A STUDY ON THE ELECTROCHEMICAL MACHINING PERFORMANCE OF TITANIUM ALLOY IN DIFFERENT ELECTROLYTES – A REVIEW

[1]K. Kiran Kumar, [2]J. Prasanna
[1]UG Student, [2]Assistant Professor Senior Grade
Department of Mechanical Engineering, College of Engineering Guindy – Anna University Chennai Tamilnadu – 600 025

Abstract:

Electrochemical machining is a non-conventional machining process that applies the Faraday's laws of Electrolysis to remove the metal from the work piece. Jet Engines and other aerospace applications requires the use of Titanium alloys in its construction. This review paper investigates the process parameters of ECM such as Material removal rate (MRR), overcut and surface roughness obtained when Titanium alloy is placed in the different electrolytes

Keywords: Surface roughness, overcut, electrolytes

I. INTRODUCTION:

Electrochemical machining (ECM) is an unconventional machining process that is used to machine extremely hard materials which are difficult to cut with conventional machining methods. In ECM of titanium alloy, defects such as pitting and poor surface roughness happens. There is also a passivation layer which is easily produced during ECM, which leads to a large decomposition voltage. [11]. In air, titanium interacts with oxygen to form a native oxide film that protects the metal from further oxidation and allows one to use titanium as the structural material. The anodic polarization of titanium in the aqueous solutions leads to the formation of anodic oxide film (AOF) and its thickening with increasing anodic potential E_a in a wide range:[5]

$$Ti + 2H_2O \rightarrow TiO_2 + 4H^+ + 4e^-$$

The advantages of ECM over other traditional machining processes include its numerous applications such as inconsideration of the material hardness, comparatively high material removal rate, free from tool wear, and achievement of fine surface features and the production of complex geometry components with surfaces free from stress and crack. The final shape of the work-piece is nearly negative mirror image of the tool which functions as electrode. [10]. The ECM is identified by small material removal of very hard to machine materials like titanium alloys, nickel alloys with almost no tool wear. The important performance parameters are mainly the tool feed rate, electrolyte flow rate and concentration of electrolyte. These parameters have a great impact on the material removal rate (MRR). Overcut is generally defined as removal of excess material while making a hole deformation in work piece. Larger values of the overcut is a direct indication on the measure of accuracy of the tool. [8]. Gamma titanium aluminium (γ-TiAl) intermetallic has the following characteristics such as low density, resistance to oxidation, high stiffness and strength at a wide range of temperature. [6]. The electrolytes which forms a part of an ECM system assists both in transfer of currents during machining as well as carry away the by-products and heat generated during the machining.[3]. The material removal solely depends on the basic electrochemistry of the cathode, anode with the electrolyte and for given current densities [1]. So this paper tries to investigate the influence of input parameters to ECM which provides various values of surface roughness, material removal rates and overcut during machining.

II. ECM PRINCIPLE:

Electrochemical machining is a process of removing work piece material by the anodic dissolution phenomena in electrolytic reaction. The work piece and tool are connected respectively to the anode and cathode of the power source. Electrolyte flow was pumped between the work piece and tool electrode [6]. For instance, if we consider iron alloy as work piece and copper as tool and a mixture of NaCl and water as electrolyte (brine solution). When the potential is applied between work piece and tool. The Reactions are as follows:

At cathode: $2H^+ + 2e^- = H_2$

At anode: $Fe = Fe^+ + 2e^-$ and $Fe^{2+} + Cl^- = FeCl_2$

$NaCl = Na^+ + Cl^-$ and $H_2O = H^+ + OH^-$ and it combines with water to give NaOH [9]

III. ECM OF TI-6AL-4V ALLOY:

1. NaCl electrolyte:

A 10% NaCl electrolyte was taken into study by Yafeng He et.al [4]. The processing pulse power voltage and initial gap were correct to 18V and 0.6 mm respectively while the temperature of the electrolyte was maintained at about 40 °C. The average processing current increases with the feed rate after initially decreasing, and then gradually stabilizes as time elapses when the feed rate is relatively high. The values of surface roughness were higher of the order of 1.3 for feed rates in 0.4 mm/min and values of surface roughness comes down to 0.4 for feed rates of 1.8 mm/min. If the feed rate increases the balance gap gradually decreases. For a feed rate of up to 1.8 mm/min, the balance gap is very small, such that a short-circuit or an interruption in the process could occur if the feed rate were to continue increasing. On considering material removal rates with increase voltage till 20V and a gap of 0.3 mm, the material removal rate of 0.5 gm/min is achieved.

