International Journal of Latest Trends in Engineering and Technology
Vol.(7)Issue(3), pp. 056-062
DOI: http://dx.doi.org/10.21172/1.73.508
e-ISSN:2278-621X

Material Removal Rate during B_4C Abrasives Mixed Electrical Discharge Machining of Titanium Alloy (Ti-6Al-4V)

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Abstract- Titanium alloy (Ti-6Al-4V) alloy is an valuable material for aerospace, automotive, biomedical, marine, chemical processing, power generation, oil and gas extraction industries. These materials have excellent properties such as high strength-to-weight ratio, fine resistance to creep and fatigue, superior corrosion resistance and biocompatibility. However, Titanium alloys (Ti-6Al-4V) alloy is always to be difficult-to-cut materials by conventional machining processes. In this study, boron carbide (B_4C) abrasives mixed kerosene fluid is used to drill blind holes in Ti-6Al-4V work piece. Important electrical parameters and B4C concentration in kerosene oil are varied as per L_{27} orthogonal array of Taguchi method to measure the material removal rate (MRR) of the material.
Keywords **-** EDM, Titanium alloy, material removal rate.

I. INTRODUCTION

EDM is a non-conventional machining process which is broadly used to produce intricate shapes on dies of any hardness value. Possibility of EDM is due to the action of sparks of short duration and high discharge current intensity between two mating parts. The method is able to cut with dimensional accuracy and surface finish by modifying the process input [1]. The fundamental phenomenon in EDM is the conversion of electrical energy into thermal energy in inter-electrode gap in presence of dielectric fluid. The dielectric fluid also served a medium to remove worn out particles. Chen et al., (1999) worked to use the kerosene oil and distilled water as dielectric during EDM of Ti-6Al-4V. It has been proved that the MRR is more and RWR is less when used distilled water as a dielectric fluid as compared with kerosene oil. Lin et al., (2000) presented an analysis of the machining characteristics of titanium alloy (Ti-6Al-4V) using a mixture method of EDM with ultrasonic machining (USM). The EDM and USM machining mechanisms were combined to improve the machining efficiency and accuracy. Researchers come to an end from the experimental results that mixture of EDM/USM method will enhance the MRR, decrease the thickness of the recast layer and yield better discharge efficiency. After feasibility study, Gu et al., (2012) investigated and proposed the efficient EDM process for Ti-6Al-4V work material with a

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bundled die-sinking tool electrode. Azad et al., (201`2) attempted for optimization for process performance during micro EDM of titanium alloy. Pulse on time, frequency, current and voltage were input factors while tungsten carbide was tool in this work. Chow et al., (2008) used SiC abrasives in pure water as dielectric for micro-slit die-sinking EDM machining process. Adding SiC abrasives enhances the fluid conductivity and extrudes worn debris easily and enlarges gap distance. Murahari et al [2014] examined the effect of additives added in the dielectric fluid on EDM of Titanium alloy (Ti-6AL-4V). Researchers conducted observations by varying concentration of additives and discharge current with their effect on output parameters MRR, SR and TWR.

A series of investigations are available in EDM of titanium and other materials. However, a few research works are carried out in the direction of mixing conductive metal abrasives in kerosene as dielectric fluid during EDM of ASTM grade 5 titanium alloy (Ti-6Al-4V). Therefore, this study aimed to analyze the effect of B_4C abrasives mixed in kerosene dielectric fluid on the MRR during EDM of Ti-6Al-4V alloy.

II. DESCRIPTION OF THE EXPERIMENTS

A. Equipment and materials used in the experiments

Number of experiments was performed on EDM machine OSCARMAX S645 (Figure 1). Integrated dielectric system of EDM machine was used for experiments in which no B_4C abrasives are mixed. But, one ten litre capacity box was made in workshop to perform abrasives mixed experiments. All experiments in which 5 g/l and 10 g/l B_4C abrasives were mixed kerosene dielectric fluid used are performed in this box. To mix uniformly the abrasives in the kerosene oil, one pump with small nozzle was used in the mild steel box.

Figure 1. OSCARMAX S645 EDM Machine

9 mm solid electrolytic copper rod was selected as tool electrode. Various properties of copper electrode are given in Table 1. Various physical and chemical properties of B_4C abrasives are given in Table 2. The work piece material used in this experimentation is

titanium alloy (Ti-6Al-4V). The experimental specimens of Ti-6Al-4V are cut into rectangular plates. Chemical compositions of titanium alloy are given in Table 3.

