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IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

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To cite this article: T Geethapiriyan *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **912** 032039

IOP Conf. Series: Materials Science and Engineering **912** (2020) 032039 doi:10.1088/1757-899X/912/3/032039

Performance Characteristics of Electrochemical Micromachining on Pure Titanium using coated tool electrode

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Abstract. Owing to its hardenable nature and corrosive resistant, Titanium is mainly utilized in fabricating turbine blade applications. Since it is very tough to creating the complex shape on this material by using traditional machining process. Generally micro holes are produced over the turbine blades to reduce the heat using EDM and LBM process. These processes can produce a heat affected zone over the machining surface and higher operating cost. The target of this present study was to make a micro hole on titanium by using electro chemical micro machining process and also attempt to identify the performance of nickel coated copper electrode for embellishing the ECM process. Since the process involves with no tool wear and less heat affect zone, it is possible to improve the machinability of the material. Titanium specimens have been machined using ECM process with uncoated copper electrode and nickel coated electrode under different process parameters combinations. From the experimental results, the better MRR and surface finish were observed from the nickel coated copper electrode.

1. Introduction

Micro-machining technology has important place in producing the miniature size product in the biomedical to sensor and chemical micro-reactors applications. Electrochemical micro machining is seeming to be very trusted material removing technology due to its unique applications they are no heat affected zone, burr free, no tool wear, no mechanical force and better surface finish on specimen surface. Electrochemical machining (ECM) is classified below unconventional machining method, in this material removing done by anodic dissolution during electrolysis method. The rate of anodic dissolutions is depending on electrochemical properties of workpiece, properties of electrolyte and amount of current/voltage supplied, which is based on the faraday's law of electrolysis. The machining that generates by ECM process on the specimen is approximately mirror image of electrode[1].While machining through conical rounded tip, the better accuracy and material removal rate were achieved, for stainless steel 304 applied voltage at 9V, concentration of electrolyte at 0.35mole/l and pulse-ON time at 15ms[2].

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In micro drilling, operating conditions such as high electrolyte concentration, low voltage applied and low duty ratio should be maintained to reduce the formation of residue hydrogen bubbles which affects the machining precision. Overcut and conicity reduces with decreasing the value of applied voltage, pulsed duration and electrolyte concentration and also increasing the value of pulse frequency and tool feeding rate[3].To improve the surface quality during pulse electrochemical micro machining ,set low pulse-ON time when compare to pulse-OFF time and also frequent restoration of electrolyte during pulse-ON time, the degree of dissolution is improved by the usage of sodium nitrate as electrolyte and thereby reducing the minimum machining depth [4].

Since a very few researches have been made to improve the electro-chemical micro machining by changing the process parameters to improves the accuracy and MRR. In this present work, the influence of process parameters to improve the MRR and machining accuracy when using uncoated and coated electrode and also sodium nitrate ($NaNO_3$) electrolyte. Hence this research aims to commercialize the technology by variable process parameters and to study the performance of Nickel coated electrode on pure Titanium.

2. Objective

- To utilize Electrochemical micromachining process in the machinability of pure-titanium on machining characteristics using uncoated and nickel-coated electrode.
- To examine the performance of nickel coated tool under input process parameters such as voltage, concentration of electrolyte, tool feed rate and duty cycle to achieve the better metal removal rate (MRR) and surface roughness (Ra).
- To fulfil the effective utilization of electrochemical micromachining of Pure Titanium and find the most significance effect of nickel-coated copper tool electrode on machinability.

3. Experimental Details

3.1. Selection of workpiece, Tool and Electrolyte

In this present study, the α-titanium material has been selected as workpiece due to its specific mechanical properties and it can withstand at any harsh environments. The following table 1 shows the chemical composition of α-Titanium. The copper has been selected as the electrode due to its properties such as high conductivity and better stiffness and corrosive resistance. The sodium chloride (NaCl) is a non-passive electrolyte, it can produce high MRR with better accuracy. So, it has been selected as electrolyte.

3.2. Selection of Coating Material

In this work, the properties of copper electrode have enhanced by metal coating. For that nickel material has been selected as the coating material due to its specific properties such as less oxidation in room temperature and high conductivity rate.

