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ELECTRODE MATERIAL ON MACHINED SURFACE DURING SPARK EROSION OF Ti-6Al-4V (MACHINED AT LOW RANGE PARAMETERS)

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Summary

Investigation of the machining performance of the titanium alloy (Ti-6Al-4V) at low range parameters by the electrical discharge machining (EDM) using copper and graphite as electrodes with positive polarity. The objective of this paper is to investigate the peak current (A), servo voltage (V), on time (T_{on}), off time (T_{off}) and show the effects on material removal rate (MRR), electrode wear rate (EWR) and surface roughness (SR).Design of experiments (DOE) method by using Taguchi technique (L18) mixed level implemented. The validity test of the fit and adequacy of the proposed model has been carried out through analysis of variance (ANOVA).SR was set the lower the better to attain the optimum dimensional precision. Experimental results indicate that copper as a tool electrode shows a better surface roughness than a graphite electrode.

Keywords: **t**itanium Ti-6Al-4V,Taguchi method, Material Removal Rate (MRR), Electrode Wear Rate (EWR),Surface Roughness (SR), ANOVA, SEM

Wpływ obróbki elektroerozyjnej stopu Ti-6Al-4V na zużycie elektrody (w zakresie małych wartości wyładowań elektrycznych)

Streszczenie

W pracy przedstawiono analizę wyników badań obróbki elektroerozyjnej stopu tytanu Ti-6Al-4V w zakresie małej wartości wyładowań elektrycznych z zastosowaniem miedzianej i grafitowej elektrody spolaryzowanej dodatnio. Wyznaczono wpływ parametrów prądowych: natężenia, napięcia, czasu włączenia i wyłączenia na chropowatość powierzchni, prędkość usuwania materiału i zużycie elektrody. W badaniach stosowano zaawansowaną metodę DOE (ang. DOE – Design of Experiments) wyznaczania wpływu zmiennych wejściowych na wynik procesu poddanego analizie. Walidację metody badawczej oraz przyjętego modelu prowadzono z użyciem wariancji ANOVA. Analiza wyników badań potwierdziła, że elektroda miedziana jest lepszym narzędziem do obróbki elektroerozyjnej stopu tytanu.

Słowa kluczowe: stop tytanu Ti-6Al-4V, metoda Taguchiego, usuwanie materiału, prędkość zużycia elektrody, chropowatość powierzchni

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1. Introduction

Electrical discharge machining (EDM) is one of the most effective manufacturing processes available for creating complex or simple shape and geometries within parts and assemblies. The process uses electrical current, which generates sparks between the electrode and workpiece, both submerged in a dielectric bath. The thermal energy leads to intense heat condition on the work piece causing local melting and vaporizing of the workpiece material [1, 2].

Electrical discharge machining (EDM) performance is not influenced by workpiece mechanical properties such as hardness, strength and toughness (Fig. 1). Therefore, EDM is suitable to machine difficult-to-machine materials [1-4].

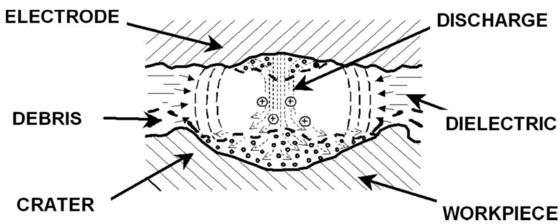

Fig. 1. Electrode discharge machine (EDM) Principle

Machining of the titanium alloys has attracted the attention of researches worldwide first by its typical properties such as very strong and high specific strength (strength-to-weight ratio), light weight, good mechanical properties and its excellent resistance to corrosion. Titanium alloys has found very wide application in aerospace, in jet engine and airframe components, automotive (in racing cars), medicine and dentistry due to their excellent Corrosion resistance, lightweight and mechanical properties (Fig. 2). They are 45% lighter than steel and only 60% heavier than aluminum [5, 6].

The conventional machining processes are unable to provide good machining characteristics on titanium alloys. Titanium alloys are generally used for components, which require reliability and therefore the surface integrity must be maintained [7, 8].

