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Establishing Optimum Process Parameters for Machining Titanium Alloys (Ti6Al4V) In Spark Electric Discharge Machining

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Abstract — In this study, the spark electric discharge machining(SEDM) of titanium alloys with different electrode materials namely electrolytic copper, beryllium copper, tungsten copper, graphite, aluminium, steel(EN24) and copper impregnated graphite, were conducted to find the suitable electrode material. Therefore the design of experiments were conducted using Taguchi method to find the optimum machining parameters with process parameters such as current, spark on time, spark off time to explore the influence of various SEDM parameters on various requirements such as material removal rate, electrode wear and over cut. The experimental results reveal that the suitable electrode material for machining titanium alloys is copper impregnated graphite. It is found that material removal rate is mainly influenced by discharge on time (T_{on}) and discharge current (I), whereas discharge off time (T_{off}) has least effect on material removal rate. Electrode wear is mainly influenced by discharge on time (T_{on}) and discharge off time (T_{off}), whereas discharges current (I) has least effect on electrode wear. Over cut is mainly influenced by discharge current (I) and discharge on time (T_{on}), whereas discharge off time have a very least effect on over cut.

Index Terms—EDM, Titanium alloys, electrode material, nontraditional machining.

I. INTRODUCTION

The continuous introduction of many new ferrous and non ferrous materials and the demand for the engineers to produce intricate shapes with close tolerances in many industries is increasing. Titanium is one such material and machining it in unconventional method finds great importance in many industries. Titanium has high strength–weight ratio, high temperature strength and exceptional corrosion resistance. Due to these properties titanium and its alloys are finding wide commercial and industrial applications such as aerospace, biomedical etc. But it has low thermal and electrical conductivity and α + β titanium is the most common alloy among the titanium alloys [1], [2].

EDM does not make any physical contact between the electrode and the workpiece and hence mechanical stress and vibrations can be avoided during machining. Materials of any hardness can be machined as long as the material is electrically conductive. Hence titanium can be machined by EDM effectively rather than any conventional method. In EDM current is the cutting force between the electrode and the workpiece which are separated by a small distance called spark gap and both submerged in dielectric fluid.

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DC voltage is applied and hence spark is produced which leads to localized heating and hence material erosion takes place.

The aim of this study is to fulfill the detailed investigation of electrical discharge machining characteristics of Ti-6Al-4V in relation to the process parameters and the different electrode materials. Trails of experiments have been conducted to finalize the suitable electrode material. Following which Taguchi's design of experiments was conducted to optimize process parameters.

II. EXPERIMENTAL PROCEDURE

The specimen used for this study was Ti-6Al-4V of size 80 x 25 x 25mm^3 (Fig 1). Chemical composition of this material is given in (Table I) and the electrode materials used for material selection were copper impregnated graphite, graphite, electrolytic copper, beryllium copper, tungsten copper, brass aluminium and steel (EN24) with the dimension of 7 mm diameter and copper impregnated graphite as 5.7 x 5.7 mm. The experiments were conducted with electric discharge machine model 1065C CHMER (die sinking type).The specimen were sparked for a depth of 5 mm. The machining time is noted from the timer of the machine. The electrode wear were found by taking the weight difference of the electrodes before and after machining with the aid of SHIMADZU BL 220 weighing scale with a capacity of 220 g and accuracy of 1 mg and the slot dimensions were measured using digital vernier caliper.

Table- I, Chemical composition of Ti-6Al-4V alloy

Material	*Weight (%)*
Ti	90
Al	6
Va	4

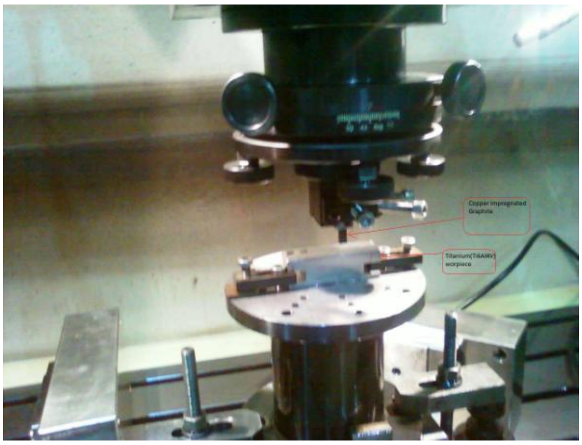

Fig 1, Electrode and workpiece

A. *Electrode material selection*

Reference [3], [4] show that that the selection of the most appropriate Sinker EDM electrode material is a key decision in the process plan for any EDM job. Electrode material properties that affect EDM are electrical conductivity, melting point, chemistry, structural integrity, mechanical properties, manufacturability and cost. The different electrode materials which can be used in sinker EDM are brass, copper, silver, tungsten, copper tungsten, silver tungsten, tungsten carbide, graphite and copper graphite.