3.2.1. *Selection of Micro-Tool Coating Method.* The thin coating can be used in many applications such as medical, aerospace and automobile to meet the miniaturization size. Therefore, the thin coating can be generated by chemical or physical vapour deposition but this process have higher production cost, less adherence bonding and non-uniformity coating process. The pulse electrodeposition or pulse electroplating has been fixed for micro-tool coating method because it has better coating characteristics such as better adhesion bonding, uniformity coating and low cost.

3.2.2. *Coating on Copper.* The tool sizes ranging from 10 to 500 μm termed as micro tools and to coating the micro tool involves major issues to handing the miniature size. To selection the nickel as a coated material for particular properties such as adhesion bonding, electrochemical stability, coating uniformity and coating strength. In this present work, nickel material is coated over copper tool electrode during this deposition process first the copper tool electrode was washed with deionized water followed by clean in an acetone and dipping in an acetic acid solution for 1 min and finally to coat the copper tool electrode by electroplating process [5].

3.3. Selection of Process Parameters

In this study, the factors like voltage, concentration of electrolyte, tool feed rate and duty cycle has been selected as process parameters with uncoated and nickel- coated copper tool electrode for machinability of pure titanium material. Therefore the voltage has been chosen as 16V, 18V, 20V with different concentration of electrolyte such as 20g/l, 30g/l and 40g/l. tool feed rate has been fixed as 0.1, 0.5 and 1µm/s. Finally, the duty cycle have been chosen as 33.3, 50 and 66.6% [6].

3.4. Performance Measures

3.4.1. *Material Removal Rate.* One of the responses of electrochemical micromachining is material removal rate. In case of electrochemical micromachining, even though the major importance is given to machining accuracy like surface roughness and the material removal monitoring is also vital in order to check the occurrence of localization effect on the machining process.

Material removal rate is determined using the following formula,

$$MPP = (\Sigma_B - \Sigma_A) / T \qquad (1)$$

Where,

Σ_B - before machining weight (g)
Σ_A - after machining weight (g)
T - Machining time (s)

In case of electrochemical micromachining, the material removal will take place in the order of few micrograms per minute.

3.4.2. *Surface Roughness.* Surface roughness responses come into picture, whenever a blind hole is required for applications. Hence this study also monitors the surface roughness of the hole on the specimen for a depth of 200 µm. The surface roughness measurements are taken by means of Non-contact surface roughness detector, which summarizes the surface roughness value by taking the average of the values taken at five spots.

The surface roughness detector machine also shows the 3D profile of the machined hole, where the areas of sludge settlings are easily detected and also the stray removal of material is easily identified [7].

Table 1. Chemical composition of Pure Titanium.

Elements	C	Fe	H	N	O	Ti
%Composition	0.1	0.23	0.014	0.03	0.24	99.39

Table 2. Orthogonal array with Response.

EXP NO.	Process Parameters				Response Parameters for Uncoated Tool Electrode		Response Parameters for Nickel-Coated Tool Electrode	
	voltage	*Concentration of Electrolyte*	*Micro-tool feed rate*	*Duty cycle*	*MRR (mm^3/mm)*	*R_a (μm)*	*MRR (mm^3/mm)*	*R_a (μm)*
1	16	20	0.1	33.3	0.1105	0.379	0.1245	0.127
2	16	30	0.5	50.0	0.0600	0.608	0.0675	0.562
3	16	40	1.0	66.7	0.0492	1.580	0.0512	0.864
4	18	20	0.5	66.7	0.0253	1.640	0.0265	0.900
5	18	30	1.0	33.3	0.1308	2.050	0.1395	1.350
6	18	40	0.1	50.0	0.0536	1.180	0.0756	0.784
7	20	20	1.0	50.0	0.0804	3.580	0.0912	1.890
8	20	30	0.1	66.7	0.0579	3.660	0.0595	2.820
9	20	40	0.5	33.3	0.1178	3.720	0.1456	3.300

4. Experimental and Methods

4.1. Equipment Setup

The Experimental setup of Electrochemical micro machining (ECMM) shows in figure 1,which contains DC power supply, Electrolyte filters and pump, Tool holder, electrolyte tank, etc.

