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Analysis of the Effect of Electrochemical Micromachining Process Parameters on Alpha-Beta Titanium

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Abstract
Electro-chemical machining is used in aerospace, automobile and other heavy industries for shaping, milling, deburring and finishing operations. Electro-chemical micro machining (EMM) is used in the micro fabrication and the processing of thin films. A variety of metals and alloys including conducting ceramics and highly corrosion-resistant alloys can be fabricated by EMM. EMM is now receiving importance particularly due to an alternate, "greener" method for processing metallic parts. The accumulation of reaction products in solution and depletion of bath components are of slight concern in EMM, it is an environment friendly manufacturing process. EMM is based on controlled anodic electro-chemical dissolution process of the required piece with the tool act as the cathode in an electrolytic cell. The performance of modern jet engine components such as turbine rotor and stator assemblies depends on a very large number of small holes. The high temperature components are difficult-to-manufacture, such as super alloys Alpha-Beta Titanium. The present work is aimed to investigate the influence of the different electro- chemical micro machining process factors such as applied voltage, micro-tool feed rate, electrolyte concentration and duty cycle on the metal removal rate (MRR) and shape accuracy to fulfil the effective utilization of electro-chemical micromachining of Alpha-Beta Titanium. The main effect plots and micro-graph have been generated to study the effect of process parameters in electrochemical micromachining process.

Keywords: Electro-chemical micro-machining, Alpha-Beta Titanium, material removal rate (MRR), shape accuracy

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INTRODUCTION

Conventional machining techniques are used to produce micro-slots, complex surfaces, micro-holes in large numbers and sometimes in a single work-piece, especially in electronic industries. The problems generally faced in conventional machining techniques are overcome by non-traditional machining processes. Non-conventional machining processes such as abrasive jet machining, ultrasonic machining, water jet and abrasive water jet machining, etc., are stress-oriented, which may cause stress acting on the machined surface. Chemical machining and electro-chemical machining are stress-free processes but chemical machining cannot be controlled properly in this micro machining domain. Electro-chemical micro machining (EMM) appears to be a very promising micro machining technology due to its advantages that include high material removal rate (MRR), better precision and control, rapid machining time and it being environmentally acceptable. It also permits the machining of chemically resistant materials like titanium, copper alloys, super alloys and stainless steel, which are widely used in bio-medical, electronic and aerospace applications. EMM is a process of removing material similar to electroplating. The work piece is dissolved according to Faraday's laws of electrolysis. In this process, the work piece to be machined is made as anode and the tool is made as cathode of an electrolytic cell with a salt solution being used as an electrolyte. On the application of a potential difference between the two electrodes with the availability of adequate electrical energy between the tool and the work piece, the positive metal ions leave the work piece. [1] Research on EMM is pursued by research groups worldwide. In the starting days researchers discussed the principal issues in ECM and summarized that extensive research work is required in the area of tool design, monitoring and control of IEG, electrolyte processing and disposal, process accuracy and power supply. [2]

Later researchers conducted experiments with the developed setup by varying the machining voltage, electrolyte concentration, pulse-on time, and frequency on work piece[3]. In the study, it has been reported that a considerable amount of MRR at a moderate accuracy can be achieved with a machining voltage of 6–10 V, pulse-on time of 10–15 ms and electrolyte concentration of 15–20 g/l. The EMM process is complex and it is not easy to decide the optimal machining parameters for improving the output quality. The optimization of process parameters is essential for the realization of a higher productivity, which is the preliminary basis for survival in today's dynamic market conditions. Since a few researches have been made to optimize the electro-chemical micro machining process parameters on higher MRR and better shape accuracy (further studies are required). Considering these requirements, the EMM setup was developed and the effect of various process parameters such as electrolyte concentration, applied voltage, micro-tool feed rate, duty cycle on MRR and shape accuracy were studied. Hence, this research aims to study and optimize the process parameters for machining of Alpha-Beta Titanium using sodium chloride (NaCl) electrolyte.

EXPERIMENTAL SETUP

The EMM setup is shown in Figure 1. The setup mainly consists of various components, such as machining unit, tool electrode feeding system, electrolyte supply system, and pulsed power supply system. The electrolyte supply and cleaning system consist of 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 ball screw of the tool movement is rotated with the help of stepper motor. Movement of the stepper motor controlled with the help of microprocessor based on the MCX314AS processor. A pulsed power supply of 0–30 V and 0–3 A with the capability for varying voltage, current, and pulse width was used. The electrolyte is passed through polypropylene polyester nylon micron filter for removal of sludge material during machining process and supply the electrolyte between the interface of work piece and tool using submersible pump. The experimental factors were selected based on the influence of process parameters affecting the machining rate and shape accuracy in general. Taguchi method, which is a powerful tool to design and analyze the experiments, is chosen for this work. It uses a special design of orthogonal array to study the entire parameter space with only a small number of experiments for reducing the cost and production time. The optimal process parameters are determined by analyzing the characteristic data acquired using Minitab package software.