B. *Experimentation for material selection*

In order to select the suitable electrode material many experimental trials have been conducted with various materials such as copper impregnated graphite, graphite, copper, beryllium copper, tungsten copper, brass, aluminium and steel(EN24) and the results have been shown in (Fig 2). Based on maximum material removal rate and minimum electrode wear, copper impregnated graphite is found to be suitable due to its maximum material removal and minimum electrode wear, and hence copper impregnated graphite has been used as the electrode material in the study.

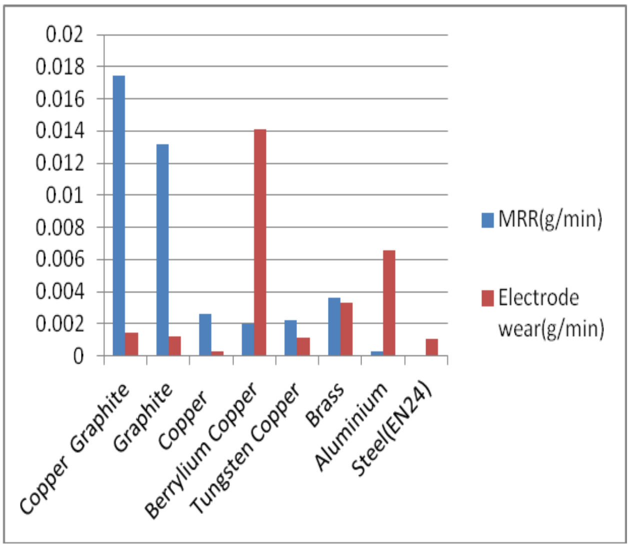

Fig 2, Electrode material Vs MRR and EW

C. *Design of experiments (Taguchi Method)*

Design of experiment has been used to study the effect of three machining parameters Current (I), Pulse on Time (T_{on}) and Pulse off time (T_{off}) on three important response factors i.e., Material Removal Rate (MRR), Electrode Wear (EW), Overcut (OC). Cutting parameters and their levels are shown in (Table-II). As in [5]-[9] for selecting the appropriate orthogonal arrays, degree of freedom (number of fair and independent comparisons needed for optimization of process parameters and is one less than the number of level of the parameters) of array is calculated. There are six degrees of freedom for the three machining input parameter, so Taguchi based L_9 orthogonal array is selected as shown in (Table-III). 9 experiments were conducted do study the effect of input.

The steps involved in DOE are as follows:

1. Response functions and the process parameters to be evaluated are identified.
2. The number of levels for the process parameters was determined.
3. Appropriate orthogonal arrays are selected and process parameters for the orthogonal arrays are assigned and the experiments were conducted accordingly.
4. Experimental results were analyzed and the optimum level of process parameters was selected.
5. Optimum process parameters were verified by conducting the conformation test.

Table- II, Machining parameters and their levels

Machining parameter	*Level 1*	*Level 2*	*Level 3*
I(A)	12	15	18
T_{on}(μs)	37	50	75
T_{off}(μs)	150	200	300

Table- III, Experimental layout using L_9 orthogonal array

	Levels of factors		
Exp No	*I*	T_{on}	T_{off}
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

D. *Quality characteristics*

Signal to noise ratio (S/N) for the response factors are processed on two aspects, (viz)

i. Larger is better characteristic

Data sequences for MRR, which is larger is better performance characteristic, are preprocessed as per (1)

$$S/N = -10 \log \left(\frac{1}{n}\sum_{i=1}^{n} \frac{1}{y_i^2}\right) \quad (1)$$

ii. Smaller is better characteristic

Data sequences for EW and OC, which is smaller is better performance characteristic, are preprocessed as per (2)

$$S/N = -10 \log \left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \quad (2)$$

Where "y_i" represents the experimental observed value of "i^{th}" experiment and "n" is the number of repetition of each experiment [10]-[12].

III. RESULTS AND DISCUSSIONS

The experimental results for MRR, EW and OC based on L_9 orthogonal array is shown in (Table-IV). After the completion of the experiments, different response factors like MRR, EW and OC of the eroded slot were calculated from the observed data.

Table-IV, Experimental results for MRR, EW, and OC

Exp No	*MRR (g/min)*	*EW (g/min)*	*OC (mm)*
1	0.022	0.0029	0.07
2	0.0221	0.00234	0.15
3	0.0205	0.00268	0.07
4	0.0256	0.00268	0.07
5	0.0272	0.00275	0.16
6	0.0232	0.00386	0.08
7	0.016	0.00175	0.03
8	0.0406	0.00462	0.02
9	0.0409	0.00538	0.02

Statistical analyses were performed on the calculated values and the S/N values of the response factors are shown in (Table-V).

