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Investigation of Die Sinking Electrical Discharge Machining of Ti-6Al-4V Using Copper and Al_2O_3-TiO_2 Coated Copper Electrode

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Abstract: Electrical Discharge Machining (EDM) is the best and economic process among the newer machining processes for performing conductive hard materials. In this paper Ti-6Al-4V is used as work piece materials, which has high strength-to-weight ratio and surprising corrosion resistance at very high temperature. The copper and Al_2O_3-TiO_2 coated copper is used as tool materials. Taguchi method is applied to create an L9 orthogonal array of input variables such as Current (I_p), Pulse On-Time (T_{on}) and Duty Factor (τ) using the design of experiments. The effect of the variable parameters such as Material Removal Rate (MRR), Tool Wear Rate (TWR) and Overcut (OC) is studied and investigated. The MRR, TWR and OC is increases with increases in peak current, followed by pulse on time and lastly the duty Factor. The experiment result clears that Al_2O_3-TiO_2 coated copper electrode gives optimum performance of 92 % reduced TWR and 62.5 % decreased OC.

Key words: Ti-6Al-4V · EDM · ANOVA · MINITAB

INTRODUCTION

Ti-6Al-4V alloy has unique properties, it is widely used in applications such as gas turbines, electric power generation equipment, nuclear reactors and high temperature chemical vessels, aerospace, automotive industries, MEMS products, dies manufacturing industries, aero engines, bio medical industries, medical instruments and consumer products [1,2]. The conventional machining of required feature on Ti6-Al-4V is tough and involving high tooling and also machining cost. These pitfalls are cultivated by the Electrical Discharge Machining (EDM) processes.

EDM is one of the best non-traditional machining processes purely intended for machining electrically conductive materials of any hardness, to obtain intricate shapes with high accuracy [3]. EDM erodes the material from the work piece by a series of discrete spark between the work and tool immersed in dielectric medium [4]. The nature of the plasma channel between the tool and work piece strongly affects MRR. However, the Material Removal Rate and dimensional accuracy of the machined product produced by the EDM process is greatly influenced by the electrode material.

The electrical discharge machining of Bohler Steel W300 was performed by different grades of graphite electrode the results shows that current has main influence on the MRR and electrode wear depends on pulse duration[5]. The Electric Discharge Machining of Ti–6Al–4V is done by using graphite, electrolytic copper and aluminium. In that, copper electrode creates surface cracks it can be overcome by graphite and aluminium electrode and graphite electrode gives better MRR among others. In additions aluminium electrode gives best surface finish [6].

The end results of another work reveled that copper electrode provides good SF, higher MRR and lower TWR than aluminum electrode. The copper electrode provides the best optimal value for the machining AISI 202 stainless steel [7].

With diverse literature review the electrode material is one of important parameter in EDM. Hence this work is intended to perform experimental investigations into the

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EDM-drilling of macro holes on Ti-6Al-4V plates with copper electrode and Al_2O_3-TiO_2 coated copper electrodes.

Experimental Procedure: The all the experiment were done using the Electrical Discharge Machine, model ELECTRONICA-ELECTRAPLUS PS 50ZNC Die Sink EDM as shown in Figure 2.1.

Fig. 2.1: ELECTRAPLUS PS 50ZNC

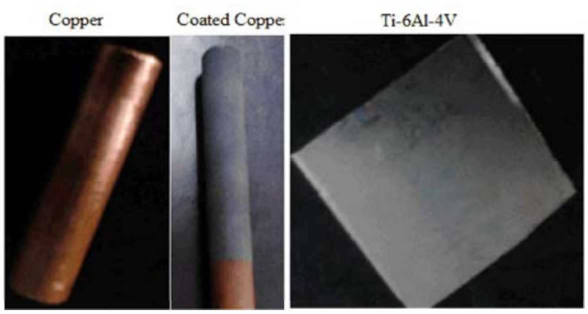

Fig. 2.2: Electrodes and Work piece Material

Copper was used as tool material in two different fashions like copper and Al_2O_3-TiO_2 coated copper electrode. The electrode diameter of 9.7 mm without coating was used for machining. To obtain very superior properties copper electrode was coated with 100 micron titanium-based aluminum oxide coating. Titanium Grade 5 (Ti–6Al–4V) alloy of 0.55 mm thickness was used as work material. The electrode and work piece material is captured in Figure 2.2.The composition of work material is drawn in the Table 2.1. The dielectric fluid used was EDM oil (specific gravity-0.763).

