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MRR and TWR evaluation on electrical discharge machining of Ti-6Al-4V using tungsten : copper composite electrode

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Abstract. In this paper Ti-6Al-4V used as workpiece material and it is keenly seen in variety of field including medical, chemical, marine, automotive, aerospace, aviation, electronic industries, nuclear reactor, consumer products etc., The conventional machining of Ti-6Al-4V is very difficult due to its distinctive properties. The Electrical Discharge Machining (EDM) is right choice of machining this material. The tungsten copper composite material is employed as tool material. The gap voltage, peak current, pulse on time and duty factor is considered as the machining parameter to analyze the machining characteristics Material Removal Rate (MRR) and Tool Wear Rate (TWR). The Taguchi method is provided to work for finding the significant parameter of EDM. It is found that for MRR significant parameters rated in the following order Gap Voltage, Pulse On-Time, Peak Current and Duty Factor. On the other hand for TWR significant parameters are listed in line of Gap Voltage, Duty Factor, Peak Current and Pulse On-Time.

Keywords: Ti-6Al-4V Electrical Discharge machining, TWR, MRR

1. Introduction

Electrical Discharge Machining (EDM) is on the pioneering machining process for machining hard to machine materials from lot of literature reviews. It comes under the category of non-contact machining process, in a dielectric medium workpiece and tools are impressed, by applying the electrical energy is to create a millions of isolated spark between the workpiece and tool for a micro seconds. This leads to the enormous heat development at the work zone in a dielectric fluid medium and resulted in material removal from both workpiece and tool. The detailed literature review is mentioned below:

The Electrical Discharge Machining finds important applications in drilling small holes in hard to machine materials [1]. J Marafona and C Wykes discovered the electric discharge machining of D2 tool steel using tungsten–copper electrode performed in two stages. The first stage was done using low current intensity and a long pulse duration to move carbon to the

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electrode thus preventing tool wear. The second stage was done using high current intensity and long pulse duration to increase the MRR with reduced TWR [2].

C H C Haron et al done MRR and TWR investigation on EDM of AISI 1045 steel using copper electrodes with diameter of 9.5 mm, 12 mm and 20 mm in two current setting of 3.5 A and 6 A. The MRR and TWR are depends on the diameter of tool and current. The (3.5 A) is suitable for small diameter workpiece. The (6 A) is suitable for large diameter workpiece [3]. The effect of TiC content varying from 5% to 40% in sintered copper-tungsten electrodes on their EDM performance during machining tool steel were studied. The 15% of TiC addition gives better surface finish, lower electrode wear and higher material removal rate has been recorded [4].

P M George et al employed Taguchi method for Electrical Discharge Machining of carbon-carbon composite under different machining conditions namely pulse current, gap voltage and pulse-on-time using copper electrode. Among these gap voltage is most significant and pulse current is ranked next to the gap voltage and pulse on time found to be insignificant on the performance characteristics such as MRR and TWR [5].

En-31 tool steel was electrical discharge machined with copper, copper-tungsten, aluminium and brass electrode materials, the results proved that the Copper tungsten provides better surface finish [6]. S Sivasankar and R Jeyapaul performed electric discharge machining of ZrB_2 using different tool materials namely Titanium, Graphite, Niobium, Tantalum, Tungsten, Stainless Steel, Molybdenum, Copper, Nickel and Silver by ANOVA, Grey and Regression analysis. The tool is having low melting produces irregular shape of the holes. From ANOVA the tool material is important next to that pulse on time. Grey analysis rated the EDM tool is the order of Titanium, Graphite, Niobium, Tantalum, Tungsten, Molybdenum, Nickel, Stainless Steel, Copper & Silver [7].

K M Kumar and P Hariharan did experimental investigation of austempered ductile iron EDM using copper electrode. They conclude that cross sectional area does not depend on the MRR and TWR. The MRR and TWR are increases with increasing the current and pulse on time [8]. T Muthuramalingam and B Mohan reviewed the electrical parameters of electrical discharge machining process and noted that, optimizing the electrical parameters will improves efficiency of electric discharge machining process [9].

With various literature reviews the tool material is one of noted parameter in EDM. Hence this work is intended to attain MRR and TWR Evaluation on Electrical Discharge Machining of Ti-6Al-4V Using Tungsten: Copper Composite Electrode**.**

2. Experimental procedure

The experiment was conducted using Electrical Discharge Machine, model Electrica Ratanparhki 550 x 350 Die Sink EDM as in figure 1 and figure 2 shows the enlarged view of work zone of Electrical Discharge Machine. Titanium Grade 5 (Ti–6Al–4V) alloy of 0.55 mm thickness was used as work material. The dielectric fluid used was EDM oil (specific gravity-0.763).

The work piece and tool material is captured in Figure 3 and 4 respectively. The composition of work material and tool is pointed in the Table 1and 2. The densities of the workpiece and tool material are tested as 4.415 g/cc and 15.2 g/cc. The hardness of the workpiece and tool material are experienced as 363 in HV10 kg and 235 in HV 10 kg.