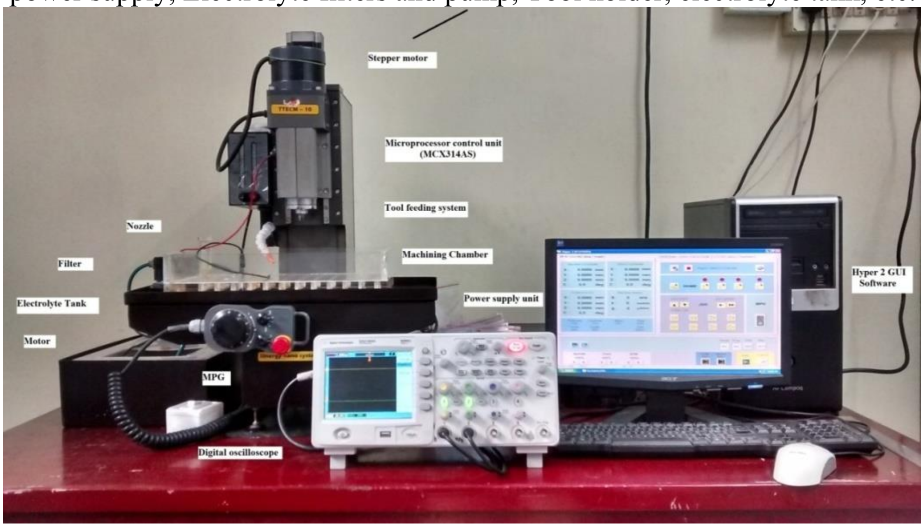

Figure 1. Experimental Setup of ECMM.

4.2. Design of Experiment

In this study orthogonal array L9 was used to machining the workpiece.The array was constructed by four input parameters and three number of levels.Then selected parameters are voltage, concentration of electrolyte, tool feed rate and duty cycle. Then values ranges are shown in their levels,that vvalues are selected by conducting some trail experiments on α-Titanium workpiece and also assuming based on the previous work.

Therefore, the experiments are conducted in the order and response as shown in the following table 2 which is basically designed by means of L9 orthogonal array [8].

5. Results and Discussion

The performance of input machining parameters in ECMM, that are discussed through the values of MRR and surface roughness of machined part by using sodium chloride (NaCl) electrolyte and uncoated and nickel coated electrode. The investigating the various input process parameters on MRR and machining exactness and the results are listed below.

5.1. Influence of Ni-coated tool electrode on MRR

In this process, the MRR happens on workpiece is because of the potential difference between workpiece and electrode and MRR is directly proportional to the current density. The properties of electrode determining the potential difference. From figure 2, the nickel coated electrode produces 5.3% higher MRR than bare tool due to its properties such as corrosion resistance and conductivity are increased by nickel coating [9]

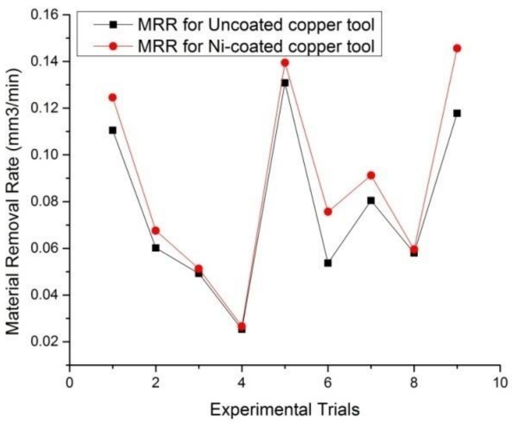

Figure 2. Performance of Ni-coated and bare electrode on MRR.

5.2. Influence of Process parameters on MRR

The Duty cycle has been the most important factor in measure of MRR. When increasing the tool feed rate, MRR also slightly increases. MRR gradually decreases and then increases with respect to the Duty cycle. If electrolyte concentration increases, the material removal rate increases significantly and the voltage increases the MRR normally increased. The effect of process parameters on MRR as shown in Figure 3 explains that the higher voltage, higher tool feed rate, higher concentration of electrolyte and high pulse off time gives higher MRR [10].