Table-V, S/N ratio of various response factors

Exp No	*S/N Ratio for MRR*	*S/N Ratio for EW*	*S/N Ratio for OC*
1	-34.340235	51.96375818	23.43796689
2	-31.136078	50.93625594	18.19179906
3	-34.552311	51.9050129	21.04448727
4	-32.622589	51.9050129	21.04448727
5	-32.49731	52.42506426	16.25752804
6	-30.714164	46.588827	23.6518245
7	-33.941524	53.45981212	32.17119914
8	-28.616867	47.17486926	31.92584816
9	-28.954222	46.59607262	34.31932778

A. Effect of input parameters on MRR

MRR response table is shown in (Table-VI). The calculation of S/N ratio is based on "Larger is better quality characteristic".

Table-VI, Response table for S/N ratio for MRR

level	*I*	T_{on}	T_{off}
1	-33.34	-33.63	-31.22
2	-31.94	-30.75	-30.9
3	-30.5	-31.41	-33.66
Delta	2.84	2.88	2.76
Rank	2	1	3

Referring (Table-VI) it is observed that "T_{on}" ranks first which means that it has a maximum effect on MRR, "I" have considerable effect and "T_{off}" has least effect on MRR (Fig 3).

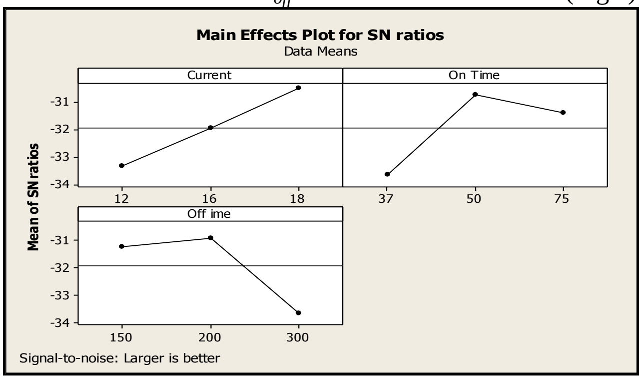

Fig 3, S/N ratio curve for MRR with I, T_{on} and T_{off}

The regression analysis (Table-VII) have been conducted to see the difference between the main effects of level 1, 2 and 3 of the variables on the MRR, EW and OC.

Table-VII, Statistical regression analysis for MRR

Predictor	*Coefficient*	*SE Coefficient*	*T*	*P*
Constant	0.00394	0.02007	0.2	0.852
I	0.001702	0.001017	1.67	0.155
T_{on}	0.00015	0.000161	0.93	0.394
T_{off}	-5.4E-05	4.07E-05	-1.33	0.242

S = 0.00761109 R-Sq = 52.1% R-Sq (adj) = 23.3%

The regression equation is

$$MRR = 0.0039 + 0.00170\ I + 0.000150\ T_{on} - 0.000054\ T_{off}$$

B. Effect of input parameters on EW

EW response table is shown in (Table-8), the calculation of S/N ratio is based on "Smaller is better quality characteristic".

Table-VIII, Response table for S/N ratio for EW

level	*I*	T_{on}	T_{off}
1	51.6	52.44	48.58
2	50.31	50.18	49.81
3	49.08	48.36	52.6
Delta	2.52	4.08	4.02
Rank	3	1	2

Referring (Table-VIII) it is observed that "T_{on}" ranks first which means that it has a maximum effect on EW, "T_{off}" has considerable effect and "I" has least effect on EW (Fig 4).

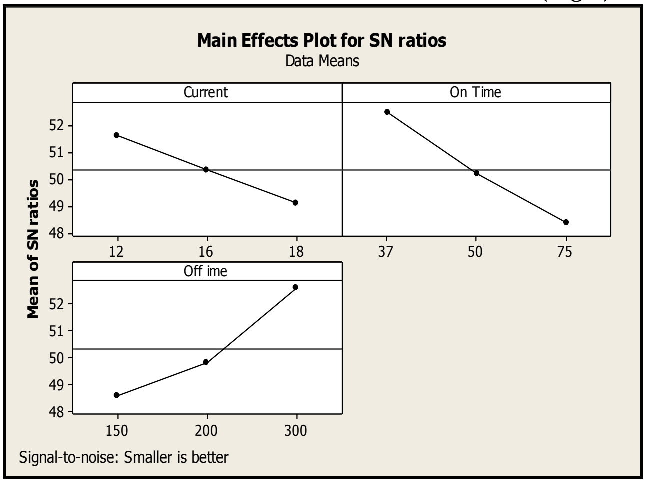

Fig 4, S/N ratio curve for EW with I, T_{on}, and T_{off}

The regression analysis (Table-IX) has been done to see the difference between the main effects of level 1, 2 and 3 of the variables on the MRR, EW and OC.

