identifying the Material Removal rate (MRR) of Titanium Alloy (Ti-3Al-2.5V) workpiece by varying the process parameters like voltage, electrolyte concentration and duty cycle on electro-chemical micro machining.

## 1. Introduction

Conventional Manufacturing methods are unable to create complex shapes, produce micro holes and micro slots,[1] has tool wear, and provide limited accuracy and precision.[2] These difficulties can be overwhelmed by using unconventional Manufacturing methods like Electron Beam Machining (EBM), Laser Beam Machining (LBM), Electro-Discharge Machining (EDM) and electro-chemical machining (ECM)[2]. Various of the non-conventional manufacturing techniques has heat effected zone on work piece but ECM doesn't have it. So, ECM shows great step for improvement in manufacturing techniques.

Electro-Chemical Machining (ECM), is one of the mainly used type of unconventional machining process which works under the principle of metal removing by anodic dissolution where the tool acts as cathode and workpiece acts as anode. In order to complete the circuit electrolyte is pumped in the middle of the tool and workpiece. The nature of tool is generally the inverted replica of the shape to be machined on the workpiece. [3] Electrochemical machining is developed based on Faraday's laws of electrolysis and Ohm's law. [4] As stated by Faraday's law of electrolysis, when two electrodes are

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dipped in an electrolytic solution and when a DC power supply is applied across the two electrodes, the MRR were occurs on anode and the removed material are deposited on cathode. ECM process is just the reverse of electroplating technique. In ECM process, anodic dissolution occurs at atomic level of the workpiece by an electrode when the electrolyte conducting the DC current at comparatively low potential variation and the electrolyte is water based neutral salt solution. Due to the high surface finish and stress-free products obtained by Electro Chemical Machining technique, it is used widely for fabrication of turbine blades, parts for electronics, high compression engines, artillery projectiles, and medical industries [5].

Due to specified properties of titanium alloy, it has the wide applications such as fuel injector of diesel engine, aerospace and marine industries [6-7]. In this ,very important to identifying the perfect input process parameter to produce the complex machined surface without heat affected zone, tool wear, stress and burr-free process [8]. Then the quality of the machined surface is based the input process parameters such as applied voltage, electrolyte concentration, micro tool feed rate and duty cycle. Then the machining performance are calculated by the output process parameters such as material removal (MRR) and overcut (OC).

Commonly the electrolytes which used for machining of workpiece are classified into passive and non-passive electrolytes (i.e.) sodium chloride and sodium nitrate. Then the concentration of the electrolyte plays the important role in the machining [10-11].

In the Electrochemical micromachining, the amount of material removal rate is mainly based on the current density which was occurred by the potential difference between the workpiece and tool. Then the potential difference is mainly determined by the electrical conductivity of tool electrode [12].

A lot of researches are done for ECM process based on its process parameters, Electrolyte, Tool shape and materials, and workpiece. Researches on coated tool and cryogenic tool are also done for tool electrode. This study is about machinability of Titanium Alloy (Ti-3Al-2.5) as workpiece of EMM process, which are yet to be studied.

## **2. Experimental setup**

The setup of Electro-chemical micro machining was clearly shown in fig.1, which mainly consists of material removing unit, feeding system of electrode, electrolyte tank and DC power supply system. The electrolyte bath is connected to a pump and a filter. The mechanical machining unit consists of work holding device, micro-tool feeding system, machining chamber and main machining body. The micro-tool feed movement is achieved through the ball screw mechanism. The electrode feeding was controlled by manually through the stepper motor. The voltage and current at 0-30V and 0-2A respectively are used as DC power supply. The investigational elements were chosen based on the effect of process parameters affecting the machining rate and shape accuracy in general. The minimum number of experiments are formed in orthogonal array method to study the effect of process parameters on experiments by Taguchi approach which is important tool to analysis and designing the experiments. This helps in reducing the cost and production time. The optimum input process parameters are obtained by examining the characteristic data attained by experiment using Minitab package software.