Discharged energy delivers into the machining zone within a single electrical discharge pulse, which enlarges with the peak current and pulse duration, so thermal erosion effects the vaporization and melting on the machined surface in EDM process.

Moreover it is extremely difficult to machine by conventional method due to its high strength. Different aspects of machining have been investigated by several researches. However, no comprehensive research work has been reported so far in the field of electric discharge machining of this alloy using copper and graphite electrodes at low range parameter. Therefore, it is imperative to develop a suitable technology guideline for optimal machining of this alloy.

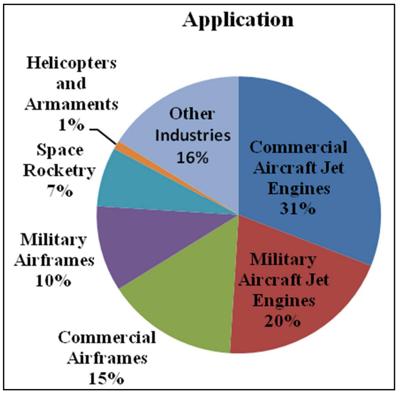

Fig. 2. Titanium alloys application

The conductive titanium (alloy Ti-6Al-4V – Tab. 1) chosen in this study, as the work piece material to investigate the EDM process machining parameters, effect on machining characteristics such as MRR, electrode wear rate (EWR), surface roughness (SR) Scanning Electron Microscopy (SEM).

Table 1. Chemical composition of Ti-6Al-4V alloy

Elements content, %							
C	**Fe**	**N2**	**O2**	**Al**	**V**	**H2**	**Ti**
0.08	0.25	0.05	0.2	5.5-6.7	3.5-4.5	0.0125	Balance

2. Experimental Setup

The experiments were performed on Joemars AZ50R EDM to drilling the workpiece (Fig. 3). Four variables such as peak current (A), pulse on time (T_{on}), pulse off time (T_{off}) and voltage (V) were considered to ascertain their effect on material removal rate (MRR), electrode wear rate (EWR), surface roughness (SR).

The Taguchi L18 mixed levels experimental design method was utilized to conduct this experiment. Table 2 shows different levels of control parameters considered for machining operation, parameter and their levels.

A digital balance (Setra BL-500S) measured the weights of work piece and electrode before and after machining with accuracy of 0.1 mg.

Fig. 3. Schematic diagram of experimental setup

Table 2. Experimental Setup

Parameter	Description
Work piece Material	Ti-6Al-4V (Grade-5)
Work piece Size	50× 60 × 5 mm
Electrode Material	Copper & Graphite
Electrode Diameter	10 mm
Electrode Polarity (P)	Positive
Dielectric Fluid	Commercial Kerosene
Flushing Pressure	35 N/cm^3
Voltage (V)	170, 205 V
Peak current (I_p)	9, 17, 21 A
Pulse on time (T_{on})	49, 100, 145 µs
Pulse off time (T_{off})	52, 40, 24 µm

3. Results and Discussion

3.1. Material Removal Rate (MRR)

Table 3 and 4 shows the results of material removal rate (MMR), electrode wear rate (EWR), surface roughness (SR) and machining time (T) of experimentation with the copper electrode and the graphite electrode.

Table 3. Results of titanium alloy (Ti-6Al-4V) with the copper electrode

Values of parameters							
V	**A**	**T_{on}, µs**	**T_{off}, µs**	**t, min**	**MMR, g/min**	**EWR, g/min**	**SR, microns**
170	9	49	52	20.5	0.000903	0.00007639	2.23
170	9	100	40	17	0.001115	0.00005922	2.89
170	9	145	24	22.23	0.000985	0.00001006	3.03
170	17	49	52	7.33	0.002402	0.00027468	2.59
170	17	100	40	11.12	0.001725	0.00012071	3.27
170	17	145	24	14.1	0.001601	0.00004760	3.30
170	21	49	52	6.05	0.002612	0.00046222	3.37
170	21	100	40	9.24	0.002272	0.00020580	3.23
170	21	145	24	10.43	0.002034	0.00012869	2.69
205	9	49	52	16.36	0.000911	0.00009572	3.37
205	9	100	40	20.05	0.001148	0.00005579	2.64
205	9	145	24	21.57	0.001193	0.00002074	2.93
205	17	49	52	7.42	0.002221	0.00034673	2.64
205	17	100	40	12.05	0.001705	0.00013924	3.1
205	17	145	24	14.13	0.001534	0.00009500	2.5
205	21	49	52	6.48	0.002404	0.00050059	3.09
205	21	100	40	9.06	0.001894	0.00016050	3.05
205	21	145	24	13.39	0.001585	0.00013366	2.23