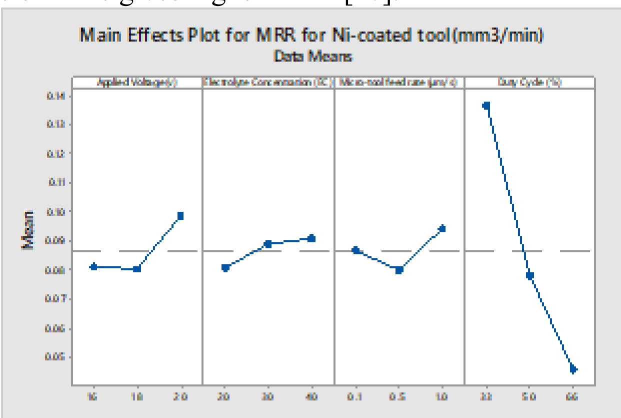

Figure 3. Effect of Process Parameters on MRR.

5.3. Influence of Ni-coated tool electrode on Ra

The surface roughness is inversely proportional to the size of crater on the specimen surface. From figure 4, while comparing the values of surface roughness generated by two types of electrode, the nickel-coated electrode produces 17% lower surface roughness than bare tool. Because bare tool generates larger craters.

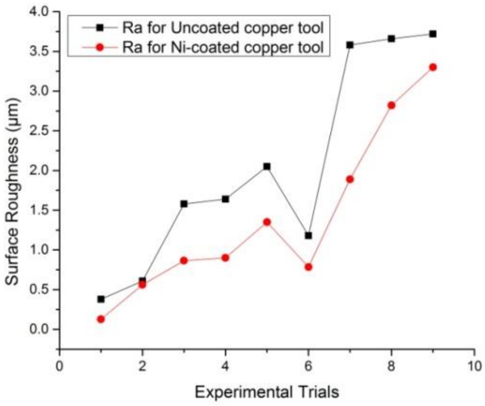

Figure 4. Effect of Ni-coated tool electrode on Ra.

5.4. Influence of Process parameters on Ra

The graphical representation shows that increase in voltage increases in surface roughness value. The concentration of electrolyte and tool feed rate varies linearly with surface roughness. Lower the value of tool feed rate, better surface finish has been achieved. If the duty cycle is kept at 50 %, the surface roughness value is low. The applied voltage has been the most significant factor in measure of Ra. As the applied voltage increases, Ra also increases. From the main effects plots has been taken with surface roughness, Figure 5 it is clear that increasing the voltage, the surface roughness value (Ra) also increased. If the tool feed rate is low, the better surface roughness has been achieved [11].

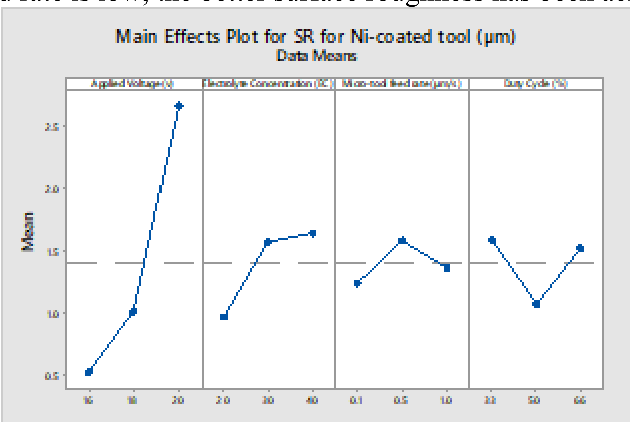

Figure 5. Effect of Process Parameters on R_a.

6. Conclusion

In this study, the performance of Ni-coated electrode on α-Titanium material has been determined and analysed. From the outcome of the results, the following conclusion have been found:

- The voltage and duty cycle have most important effects on the machining performance in electrochemical micromachining process.
- The high voltage, moderate tool feed rate, low duty ratio and high concentration of electrolyte has created moderate MRR and better Ra.
- The nickel coated tool has generated 17% lower surface roughness and 5.3 % higher material removal rate in Electrochemical micromachining process.

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