Table 2.1: Composition of Work piece Material

Composition	Al	Ti	V	Others
Percentage (%)	5.710	90.10	3.7200	Rest

The through hole was machined in Ti-6Al-4V using copper Electrode under varying combination of machining processes parameter such current, pulse on time and duty factor to analyze the performance characteristics such as material removal rate, tool wear rate and overcut.

Optimization: The experiments were conducted using Taguchi L9 design approach. This design provides a potential and efficient method for designing different products that can operate consistently over a wide range of conditions. The optimal process parameters were determined by using S/N graphs. The importance and each influential parameter that affect each of the MRR, TWR and OC were found out using ANOVA method. The objective of this research work was to determine the process parameters required to achieve higher material removal rate and lesser overcut and tool wear rate. The S/N graphs and the ANOVA results were constructed by using the statistical software MINITAB. Each process parameter was planned to have three levels which are presented in Table 3.1 and the experimental results were accessible in Table 3.2

Table 3.1: Experimental parameter

		Levels		
Machining Process Parameter	Symbol	1	2	3
Current (A)	I_p	2	5	8
Pulse on time (μs)	T_{on}	50	100	150
Duty Factors (%)	τ	60	70	80

Table 3.2: Results of the experiment

I_p (A)	T_{on} (μs)	τ (%)	MRR (mm3/min)	TWR (mm3/min)	OC (mm)
2	50	60	0.22035	0.01000	0.010
2	100	70	0.20423	0.01323	0.086
2	150	80	0.20208	0.01323	0.086
5	50	70	0.21068	0.00310	0.106
5	100	80	0.22573	0.53260	0.144
5	150	60	0.42513	0.00992	0.094
8	50	80	0.25193	0.22118	0.174
8	100	60	0.25446	0.01961	0.185
8	150	70	0.25309	0.01826	0.201

RESULTS AND DISCUSSIONS

Analysis of Machining Performance on MRR: The S/N graphs, as shown in Fig. 4.1, it can be seen that MRR increases as the current increases throughout the entire range. In case of pulse on time, the MRR first slightly decreases up to 100 μs and then increases in a similar fashion till 150 μs. The MRR increases linearly along with the increase in duty factor within the range but the magnitude of increase is not very large.

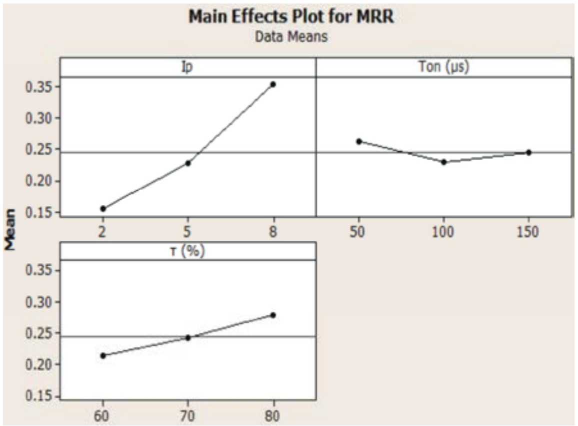

Fig. 4.1: Main effects plot for MRR

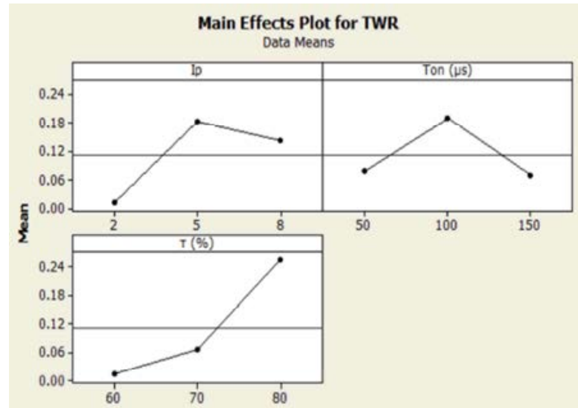

Fig. 4.2: Main effects plot for TWR

From ANOVA table for MRR Table 4.1 it can be noted that standard deviation of errors in the modeling, S=0.0336. R^2=96.78% which indicates that the model is capable of predicting the response with a high accuracy.