Table 4. Result of Titanium (Ti-6Al-4V) through Graphite Electrode

Values of parameters							
V	**A**	**T_{on}, µs**	**T_{off}, µs)**	**t, min**	**MMR, g/min**	**EWR, g/min**	**SR, microns**
170	9	49	52	22.07	0.000440	0.000426	2.47
170	9	100	40	34.48	0.000439	0.000136	2.32
170	9	145	24	27.37	0.000693	-0.000064	3.14
170	17	49	52	7.5	0.001174	0.000941	2.47
170	17	100	40	12.2	0.001258	-0.000096	3.23
170	17	145	24	8.53	0.000794	0.000138	3.28
170	21	49	52	15.08	0.000599	0.000195	2.81
170	21	100	40	8.28	0.001663	0.000284	3.35
170	21	145	24	13.3	0.001171	0.000310	2.67
205	9	49	52	13.7	0.000857	0.000730	2.82
205	9	100	40	17.33	0.000912	0.000034	2.86
205	9	145	24	23.35	0.000696	0.000252	3.48
205	17	49	52	13.24	0.000938	0.272037	3.04
205	17	100	40	11.33	0.001136	0.298167	2.79
205	17	145	24	15.26	0.001006	0.255300	3.92
205	21	49	52	8.25	0.001614	0.430660	2.72
205	21	100	40	9.33	0.001621	0.000441	3.55
205	21	145	24	11.3	0.000939	0.001197	3.66

Table 3 shows the relationships between MRR and pulse duration at various peak currents, voltage, pulse on time & pulse off time. Conductive titanium MRR increased with peak current and pulse duration, as shown by experimental results.

The material removal rate (MRR) is the amount of workpiece material being removed during the machining process and it is calculated by equation,

$$MRR = \frac{Wb - Wa}{\rho Material \times T} \times 100 \left[\frac{g}{\min} \right] \quad (1)$$

Where, W_b is the weight of work piece before machining and W_a is the weight of work piece after machining, $\rho_{Material}$ density of the workpiece material and T time of the machining.

Table 4 shows values MMR, EWR, SR at different voltage, current, on time & off time when EDMing through graphite electrode.

3.2. Material Removal Rate (MRR)

The ANOVA interaction plot and main effective plot results presented in Figure 4 reveal that the machining polarity is positive and voltage (V), peak current (I_p), on time (T_{on}) and off time (T_{off}) significantly affect MRR where signal to noise ratio, the larger is better. In Figure 4 (a) and (b) shows, the results of material removal rate while EDMing by sue of the copper and the graphite electrode.

a) b)

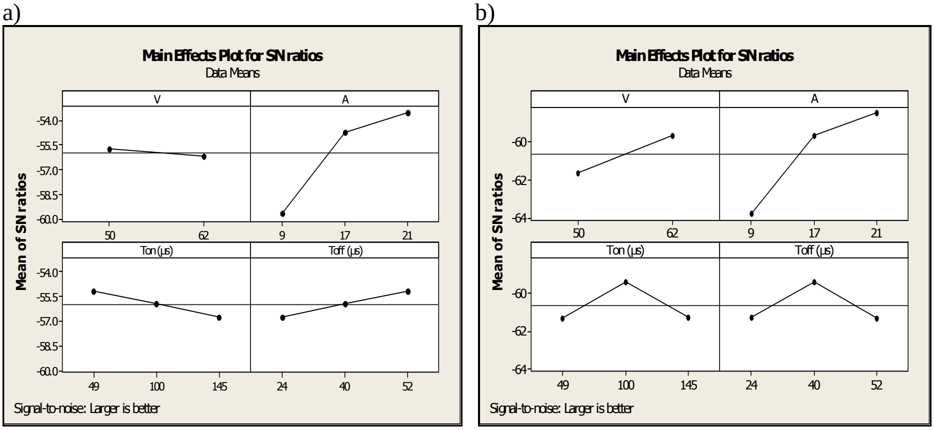

Fig. 4. MRR results of copper electrode (a) and graphite (b)

Maximum MRR was obtained during gap voltage – 170 V, peak current – 21A, T_{on} – 49, T_{off} – 52, MRR-0.002612 with in 6.05 minute short machining time.