Table 1. Various properties of copper

Property	Melting point	Density	Thermal conductivity	Electrical Resistivity
Value	1360 K	8.94 g/cm^3	226 W/m.K	17.1 n.Ω.m

Table 2. Properties of boron carbide (B_4C) abrasives

Properties	Colour	Density	Hardness	Coeff. of thermal exp.	Grain size	Thermal conductivity	Melting point
Value	Dark grey	2.51 g/cm^3	3580 kg/mm^2	4.6 x 10^{-6} (/°C)	100 µm	35-42 $W{\cdot}m^{-1}{\cdot}K^{-1}$	2630 °C

Table 3. Chemical composition of Ti-6Al-4V (wt %)

Element	Carbon	Aluminium	Vanadium	Nitrogen	Oxygen	Iron	Hydrogen	Titanium
Wt (%)	0.014	6.07	4.02	0.0036	0.1497	0.03	0.0115	Bal

III. **EXPERIMENTATION**

A. *Input Factors and response variable selected*

The boron carbide powder mixed in the dielectric fluid plays an important role in determining and evaluating the EDM character statics of the titanium alloy workpiece. There is large number of factor which affects the EDM process performance. Mainly one factor related to abrasives is the net quantity of abrasives particles added to the dielectric fluid is used in this study. Other four electrical factors i.e. pulse off time, pulse on time, peak current and gap voltage are taken to study the process. All these factors are varied at three levels as per the values given in Table 4. Taguchi recommended OA (L_{27}) is used to design the experiments. Table 5 shows the coded values of factors, actual values of factors and the MRR obtained in these 27 experiments. MRR may be expressed as material wear away from the Ti-6Al-4V work-piece per unit time. The Ti-6Al-4V weight was measured using electronic weight balance of 0.01 mg resolution. These values are used in Eq. (1) to calculate MRR values.

Table 4. Natural values of input machining factors at three levels

Symbol	Machining factors	Levels and corresponding values of input machining factors		
		Level 1	Level 2	Level 3
A	Concentration of B_4C abrasives in kerosene	0 g/l	5 g/l	10 g/l
B	Pulse off Time	30 µs	45 µs	60 µs
C	Pulse on Time	90 µs	150 µs	200 µs

D	**Peak Current**	**4 A**	**8 A**	**12 A**
E	**Gap Voltage**	**20 V**	**30 V**	**40 V**

In this study, MRR was calculated by using Eq. (1).

$$MRR\ (g/min) = \frac{\text{Work piece material weight loss (g)}}{\text{Operation time (min)}} \quad \text{..... Eq. (1)}$$

Ti-6AL-4V and copper rod machined as per dimensional requirements and initial surface preparation. As per the plan made earlier (L_{27} OA) using Taguchi method, B_4C abrasives were selected with 100 micron grain size. Kerosene oil was taken to be used as dielectric fluid for the experimental work. After selecting all the five machining parameters, electrode and work-piece material, abrasive powder material, dielectric fluid and most importantly machine tool next step was to conduct the experiments. Starting from the measurement of initial weight of Ti-6Al-4V plate, with the help of weight balance, work-piece and electrode were fixed in the machine. As per experimental plan in table 4 and table 5, various input factors like B_4C abrasive concentration in kerosene, pulse off time, pulse on time, peak current and gap voltage were applied on the EDM machine tool with the help of a PLC system. It is for performing first experiment. Then the other settings like maintaining the proper inter-electrode gap, supply of dielectric fluid etc. was opened with the help of machine control panel.