Figure 1 Electrica Ratanparhki 550 x 350 Die Sink EDM

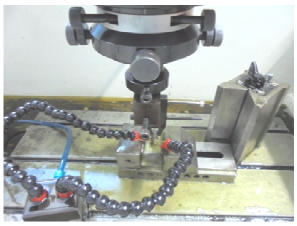

Figure 2 Work zone of EDM

Figure 3 Workpiece – Titanium (Ti-6Al-4V)

Figure 4 Tool-Tungsten:Copper (70:30)

Table 1 Composition of Work piece Material

Composition	Percentage (%)
Aluminium	5.710
Titanium	90.10
Vanadium	3.720
Others	Rest

Table 2 Composition of Tool Material

Composition	Percentage (%)
Tungsten	69.16
Copper	28.62
Nickel	0.67
Manganese	0.16
Vanadium	0.42
Zinc	2.04
Bismuth	0.02
Iron	0.49

The Ti-6Al-4V sheet of 50 x 50 mm of required no is cut by hand shearing machine and Tungsten:copper(70:30) tool is cut wire electrical discharge machine of 3 mm length are prepared. Using Electrical Discharge Machine experiment were conducted for 15 minutes of constant time by considering different levels of Gap Voltage, Peak Current, Pulse On-Time, Duty Factor to analyse the performance charecteristics such as MRR and TWR.

3. Taguchi optimization technique

Taguchi optimization technique offers organized, straightforward and clean methodology for the optimization of the parameters with only a minimum number experimental set that can operate consistently over a wide range of conditions. The L9 Taguchi orthogonal array is planned to carry out the experiment. The significant parameters were determined by using S/N graphs and Response table obtained from Minitab software trail version 15.

The aim of this research work was to determine the process parameters required to achieve higher material removal rate and lower tool wear rate. All machining process parameter was planned to have three levels which are presented in Table 3.

Table 3 Experimental Parameter and their Levels

Machining Process Parameter	Symbol	Levels		
		1	2	3
Voltage (V)	v	50	100	150
Peak Current (A)	I_p	5	10	15
Pulse on time (□s)	T_{on}	20	30	40
Duty Factors (%)	□	3	6	9

4. Results and discussion

The weight of workpiece and tool material is measured before and after machining. The constant time of 15 min set for each experiment. MRR and TWR for all the experiment were calculated using the equations 4.1.

$$Material\ removal\ rate\ = \frac{weight\ before\ machining - weight\ after\ machining}{machining\ time} \quad ....(4.1)$$

Results obtained were tabulated in table 4. The difference of MRR for various experiments is illustrated in figure 5 and 6. It is witness that the larger MRR of experiments are ranked in the following order 2, 3, 1, 6, 4, 9, 5, 8, 7. It is observed that the smaller TWR of experiments are graded in the following order 1, 7, 9, 8, 5, 2, 6, 4, 3.

Table 4 Results of the Experiment

V (v)	I_p (A)	T_{on} (s)	(%)	MRR (mm^3/min)	TWR (mm^3/min)
50	5	20	3	0.00933	0.00004
50	10	30	6	0.01227	0.00101
50	15	40	9	0.00951	0.00157
100	5	30	9	0.00319	0.00123
100	10	40	3	0.00290	0.00085
100	15	20	6	0.00322	0.00113
150	5	40	6	0.00069	0.00013
150	10	20	9	0.00145	0.00023
150	15	30	3	0.00311	0.00018

4.1 Analysis of Machining Performance on MRR

The main effects plot for SN ratios- MRR graphs, as shown in Figure 7, it can be seen that MRR decreases as the gap voltage decreases throughout the entire range. In case of pulse on time, the MRR increases in a similar fashion as the peak current increases. The MRR increases linearly along with the increase in Pulse On-Time up to second level then it starts decreases on the other side for duty factor decreases up to second level then it starts increases. The response table – MRR is created in Table 5 gives the most significant factor for MRR is Gap Voltage and the least significant for MRR is duty factor.