Maximum MRR were obtained (EDMed by graphite electrode) for the following work material are: gap voltage – 170 V, peak current – 21 A, T_{on} – 100, T_{off} – 40, MRR – 0.001663 with in 8.28 minute machining time.

3.2. Electrode Wear Rate (EWR)

The relationships between EWR and pulse duration at various peak currents is shown in Figure 5 (a) and (b).

Conductivy of titanium EWR is increased with peak current and declined with pulse duration, according to experimental results. The electrical discharge column induced between the electrode and workpiece during the EDM process generally eroded, not only work piece materials, but also tool electrodes. Increasing peak current could magnify the discharge energy amount delivered to the machining zone to enhance the MRR, and enlarge electrode wear amount. Thus, EWR enlarged with peak current. Discharge energy delivered to the machining gap increased with extending pulse duration. However, the discharge column diameter is expanded with pulse duration during the EDM process [9-15], so electrical discharge energy density within the discharge column is reduced with long pulse duration. Consequently, material removal effects, such as vaporization and melting are also reduced. Therefore, EWR is reduced with pulse duration due to discharge column expansion and energy density reduction within the discharge spot.

The electrode wear rate (EWR) is the amount of electrode being used in the machining process and it's calculated by equation:

$$EWR = \frac{Eb - Ea}{\rho_{Material} \times T} \times 100 \left[\frac{g}{\min} \right] \tag{2}$$

Where, Eb is the weight of the electrode before machining and Ea is the weight of the electrode after the machining, $\rho_{Material}$ density of the electrode material and time (T) taken for the machining.

The ANOVA results listed in Fig. 5 reveal that machining polarity positive and peak current (I_p) significantly affect EWR. Small peak current generated less discharge energy in the machining zone, so EWR was small. Moreover, when the positive machining was selected, the MRR would reduce.. The S/N ratio response graph of EWR is plotted in Fig. 5 (a) and (b). While signal to noise ratio: the smaller is better.

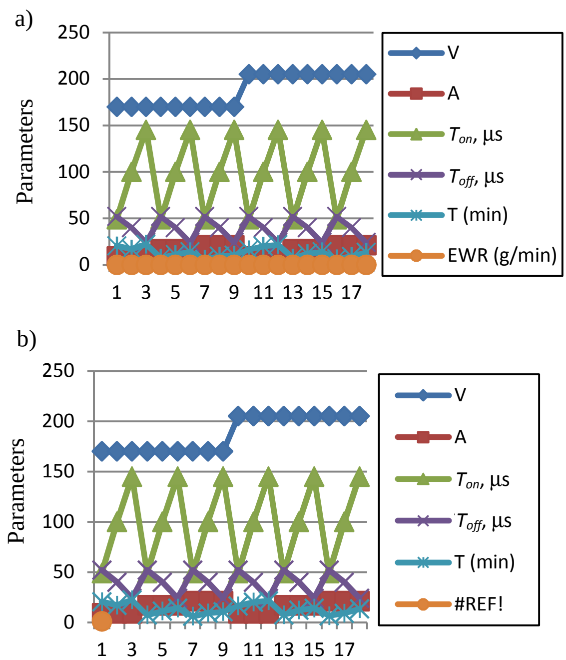

Fig. 5. Results of electrode wear rate of copper electrode

3.3. Surface Roughness (SR)

The surface roughness highly depends on the pulse current and erosion duration of EDM process.

