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High rate anodic dissolution of Titanium workpiece during Electrochemical Machining

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ABSTRACT

Titanium workpiece has been machined by Electrochemical Machining in 5.0 M NaCl electrolyte. Dependence of material removal rate on current densities has been determined and compared with theoretical values. It is interesting to note that the dissolution valence decreases with increase in current density. The electrochemical reactions occurring at cathode & anode have also studied .The Electrochemical machining parameters are optimized for maximum material removal rate and better surface finish.

Introduction

Among several non-conventional processes, electrochemical machining (ECM) is interesting because the removal of material is by an atom to an atom and independent of the hardness of the work materials. The Electrochemical machining has got an industrial importance due to wide applications in aeronautics, nuclear reactors, automobiles etc which are demanding advanced materials that are known for their improved strength, thermal resistance, wear resistance and corrosion resistance. Dissolution of work metal in lowest valence state is having sound impact on the MRR during electrochemical machining [1-3]. The Electrochemical machining parameters have been optimized from different angles [4-6]. In microsystem technologies, it plays an important role for two reasons. At first, it allows microstructuring of hard metals and alloys and Second, it is a technology without mechanical surface damage as it appears during mechanical polishing, spark erosion or other techniques [7-10]. Now it is widely applied for preparation of miniaturized nozzles for motor injection devices, for deburring, for razor head production and other systems [7]. Electrochemical Machining have been optimized from different angles, however its capabilities have not been fully exploited mainly because of some inherent problems associated with tool design, electrolyte, heat transfer, hydrogen gas evolution and variable valences of work piece metal [8-12].

In this paper an attempt have been made to optimize the machining parameters during Electrochemical machining of titanium with respect to metal ion valences for maximum material removal rate

Experimental set up for electrochemical machining:

The electrochemical machining experiments were carried out in a rectangular flow chamber. A brass tool was used as cathode and titanium as anode. The gap between cathode and anode was set at the beginning of each experiment. An aqueous NaCl solution (5 M) at 25°C was used as electrolyte. Experiments were performed by varying current densities (10 A/cm^2 to 50 A/cm^2) and interelectrode gap (0.005 cm – 0.15 cm). A typical experimental set up of Electrochemical Machining is shown in fig.1

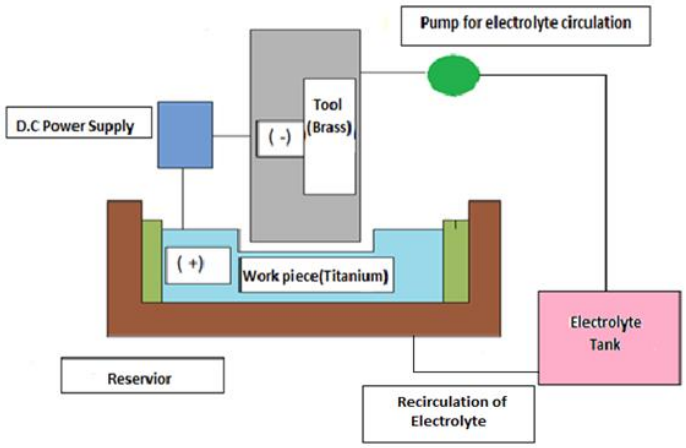

Fig 1. Diagram of Electrochemical Machining set up

The Electrochemical machining system consists mainly of four sub-systems: power source, electrolyte cleaning and supply system, tool and tool-feed system, and work and work-holding system.

Low voltage DC (2- 50 V) capable of giving high current density is used as power source. The material removal rate mainly depends upon the current density employed. The electrolyte supply and cleaning system consists of a pump, filters, pipings, control valves, pressure gauges and a reservoir. Electrolyte supply ports (connections) are made in the tool, The experiment were performed at different inter electrode gap (IEG) .A brass tool has been used which can be operate in a corrosive environment for a long period of time.

The electrochemical machining was conducted on five pieces of titanium work pieces (dimension: 10 cm x 5 cm) having following specifications.