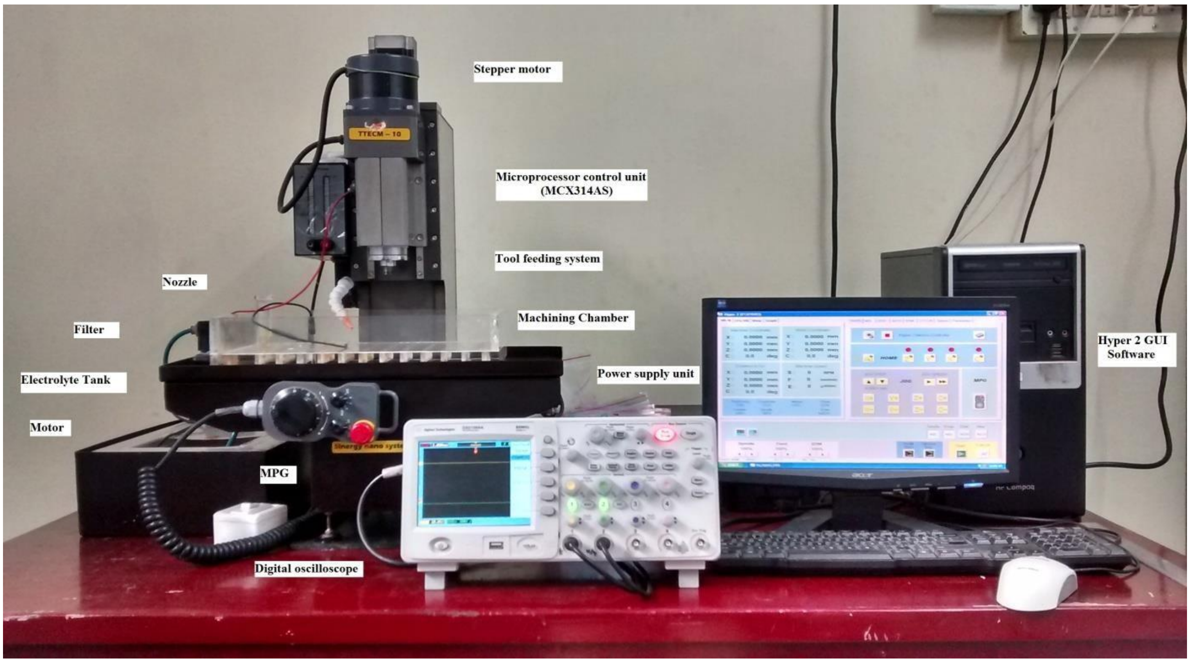


Fig. 1: *EMM Setup.*

Table 1: *Chemical Composition of Alpha-Beta Titanium.*

Element	**Ti**	**Al**	**V**	**C**	**Fe**	**O**	**N**	**H**
(%) composition	89.707	6	4	2.98	4.96	0.09	0.09	0.008

EXPERIMENTS AND METHODS

In this research work, an endeavor has been made to know the influence of various process parameters on the machining characteristics. MRR and shape accuracy have been taken as the performance measures. Applied voltage, electrolyte concentration, micro-tool feed rate, duty cycle have been chosen as process parameters with φ 500 μm copper tool electrode material. Alpha-Beta Titanium has been decided as the work piece material of size of 20 mm x 50 mm x 0.4 mm, the composition of the work piece is presented in Table 1. The electrolyte used for experimentation was fresh aggressive anions such as sodium chloride (NaCl) having concentrations of 20, 30, 40 g/l. Voltage range i.e. 16 V, 18 V and 20 V have been selected for experiments. Micro-tool feed rate of 0.1, 0.5 and 1 μm/s have been chosen for this experiments and duty cycle has been fixed as 33, 50 and 66%. MRR have been calculated by finding weight variation of material before and after machining of work piece, per machining time. Shape accuracy have been measured with the help of optical microscope (Leica DMRM). The digital oscilloscope was used for measuring the various process parameters during machining the material and the voltage pulse pattern have been found in the micro-sparks of various set of experiments. The influence of various process parameters on MRR and shape accuracy for machining micro holes was observed through optical microscope.