Table 5. Taguchi recommended L_{27} orthogonal array design (coded and natural values) and obtained MRR

Exp. No.	Coded Parameters					Actual Parameters					MRR (g/min)
	A	B	C	D	E	A	B	C	D	E	
1	1	1	1	1	1	0	30	90	4	20	0.002333333
2	1	1	1	1	2	0	30	90	4	30	0.002333333
3	1	1	1	1	3	0	30	90	4	40	0.003333333
4	1	2	2	2	1	0	45	150	8	20	0.004666667
5	1	2	2	2	2	0	45	150	8	30	0.005000000
6	1	2	2	2	3	0	45	150	8	40	0.003666667
7	1	3	3	3	1	0	60	200	12	20	0.001333333
8	1	3	3	3	2	0	60	200	12	30	0.001666667
9	1	3	3	3	3	0	60	200	12	40	0.001666667
10	2	1	2	3	1	5	30	150	12	20	0.005666667
11	2	1	2	3	2	5	30	150	12	30	0.004666667
12	2	1	2	3	3	5	30	150	12	40	0.004333333
13	2	2	3	1	1	5	45	200	4	20	0.002000000
14	2	2	3	1	2	5	45	200	4	30	0.002000000
15	2	2	3	1	3	5	45	200	4	40	0.002666667
16	2	3	1	2	1	5	60	90	8	20	0.002000000
17	2	3	1	2	2	5	60	90	8	30	0.003000000
18	2	3	1	2	3	5	60	90	8	40	0.002333333
19	3	1	3	2	1	10	30	200	8	20	0.002000000
20	3	1	3	2	2	10	30	200	8	30	0.002000000
21	3	1	3	2	3	10	30	200	8	40	0.001666667
22	3	2	1	3	1	10	45	90	12	20	0.003333333

23	**3**	**2**	**1**	**3**	**2**	**10**	**45**	**90**	**12**	**30**	**0.004000000**
24	**3**	**2**	**1**	**3**	**3**	**10**	**45**	**90**	**12**	**40**	**0.003333333**
25	**3**	**3**	**2**	**1**	**1**	**10**	**60**	**150**	**4**	**20**	**0.006333333**
26	**3**	**3**	**2**	**1**	**2**	**10**	**60**	**150**	**4**	**30**	**0.005333333**
27	**3**	**3**	**2**	**1**	**3**	**10**	**60**	**150**	**4**	**40**	**0.006333333**

Time of cut was fixed in 30 minutes in each operation. After 30 minutes operation was finished and the machine gets stop automatically. Then both the electrode material and work-piece material were removed from the machine fixture and cleaned. Final weights of work-piece material measured with the help of weight balance. After completion of first experiment and then all the next experiments performed by same procedure only vary the input parameter. Abrasives mixed EDM experiments were performed using the mild steel tank to avoid any clogging in integrated flushing system of machine tool. For all experiments, initial and final weight of Ti-6Al-4V are measured and used in Eq. (1) to calculate MRR.

IV. RESULTS AND DISCUSSION

A. *The effect of abrasives on discharge mechanism:*

B_4C presence reduces the insulating strength of kerosene and increase the spark gap between copper rod and Ti-6Al-4V plate. This is more accurate process and increases the machining efficiency. The spark gap area is filled by B_4C abrasive particles and increase the gap distance between copper rod and Ti-6Al-4V. The B_4C particles get activated. These particles are near to each other under sparking area and come together in cluster, The interlink takes place due to different shape of B_4C particles and arrange in the shape of chain at various places in sparking area. As result series discharge works under the electrode area, the uniform distribution of discharge takes place which cause uniform wearing away on Ti-6Al-4V, hence results in improvement in MRR. In the current study work, Taguchi method is used to analyze the results of MRR for larger the better criteria. Table 6 describes the ANOVA and F-test data for S/N ratios for MRR.

Table 6. Analysis of variance for signal to noise ratios and F-test data for MRR

Source	DF	Seq SS	Adj SS	Adj MS	F-value	F - critical*	P	Significance
Abrasives Concentration	**2**	**24.208**	**24.208**	**12.104**	**6.46**	**3.63**	**.009**	**Significant**
Pulse off Time	**2**	**8.056**	**8.056**	**4.028**	**2.15**	**3.63**	**0.149**	**Non Significant**
Pulse on Time	**2**	**341.192**	**341.192**	**170.596**	**91.06**	**3.63**	**0.000**	**Significant**
Peak Current	**2**	**11.363**	**11.363**	**5.681**	**3.03**	**3.63**	**0.076**	**Non Significant**
Gap Voltage	**2**	**1.137**	**1.137**	**0.568**	**0.30**	**3.63**	**0.742**	**Non Significant**
Residual error	**16**	**29.976**	**29.976**	**1.873**				
Total	**26**	**415.931**						