**Figure 1.** Experimental setup.

### 3. Experiments and Methods

In this work, the influence of process parameters has been deliberated when the material removing process on Titanium Alloy (Ti-3Al-2.5) material by EMM process. MRR have been selected as performance measures. L4 orthogonal array of Taguchi Method was selected based on number of controllable input process parameters. The input process parameters are Voltage, Concentration of electrolyte and duty cycle with Stainless Steel 316L tool as electrode. Titanium Alloy (Ti-3Al-2.5) has been decided as the work piece material of size of 40mm x 20mm x 1.7mm, the composition of the work piece is presented in Table 1. The electrolyte used for investigation was 1mol/L of Sodium Nitrate and 1mol/L of Sodium Nitrate with 0.02mol/L of Sodium Citrate. Voltage range i.e. 15V and 17V have been selected for experiments. Duty cycle has been fixed as 50 and 66%. Frequency for experiment was 50 Hz. Manual Micro-tool feed rate of 0.4 $\mu$ m/min have been chosen for this experiment. MRR have been calculated based on the weight difference between before machining and after machining workpiece.

**Table 1.** Chemical Composition of Titanium Alloy (Ti-3Al-2.5V).

Elements	Composition (%)
<b>Iron (Fe)</b>	0.23
<b>Aluminium (Al)</b>	3.01
<b>Vanadium (V)</b>	2.19
<b>Titanium (Ti)</b>	94.65

The digital oscilloscope was used for measured the various process parameters during machining the material and the voltage pulse pattern have been find the micro sparks of various set of experiment. The effect of several input process parameters on MRR.

### 4. Results and Discussions

The effects of electro-chemical micro machining variables, namely, Voltage, Concentration of electrolyte, and duty cycle on MRR of Titanium Alloy (Ti-3Al-2.5V) with additive manufacture stainless steel 316L tool using Sodium Nitrate electrolyte with Sodium Citrate as complexing agent for electrolyte and investigate the various process parameters on MRR and the results are listed below.

#### 4.1. Effect of process parameters on MRR

The MRR has been obtained by ratio between the difference between before machining weight and after machining weight to the machining time.

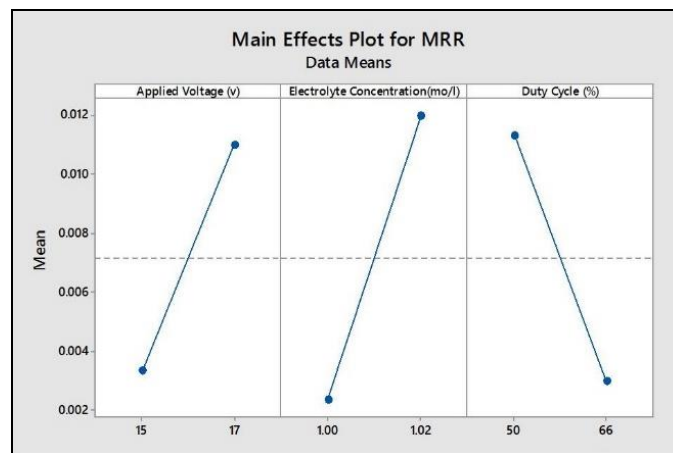
$$\text{MRR} = (W_{\text{before}} - W_{\text{after}}) / T \quad (1)$$

$W_{\text{before}}$  = before machining weight (g)

$W_{\text{after}}$  = after machining weight (g)

$T$  = time of Machining (hours)

MRR is directly proportional to the electrolyte concentration. The experimental analysis of highest amount of material removal rate is achieved at 1mol/L electrolyte concentration with 0.02mol/L complexing agent. The duty cycle was another important factor for machining the work piece at higher MRR. From the investigational results, the effect nature of the process parameters could be computed by Mini-tab software package.



**Figure 2.** Contribution of process parameter on MRR.

Figure 2 shows the involvement of input process parameters on MRR. Since the deviation from the mean level line indicates momentous contribution on EMM variables, it is clear that Electrolyte with Complexing agent has the more dominant effect than the other process parameter such as applied voltage, Duty cycle. The more significant effect was electrolyte concentration with 1mol/L Sodium Nitrate and complexing agent 0.02mol/L of Sodium Citrate. Finally, to find the optimal combination of EMM parameters for effective machinability on titanium alloy (Ti-3Al-2.5).

## 5. Conclusion

The machining performance of electro-chemical micro machining process parameters on machinability of Titanium Alloy (Ti-3Al-2.5V) with Stainless Steel 316L tool electrode has been evaluated. From the results of the study, the following conclusions have been drawn:

- The duty cycle and electrolyte concentration significantly affect the machining characteristics in the EMM process.
- The high electrolyte concentration with Complexing agent, low duty cycle and high applied voltage have produced moderate MRR.
- The main effect plots and micrograph are generated to study the effect of various process parameters on machining Alloy (Ti-3Al-2.5V) with moderate MRR. i.e. increase the localization effect and decrease the stray current effect to avoid micro-sparks and get better accurate products.

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