Atomic Weight: 47.867

Density (g cm^{-3}) : 4.506

Melting Point : 1668 ^{0}C

Electrical Resistivity : 420 n$\Omega\cdot$m

Thermal Conductivity : 21.9 W$\cdot$m$^{-1}\cdot$K^{-1}

Tele:

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Brinell Hardness 716 MPa

The various working parameters of the experiment are summarized in table 2.

Table 1. Experimental Details

S.N		Experimental Details
1	Voltage	10 V
3	Current Density	0 – 50 A/cm2
4	Inter electrode gap	0.005 – 0.15 (cm)
6	Power Supply	0-50 V DC
7	Electrolyte flow rate	15 l//min
8	Electrolyte type	NaCl aqua solution
9	Electrolyte concentration	5.0 M
10	Tool Material	Brass
11	Electrolyte temperature	20- 30 ^{0}C
12	Work piece	Titanium
13	Machining time	1.5 minutes

The initial weight of the work piece was taken for calculation of MRR. Keeping the flow rate constant at 15 lit/min and the rest of the parameters are set according to Table 1 for each run. Work piece was kept horizontal, and cylindrical electrode was used for machining. Gap between tool and workpiece was maintained carefully to avoid the choking. The electrode was fed continuously towards the work piece during machining and time was recorded. After machining, the cavity was formed on the work-piece. The final weight of the work-piece was taken and material removal rate was calculated.

Electrochemical and Chemical Reaction Scheme:

In aqueous solution of NaCl following reaction occurs

$NaCl \Leftrightarrow Na^+ + Cl^-$

$H_2O \Leftrightarrow H^+ + OH^-$

On passing the electric current through the solution positive ions moves towards cathode and negative ions moves towards anode. Each Na^+ ions gain an electron and is converted to Na. Hence Na^+ ions are reduced at the cathode by means of electrons.

Reactions at Cathode:

$Na^+ + e^- \Leftrightarrow Na$

$Na + H_2O \Leftrightarrow NaOH + H^+$

$2H^+ + 2e^- \Leftrightarrow H_2$

It shows that only hydrogen gas will evolve at cathode and there will be no deposition.

$Ti \Leftrightarrow Ti^{2+} + 2e^-$

$Ti^{2+} + 2Cl^- \Leftrightarrow TiCl_2$

$Ti^{2+} + 2(OH)^- \Leftrightarrow Ti(OH)_2$

$2TiCl_2 + 4(OH)^- \Leftrightarrow 2Ti(OH)_2 + 4Cl^-$

$4Cl^- \longrightarrow 2Cl_2 + 4e^-$

$2TiCl_2 + Cl_2 \Leftrightarrow 2TiCl_3$

$2Ti(OH)_2 + H_2O + O_2 \Leftrightarrow 2Ti(OH)_3$

$2TiCl_3 + 8(OH)^- \Leftrightarrow 2Ti(OH)_4 + 6Cl^-$

$H^+ + Cl^- \Leftrightarrow HCl$

$Ti(OH)_4 + 4HCl \Leftrightarrow TiCl_4 + 4H_2O$

$TiCl_4 + 4NaOH \Leftrightarrow Ti(OH)_4 + 4NaCl$

Results and Discussion:

Titanium metals and its alloys are getting industrial importance due to its unique properties (as shown in Fig. 2 and wide application in aeronautics, nuclear reactors, automobiles etc.

Experimental material removal rate of titanium workpiece was determined and recorded along with the theoretical material removal rate in table 2. The Experimental material removal rate was calculated as per the following formula:

$$MRR = \frac{\text{Initial weight} - \text{Final weight}}{\text{density x total time}} \quad \ldots\ldots\ldots\ldots(1)$$