Table-IX, Statistical regression analysis for EW

Predictor	*Coefficient*	*SE Coefficient*	*T*	*P*
Constant	0.000141	0.001714	0.08	0.938
I	0.00019869	0.00008688	2.29	0.071
T_{on}	0.00003882	0.00001374	2.82	0.037
T_{off}	-0.00000953	0.00000348	-2.74	0.041

S = 0.000650123 R-Sq = 80.6% R-Sq(adj) = 68.9%

The regression equation is

EW = 0.00014 + 0.000199 I + 0.000039 T_{on} - 0.000010 T_{off}

C. Effect of input parameters on OC

Electrode wear response table is shown in (Table-X), the calculation of S/N ratio is based on “Smaller is better quality characteristic”.

Table-X, Response table for S/N ratio for OC

level	*I*	T_{on}	T_{off}
1	20.89	25.55	26.34
2	20.32	22.13	24.52
3	32.81	26.34	23.16
Delta	12.49	4.21	3.18
Rank	1	2	3

Referring (Table-X) it is observed that “I” ranks first which means that it has a maximum effect on OC, “T_{on}” has considerable effect and “T_{off}” has least effect on OC (Fig 5).

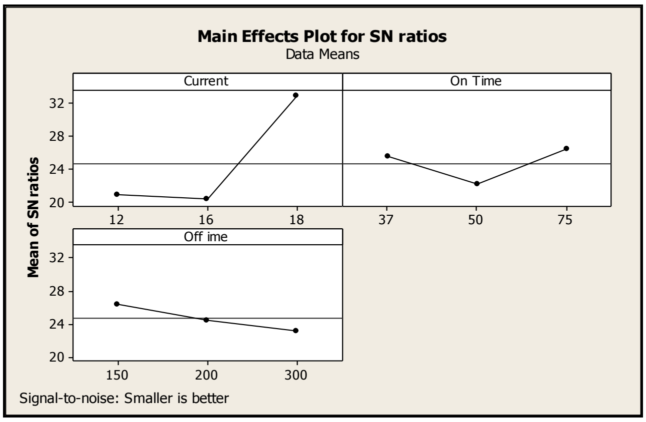

Fig 5, S/N ratio curve for OC with I, T_{on}, *and* T_{off}

The regression analysis (Table-XI) have been conducted to see the difference between the main effects of level 1, 2 and 3 of the variables on the MRR, EW and OC.

Table-XI, Statistical regression analysis for OC

Predictor	*Coefficient*	*SE Coefficient*	*T*	*P*
Constant	0.2077	0.1387	1.50	0.194
I	-0.010238	0.007026	-1.46	0.205
T_{on}	-0.000286	0.001111	-0.26	0.807
T_{off}	0.0001810	0.0002811	0.64	0.548

S = 0.0525801 R-Sq = 34.2% R-Sq (adj) = 0.0%

The regression equation is

OC = 0.208 - 0.0102 I - 0.00029 T_{on} + 0.000181 T_{off}

IV. CONCLUSIONS

Experimental study of establishing optimum process parameters for machining titanium alloys in spark electric discharge machining is undertaken and following conclusions have been drawn

i. The study has been done on various electrode material like copper impregnated graphite, graphite, copper, beryllium copper, tungsten copper, brass, aluminium and steel (EN24) and the most suitable electrode material was found to be copper impregnated graphite.

ii. The material removal rate (MRR is mainly affected by discharge on time (T_{on}) and discharge current (I) has considerable effect on MRR. The effect of discharge off time (T_{off}) is negligible.

iii. The electrode wear (EW) is mainly affected by discharge on time (T_{on}) and discharge off time (T_{off}) has considerable effect on EW. The effect of discharge current (I) is negligible.

iv. The over cut (OC) is mainly affected by discharge current (I) and discharge on time (T_{on}) has considerable effect on OC. The effect of discharge off time (T_{off}) is negligible.

v. The optimum parameters for which maximum material removal rate, minimum electrode wear and minimum over cut cab be obtained with the parameters given in (Table-XII).

Table-XII, Optimum process parameters

Physical requirements	Optimum combinations		
	I (A)	T_{on}(µs)	T_{off}(µs)
Maximum Material Removal Rate (g/min)	18	50	200
Minimum electrode wear (g/min)	12	37	300
Minimum Over Cut (mm)	18	75	150

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