The surface roughness of the workpiece can be measured by Mitutoyo-SJ 201. The process parameters are used to select the best conditions for stability in the Design of experiment process. The experimental observations are further converted into a signal to noise (S/N) ratio on using eq. 4.

$$HB:\eta = -10\log\left[n^{-1}\sum_{n=1}^{n} yj^{-2}\right] \quad (3)$$

$$LB:\eta = -10\log\left[n^{-1}\sum_{i=1}^{n} yj^{2}\right] \quad (4)$$

Lower value represents better machining performance for surface roughness. The signal –ti-noise (S/N) ratio for the “Lower the better” is calculated as follows

Where, η denotes the S/N ratio calculated from observed values (unit:dB) y_j represents the experimentally observed value of the i^{th} experiment, and n is the repeated number of each experiment.

Figure 6 shows the surface roughness of EDMing maching by the copper electrode, good surface at lower voltage and peak current. Surface roughness is directly proportional to voltage, peak current, on time and off time. It is a clear from Fig. 6a that there is a strong interaction effect between peak current and pulse on time affecting surface roughness at a given levels of peak current and pulse on time have strong effect on surface roughness. Surface roughness of the material is better but machining timing is longer. Figure 6b represents the effect of interaction between peak current, on time & off time effect on the surface roughness and Figure 6c represents the effect of interaction between voltage, peak current and spark gap effect on surface roughness.

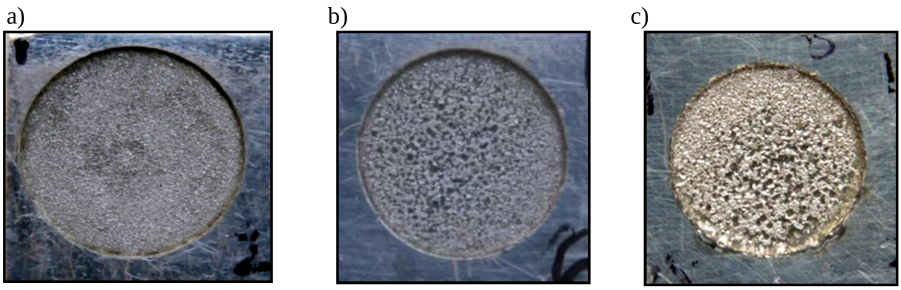

Fig. 6. Titanium alloy (Ti-6Al-4V) EDMed through copper electrode: a) V-170, A-9, T_{on} – 49, T_{off} – 52, b) V-170, A-17, T_{on} – 100, T_{off} – 40, c) V-205, A-21, T_{on} – 145, T_{off} – 24

The ANOVA results presented in Fig. 7 show that peak current (I_p), on time and off time was the significant parameter affecting SR. The S/N ratio response graph of SR (Fig. 7) illustrates machining parameter optimal combination levels that minimized SR were as follows: positive machining polarity, peak current (I_p); 9, 17, and 21 A.

Figure 7 shows the results of surface roughness, while EDMing through copperas a electrode. In Figure 8 shows the surface roughness of EDMing maching by graphite electrode at different range of parameters, while EDMing by the graphite electrode in rough surface at lower voltage and peak current. When voltage, on time is increased then surface roughness is good. Here Surface roughness is directly proportional to potential, on time and off time.

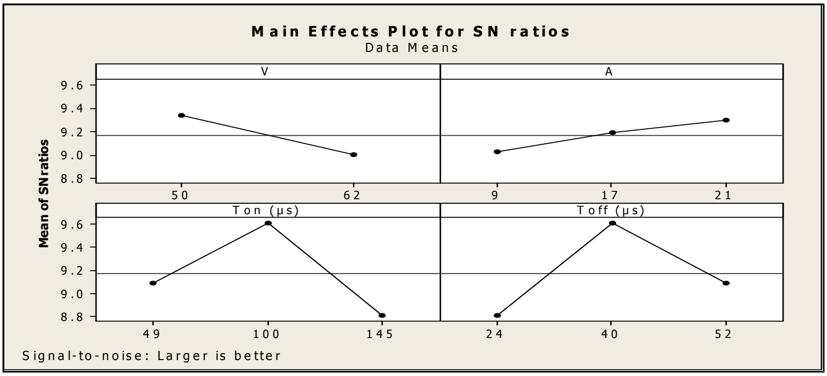

Fig. 7. Results of Surface Roughness of copper Electrode EDMing

It is a clear from Fig. 8a that there is a strong interaction effect between peak current and spark gap affecting surface roughness. Peak current and pulse on time have strong effect on surface roughness. Here Figure 8a shows pinhole defect on workpiece material and more graphite deposition in pinhole. Figure 8b represents the effect of interaction between peak current and spark gap on surface roughness. Black color structure shows the deposition graphite material.