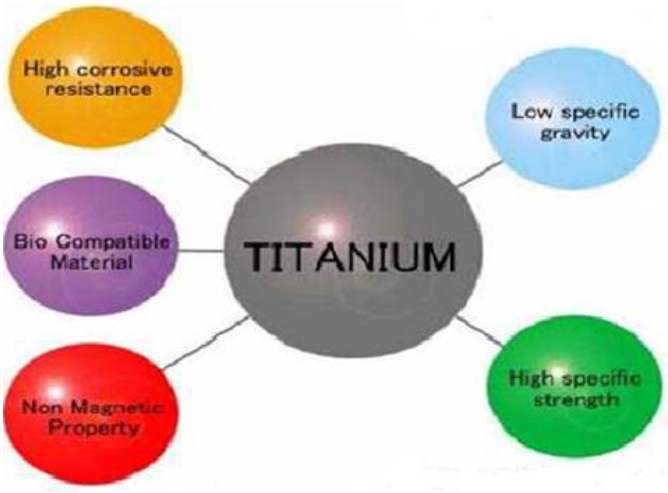

Fig 2. Applications of Titanium work Material

The machining was performed on titanium workpiece at various current densities the theoretical material removal rate was determined by equation 2 and data has been recorded in table. 2 the experimental and theoretical material removal data are plotted in figure 3.

$$\therefore MRR = \frac{m}{t\rho} = \frac{IA}{F\rho v} \quad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Where F = Faraday's constant = 96500 coulombs, I = current and ρ= density of the material

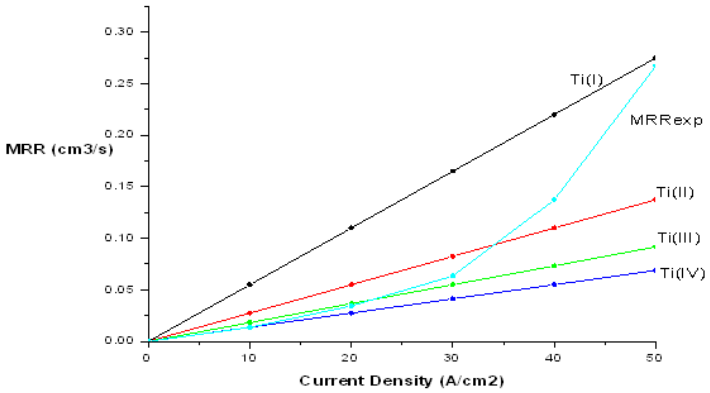

Fig 3. Plot of material removal rate against current density

Dissolution valence was calculated at different current densities by using equation 3 and data are recorded in table 3.

$$v = \left(\frac{A}{Fx\rho}\right) x \left(\frac{I}{MRR}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

The plot of MRR and current density against the dissolution valence is shown in Fig.4 & Fig.5.

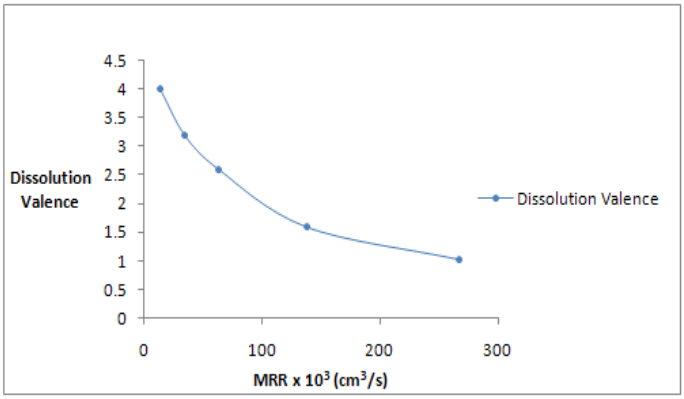

Fig 4. Plot of dissolution valence against material removal rate

Table 2. Theoretical and Experimental MRR at different current densities

			Theoretical MRR (cm^3/s)			
S.No.	Current Density (A/cm^2)	Experimental MRR (cm^3/s)	Ti (I)	Ti (II)	Ti (III)	Ti (IV)
1	10	$13.7x10^{-3}$	$55.04 x10^{-3}$	$27.5 x10^{-3}$	$18.3x10^{-3}$	$13.7x10^{-3}$
2	20	$34.4x10^{-3}$	$110 x10^{-3}$	$55.04 x10^{-3}$	$36.6x10^{-3}$	$27.5x10^{-3}$
3	30	$63.5x10^{-3}$	$165 x10^{-3}$	$82.5 x10^{-3}$	$55.04x10^{-3}$	$41.3x10^{-3}$
4	40	$137.6x10^{-3}$	$220 x10^{-3}$	$110 x10^{-3}$	$73.38x10^{-3}$	$55.04x10^{-3}$
5	50	$267.1x10^{-3}$	$275 x10^{-3}$	$137 x10^{-3}$	$91.7x10^{-3}$	$68.8x10^{-3}$