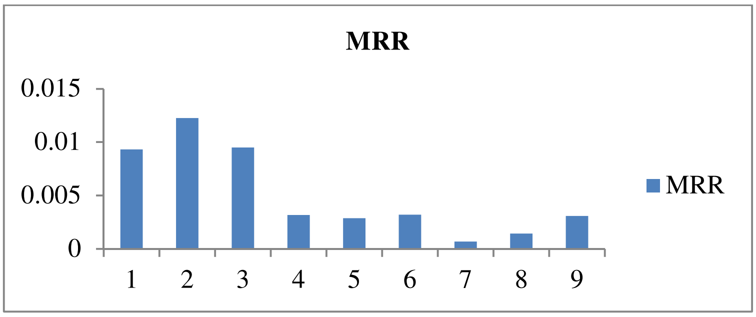

Figure 5 Difference of MRR for Various Experiments

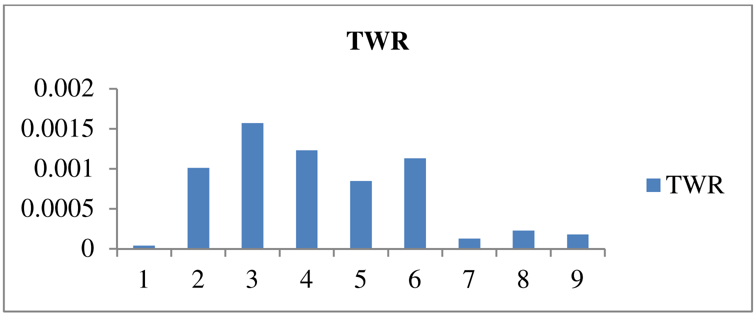

Figure 6 Difference of TWR for Various Experiments

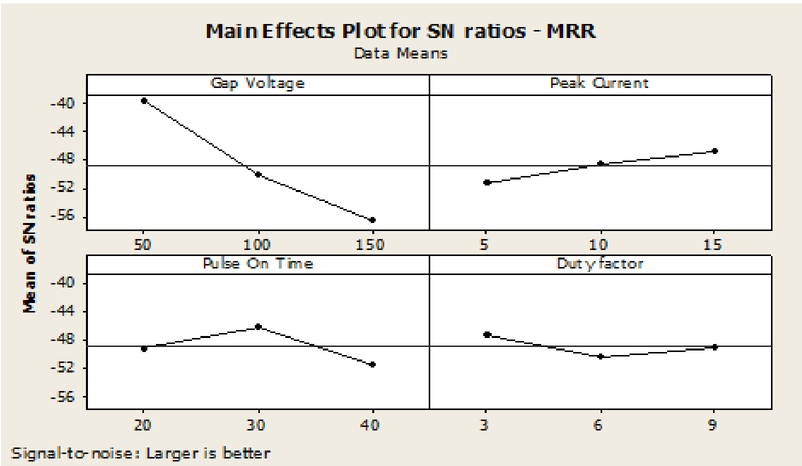

Figure 7 Main Effects Plots for SN ratios – MRR

Table 5 Response Table -MRR

Source	V	I_p	T_{on}	
1	-39.75	-51.25	-49.07	-47.17
2	-50.17	-48.58	-46.10	-50.43
3	-56.71	-46.81	-51.47	-49.04
Delta	16.96	04.44	05.37	03.26
Rank	1	3	2	4

4.2 Analysis of machining performance on TWR

The main effects plot for SN ratios- TWR graphs, as shown in Figure 8, it can be seen that TWR decreases as the gap voltage decreases TWR up to second level then it increases the TWR linearly. In case of pulse on time, the TWR decreases in a similar fashion as the peak current increases. The TWR decreases linearly along with the increase in Pulse On-Time and duty factor increases. The response table – TWR is formed in Table 6 furnish the most significant factor for TWR is Gap Voltage and the least significant for TWR is Pulse On-Time.

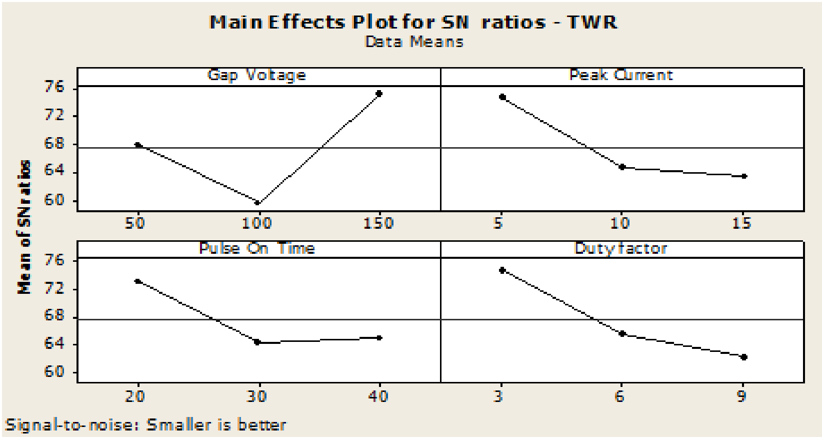

Figure 8 Main Effects Plots for SN ratios – TWR

Table 6 Response Table for TWR

Source	V	I_p	T_{on}	
1	67.98	74.63	73.22	74.75
2	59.52	64.70	64.34	65.52
3	75.13	63.30	65.07	62.35
Delta	15.61	11.32	08.88	12.41
Rank	1	3	4	2

5. Conclusion

The elaborate study on MRR and TWR Evaluation on Electrical Discharge Machining of Ti-6Al-4V Using Tungsten: Copper Composite Electrode has drawn the following conclusions.

The most advantageous combination of process parameters for obtaining maximum MRR are as detected at Gap Voltage 50 V, Peak Current 10 A, Pulse On Time 30 □Sec, Duty Factor 6 % on the other hand minimum TWR are founded at Gap Voltage 50 V, Peak Current 5 A, Pulse On Time 20 □Sec , Duty Factor 3, respectively.

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