2. NaNO3 electrolyte:

Hansong Li et.al[3] carried out a study that uses a 10% $NaNO_3$ solution as a single-electrolyte solution to create multiple holes in Ti-6Al-4V sheets. The Micro holes obtained with input parameters such as voltage of 35V, pulse frequency of 400 HZ, and duty ratio of 20% exhibited excellent surface morphologies with linear material removal obtained in TMECM machine.

3. Mixture of NaCl and NaNO3 electrolyte:

The behavior of Ti-6Al-4V under an external electric field was investigated using a three-electrode system by Huaxing XIAO et.al[2] by using the electrolyte whose composition is 0229.6 g/l NaCl + 106.7 g/l $NaNO_3$ which is a mixed electrolyte composition. At low current densities, the surface morphology after machining is found to be rugged as well as flat because titanium alloy is active in NaCl electrolyte and a passivation phenomenon was found in the $NaNO_3$ electrolyte. At high current densities, due to the sensitivity of titanium alloy Ti_6Al_4V to the electrolyte, it is easy to cause a pitting corrosion phenomenon under sodium chloride electrolyte and pit-like dissolution under sodium nitrate electrolyte. But with use of Cl- ion activity in sodium chloride electrolyte and the NO_3- replication in sodium nitrate electrolyte are used, and the two electrolytes are mixed in accordance with 229.6 g/lNaCl+106.7g/l $NaNO_3$, the surface of Titanium alloy is found to be improved after electrolysis.

4. Alkali Metal Halides:

From the experiment of Davydova et.al [5] a low concentration of bromide of the order of 3.6×10^{-3} M is sufficient for titanium activation. On titanium coated with native layer of oxide film, the anodic oxidation of bromide occurs at a relatively low values of anodic polarization. At higher anodic potentials ($E_{a)}$, the process ceases as a result of anodic oxidation film thickening and the prevailing process of healing of the defects in the oxide film. The pitting characteristics on commercially pure titanium was studied in the potassium bromide solution with a small addition of H_2SO_4. It was shown that the pits were initiated on the particles of inclusions containing aluminium and silicon particles on titanium work piece.

5. NaClO4:

The anodic dissolution of titanium in the NaClO4 (sodium perchlorate) solutions experiments were carried out by Davydova et.al[5] and the results were found to have significant activating effect on titanium. The anodic polarization curve measured on titanium in the NaClO4 solution is similar in shape to that experiment carried out in the potassium bromide solution. The aqueous solutions compounds of Ti (IV) forms as a result of further chemical oxidation of intermediate low-valent Ti(IV – n) species with perchlorate as given by the following reaction:

$$Ti\ (III) + ClO_4^- + 2H^+ \rightarrow Ti\ (IV) + ClO_3 + H_2O$$

IV. ECM OF γ-TI-Al alloy:

Jia Liu et.al[6] conducted orthogonal experiments to study the influences of process parameters such as applied voltage, electrode feed rate, electrolyte pressure and temperature on material removal rate (MRR), surface roughness (SR) and machining gap (MG) in NaCl aqueous solution when the Titanium alloy is allowed to machining. The results clearly indicated that electrode feed rate has a crucial effect on material removal rate, surface roughness and machining gap. The number of combination with four factors (Applied voltage, electrode feed rate, electrolyte pressure and electrolyte temperature) and four levels is 256 groups. Out of 256 groups, the following factors with values are found to be efficient:

1. Applied voltage = 35V
2. Electrode feed rate = 2 mm/min
3. Electrolyte pressure = 0.8 MPa
4. Electrolyte temperature = 35 degree Celsius

The MRR, SR and MG of machined specimen at the optimum conditions were found to be 273mm3/min, Ra1.0 μm and 0.31mm. The Work piece specimen dimensions are: A rectangular plane of 15mm length and 10mm width was processed with the flatness error of 0.009mm.