Table 3. Effect of Current density and IEG on feed rate and dissolution valence

S.No.	Current Density (A/cm^2)	Interelectrode Gap (IEG) (cm)	Feed Rate (cm/sec)	Dissolution Valence
1	10	0.0075	0.0014	4.01
2	20	0.006	0.0023	3.2
3	30	0.0045	0.0044	2.6
4	40	0.003	0.0072	1.6
5	50	0.0015	0.015	1.03

It is clear from Fig.4 that as the MRR increases, titanium starts dissolving in lower valence, when the MRR approaches to about 300 x 10^{-3} cm^3/sec the dissolution valence approaches to one.

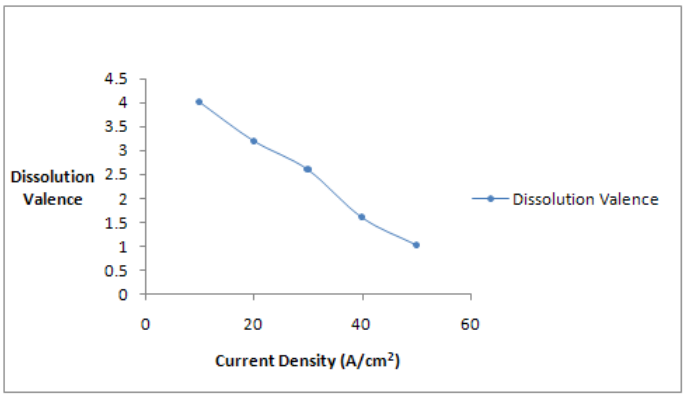

Fig 5. Plot of dissolution valence against current density

It is clear from the Fig.5 that as the current density increases dissolution valence decreases and approaches to one at current density about 50 A/cm^2. It appears that at higher current densities machining facilitates the removal of material in relatively lower valence state.

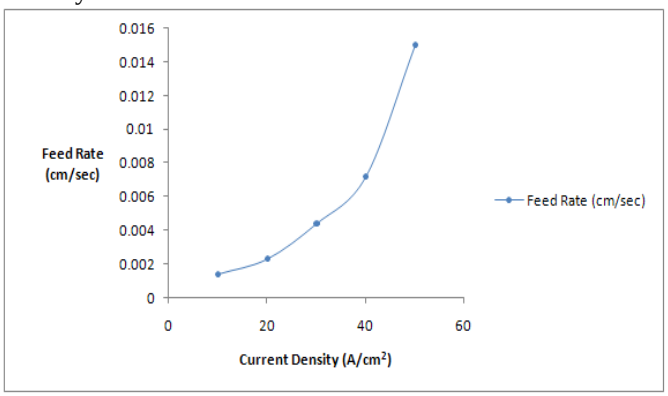

Fig 6. Plot of Feed rate against current density

Table 3. Effect of Current density and IEG on feed rate and dissolution valence

S.No.	Current Density (A/cm^2)	Interelectrode Gap (IEG) (cm)	Feed Rate (cm/sec)	Dissolution Valence
1	10	0.0075	0.0014	4.01
2	20	0.006	0.0023	3.2
3	30	0.0045	0.0044	2.6
4	40	0.003	0.0072	1.6
5	50	0.0015	0.015	1.03

The variation of tool feed rate with respect to current density is plotted in fig 6 which shows that with increase in current density tool feed rate also increase. The feed rate up to current density 40 A/cm^2 increase rapidly but above this increase is very sharp.

Conclusion:

The Electrochemical machining of titanium metal was performed at various current densities. It observed that machining of titanium is favored at higher current densities and ejection of metal ions takes place in lower valence state than that of common valence of titanium. Based upon the observation a tentative anodic and cathodic reaction mechanism is proposed.

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