ANOVA and F-test values for this study are given in table 6. It is witnessed that B_4C concentrations in kerosene and pulse on time have the significant effect on MRR. F-value of pulse on time is more than other input factors, which indicate that it has the largest contribution towards MRR. Significant effect of B_4C concentration and pulse on time is also clear from their calculated P-value, which is inferior than 0.05 at 95% confidence level. All the other three factors namely pulse off time, peak current and gap voltage are having average affect on MRR. Contribution of these factors is non-significant because the calculated F-value of all these factors are inferior than the F-value taken from table of statisticians. Same witness is shown in terms of P-value, which is larger than 0.05. All the results of ANOVA including F-test value are calculated using $\alpha = 0.05$.

Table 7. Response table for signal to noise ratio for material removal rate

Level	Concentration of B_4C abrasives	Pulse off time	Pulse on time	Peak current	Gap voltage
1	-51.65	-50.80	-50.99	-49.74	-50.79
2	-50.59	-49.76	-45.95	-51.33	-50.30
3	-49.33	-51.01	-54.62	-50.50	-50.48
Delta	2.32	1.25	8.67	1.59	0.50
Rank	2	4	1	3	5

Minimum and maximum values of S/N ratio of all given factors and affiliate levels are used to compute delta value in Table 7. Delta value analyze the comparative signification of factor effects. The higher the delta data the higher the effect the factor have on MRR. Hence delta values of pulse on time and gap voltage are showing them as most effective input factor least effective input factor. Figure 2 shows the main effect plots for S/N ratios of MRR.

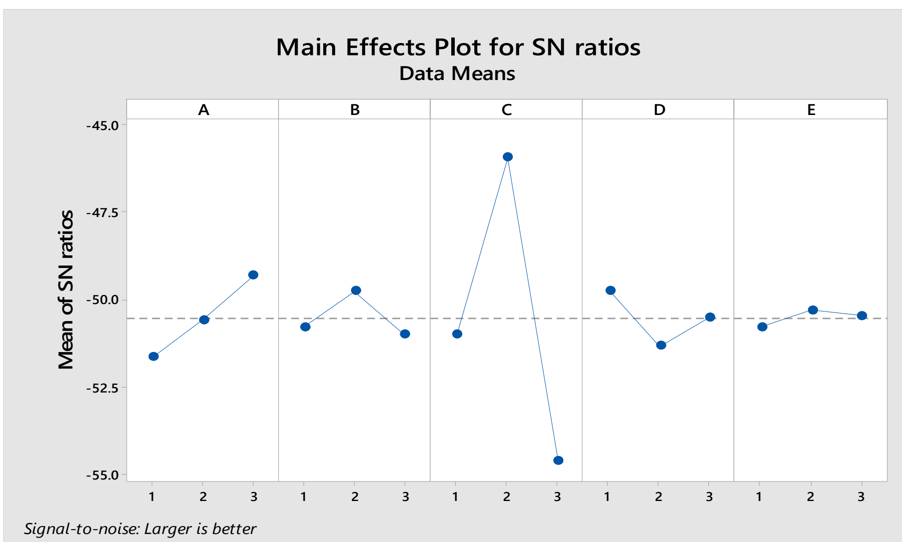

Figure 2. Main effects plot for S/N ratios for MRR

Figure 2 shows more MRR at level 3 of B_4C abrasives concentration in kerosene. Further it is witnessed that addition of B_4C into the kerosene oil as dielectric fluid improves MRR. MRR increases with increase in pulse off time firstly and then decreases. Increase in pulse on time due to higher spark energy in the inter electrode gap, due to maintaining of spark for more time in the inter-electrode gap, is responsible for raising MRR. Increasing peak current produce powerful spark, result increase the temperature, causing more melting and wear away of Ti-6Al-4V when B_4C abrasives added in kerosene oil.

V. **CONCLUSIONS**

On the basis of present experimental study, following conclusions can be drawn:

1. Addition in B4C abrasives in kerosene oil as dielectric improves MRR of EDM of Ti-6Al-4V alloy.
2. At very high peak currents, after a certain critical value at level 2, powerful sparking occurs, resulting the raise in temperature, causing more melting and wear away of material from Ti-6Al-4V surface. Result is improved MRR.
3. Increasing pulse on time is favourable to improve efficiency of EDM of Ti-6Al-4V alloy.

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