V. ECM of Ti-60:

Chen Xuezhen et.al [11] carried a research on ECM of Titanium 60 for manufacture of blisk. The work piece is Ti60 with heat treatment of 1050ºC/2 h air cooled followed by 700ºC/2 h air cooled with a cylindrical diameter of 0.02 m. The concentration of NaCl electrolyte is in the range of4wt% - 16wt%. A voltage range of 20–40 V with a temperature range of 23–55 ºC are used in the experiments. Along with the frequency and duty cycle of the pulsed power supply are as follows: 0.2–1.0 kHz and 0.2–0.6, respectively. Feed rates between the values 0.2–0.6 mm/min are used.

The optimum parameters used to achieve a surface finish of 0.912 µm are

- Electrolyte concentration: 16.0 wt%
- Voltage : 20.0 V
- Frequency : 0.4 kHz
- Duty cycle : 0.3
- Temperature : 23.0^{o}C
- Feed rate : 0.5 mm/min

By using the above mentioned values in the experiment, the blades of a Ti60 alloy blisk have been successfully manufactured with a surface roughness of approximately 1.019 µm.

VI. Conclusion:

From the above discussions we can differentiate clearly the behavior of different titanium alloys when subject to electro chemical machining in different electrolytes. When using NaCl with a feed rates of 1.8 mm/min, the surface roughness has 0.4 µm with material removal rates of 0.5gm/min is achieved. When $NaNo_3$ used instead of similar surface roughness and MRR are achieved with higher voltages and pulsating frequencies. But when a mixture of NaCl and $NaNO_3$ solution, the surface finish is greatly improved after machining. Use of KBr solutions are also similar to that of using NaCl solution but the activation of Titanium is quicker in the former electrolyte. Sodium perchlorate electrolyte improves the oxidation states of Titanium with a hydroxide formation of electrolytes. When different alloys of Titanium such as γ-Ti-Al alloy and Ti-60 are used in ECM different parameters influence the deformation on the Titanium work piece and surface roughness of approximately 1.0 µm are obtained.

VII. References:

[1] F. Klockea, M. Zeisa, A. Klinka, D. Veselovaca: Experimental research on the electrochemical machining of modern titanium- and nickel-based alloys for aero engine components.

[2] Yafeng HE, Huaxing XIAO, Weiming GAN, Qing YU, Feihong YIN: The Electrochemical dissolution behavior research of Titanium alloy under different electrolyte.

[3] Hansong Li, Chuanping Gao, Guoqian Wang, Ningsong Qu & Di Zhu: A Study of Electrochemical Machining of Ti-6Al-4V in NaNO3 solution.

[4] Yafeng He, Jianshe Zhao, Huaxing Xiao1, Wenzhuang Lu, Weiming Gan , Feihong Yin, Zhenwen Yang: Electrochemical Machining of Titanium Alloy Based on NaCl Electrolyte Solution

[5] A. D. Davydova, T. B. Kabanovaa, and V. M. Volginb : Electrochemical Machining of Titanium.

[6] Jia Liua, Di Zhua, Long Zhaoa, Zhengyang Xu: Experimental Investigation on Electrochemical Machining of γ -TiAl Intermetallic.

[7] F. Klockea, M. Zeisa, S. Harsta, A. Klinka, D. Veselovaca, M. Baumgärtner: Modeling and Simulation of the Electrochemical Machining (ECM) Material Removal Process for the Manufacture of Aero Engine Components.

[8] N Manikandan, S Kumanan* & C Sathiyanarayanan: Multi response optimization of electrochemical drilling of titanium Ti6Al4V alloy using Taguchi based grey relational analysis.

[9] Pravin D.Babar, Baliram R.Jadhav: Experimental Study on Parametric Optimization of Titanium based Alloy (Ti-6Al-4V) in Electrochemical Machining Process.

[10] T.Florence, S.Dharmalingam, V.Ragupathy, P.Satishkumar: Machinablity study on Electrochemical Machining – A Review.

[11] Chen Xuezhen, Xu Zhengyang , Zhu Dong, Fang Zhongdong, Zhu Di: Experimental research on electrochemical machining of titanium alloy Ti60 for a blisk.