RESULTS AND DISCUSSION

The effects of electro-chemical micro machining variables, namely, applied voltage, electrolyte concentration, micro-tool feed rate and duty cycle on MRR and shape accuracy of Alpha-Beta Titanium with copper tool using sodium chloride (NaCl) electrolyte and investigate the various process parameters on MRR and shape accuracy and the results are listed below.

Effect of Process Parameters on MRR

The MRR has been obtained from the weight difference of electrode before and after machining of work piece per machining time.

$$\mathbf{MRR=(W_b-W_a)/T} \qquad \text{Eq. (1)}$$

W_b=Weight of the piece before machining in g,
W_a=Weight of the piece after machining in g,
T=Machining time in min.

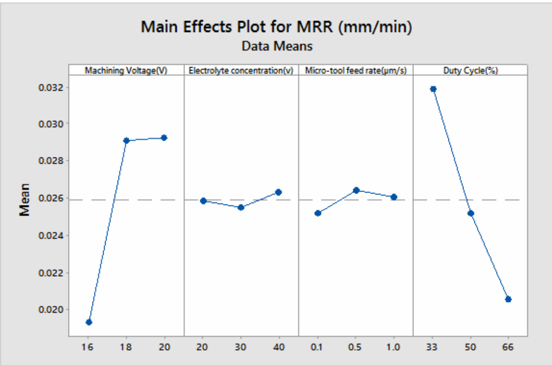
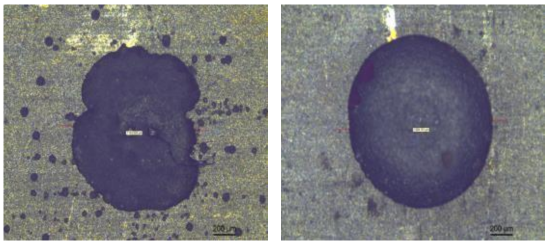


Fig. 2: *Contribution of Process Parameters on MRR.*

MRR is directly proportional to the electrolyte concentration during machining process. The experimental analysis of highest amount of material removal rate is achieved at 40 g/l electrolyte concentration but the intermediate concentration of 20 to 30 g/l the MRR was reduced. The duty cycle was another important factor for machining the work piece at higher MRR. From the experimental results, the influence nature of the process parameters could be computed by Minitab software package. Figure 2 shows the contribution of process parameters on MRR. Since the deviation from the mean level line indicates momentous contribution on EMM variables, it is clear that duty cycle has the more dominant effect than the other process parameters such as applied voltage, electrolyte concentration, micro-tool feed rate [6,7]. The more significant effect was duty cycle in the range of 33% (T_{on} = 6.66 ms, T_{off} = 13.33 ms). Finally, to find the optimal combination of EMM parameters for effective micro machining.

Effect of Process Parameters on Shape Accuracy



(a) *Irregular Shape Micro Hole.* ***(b)*** *Accurate Shape Micro Hole.*

Fig. 3: *Microscopic Analysis of Machined Surface.*

Figure 3(a) shows the influence of higher micro-tool feed rate to produce irregular micro hole shape due to MRR is less than feed rate so therefore the tool touches the work piece, micro-sparks are produced during machining and the duty cycle was another influence factor. The micro-sparks are avoided to improve the shape accuracy of the surface and increase the localization effect. The microscopic image of micro hole machined by EMM at particular machining conditions i.e. applied voltage of 20 V, electrolyte concentration of 40 g/l, micro-tool feed rate of 0.5 µm/s, duty cycle of 33% is shown in Figure 3(b). In this machining condition the accurate micro holes were produced due to high electrolyte concentration and more reaction product produced intermediate of tool and work piece. The micro-tool feed rate is also low, i.e. 0.5 µm/s which results in reaction products flushed away by electrolyte flow and the accurate circular shape was produced. Due to higher electrolyte concentration and low micro-tool feed rate to produce moderate MRR and shape accuracy of micro hole. The most optimal value of various process parameters on material removal rate and shape accuracy are found.

CONCLUSION

The machining performance of electro-chemical micro machining process parameters on machining Alpha-Beta Titanium with copper tool electrode has been evaluated. From the results of the study, the following conclusions have been drawn:

1. The duty cycle and electrolyte concentration significantly affect the machining characteristics in the EMM process.
2. The high electrolyte concentration , low duty cycle, moderate micro-tool feed rate and high applied voltage have produced moderate MRR and better shape accuracy.
3. The main effect plots and micrograph are generated to study the effect of various process parameters on machining Alpha-Beta Titanium with moderate MRR and shape accuracy. 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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