Figure 8b shows that lower voltage and medium peak current create heat affected zone.

Figure 8c and Figure 9 represents the effect of interaction between voltage and spark gap on surface roughness. Surface roughness of the material is very good and machining timing is preferable.

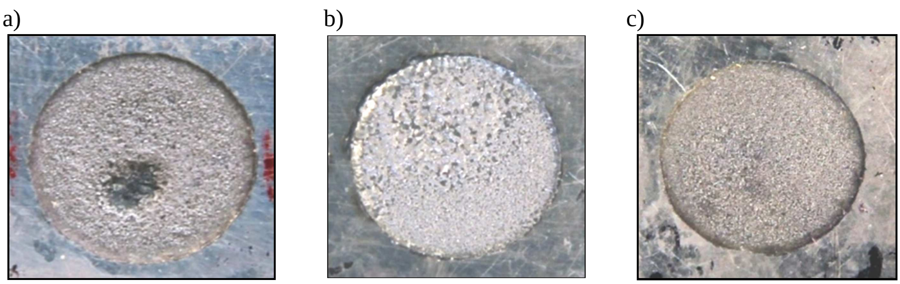

Fig. 8. Titanium alloy (Ti-6Al-4V) EDMed through graphite electrode: a) V-170, A-9, T_{on} – 49, T_{off} – 52, b) V-170, A-21, T_{on} – 100, T_{off} – 40, c) V-205, A-9, T_{on} – 145, T_{off} – 24

The Figure 9 shows the results of EDMing by the graphite electrode. Voltage, on time and off time is directly affecting the surface roughness.

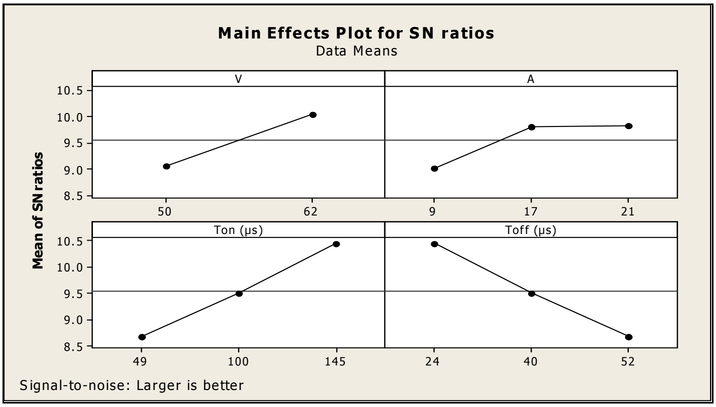

Fig. 9. Results of Surface Roughness of graphite Electrode EDMing

Conclusion

Electro discharge machining (EDM) process is widely applicable in industry because it is capable of cutting like hardened material in any shape.

In current trends super alloys are high in demand in aerospace industry for instance space craft engine, chemical plant, biomedical industry and heat treatment processes because of its high strength to weight ratio, corrosion resistance at very high temperature, high structural strength.

Consequently, numerous applications of super alloys need innovative process for machining. By using EDM, it can be fairly accomplished.

Average voltage and current gives maximum material removal rate. When maximum voltage and current gives higher electrode wear rate. Surface roughness decrease with increasing the voltage and current.

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Abbrivation

V – voltage
A – peak current
T_{on} – pulse on time
T_{off} – pulse off time
T – machining time (Min.)
Wb – workpiece weight before machining
Wa – workpiece weight after machining
E_b – electode weight before machining

Ea – workpiece weight after machining
SR – surface roughness
MMR – material removal rate
EWR – electroe wear rate
HB – higher is better
LB – lower is better

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