Table 4.1: ANOVA Table for MRR

Source	DF	Seq SS	Adj SS	Adj MS	F	M
IP	2	0.060539	0.060539	0.030270	26.66	0.036
Ton	2	0.001490	0.001490	0.000745	0.660	0.604
τ	2	0.006245	0.006425	0.003123	2.750	0.267
Error	2	0.002271	0.002271	0.001135		
Total	8	0.070545				

S=0.0336952 R^2 = 96.78% R^2 (Adj)=87.12%

It can be noted from the response table for MRR Table 4.2 it can be seen that the most significant factor is IP followed by Ton and the least significant being τ.

Table 4.2: Response Table for MRR

Source	I_p	T_{on}	τ
1	01.924	8.720	08.123
2	08.627	9.780	09.573
3	17.218	9.268	10.072
Delta	15.924	1.060	01.949
Rank	1	2	3

Analysis of Machining Performance on TWR: The S/N graphs, as Figured in Fig. 4.2, it can be seen that TWR increases with respect to current till 5 A but further decreases with smaller magnitude. In case on pulse on time the MRR increases till 100 µs further decreases in the similar fashion and with respect to duty factor,the TWR increases with smaller magnitude.

The ANOVA table for TWR Table 4.3 it can be observed that standard deviation of errors in the modeling, S=0.204067, R^2=67.28% which indicates that the model is capable of predicting the response with a high accuracy.

Table 4.3: ANOVA Table for TWR

Source	DF	Seq SS	Adj SS	Adj MS	F	M
IP	2	0.04708	0.04708	0.02354	0.57	0.639
Ton	2	0.02664	0.02664	0.01332	0.32	0.758
τ	2	0.09751	0.09751	0.04875	1.17	0.461
Error	2	0.08329	0.08329	0.04164		
Total	8	0.25452				

S=0.204067 R^2 = 67.28% R^2 (adj)=0.00%

From the response table for TWR Table 4.4 it can be seen that the most significant factor is IP followed by Ton and the least significant being τ.

Table 4.4: Response Table for TWR

Source	I_p	T_{on}	τ
1	0.05933	0.09367	0.11656
2	0.11856	0.12600	0.13689
3	0.19533	0.15356	0.11978
Delta	0.13600	0.05989	0.02033
Rank	1	2	3

Analysis of Machining Performance on OC: The S/N graphs, as illustrated in Figure 4.3, it can be seen that overcut increases as the current increases throughout the entire range. In case of pulse on time, the overcut first slightly increases up to 100 µs but the magnitude of increase is not very large and then increases in a similar fashion till 150 µs.

The overcut increases linearly along with the increase in duty factor till 70% and then decreases in the similar fashion.

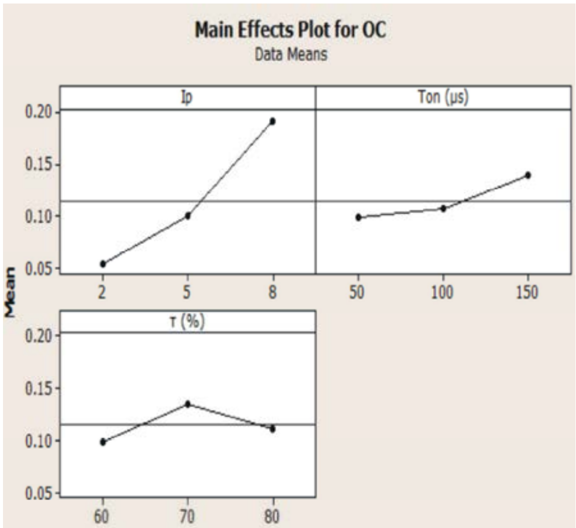

Fig. 4.3 Main effects plot for OC

With the given ANOVA table for OC Table 4.5 it can be viewed that current and pulse on time are the significant parameters. Also there are no significant interactions. The standard deviation of error S=0.0332 and R^2= 93.86%.

Table 4.5: ANOVA Table for OC

Source	DF	Seq SS	Adj SS	Adj MS	F	M
IP	2	0.029107	0.029107	0.014553	13.15	0.071
Ton	2	0.002675	0.002675	0.001337	01.21	0.453
T	2	0.002074	0.002074	0.001037	00.94	0.516
Error	2	0.002214	0.002214	0.001107		
Total	8	0.036069				

S=0.0332683 R^2 = 93.86% R^2 (adj)=75.45%

The response table for OC Table 4.6 it can be seen that the most significant factor is IP followed by Ton and the least significant being τ.

Table 4.6: Response Table for OC

Source	I_p	T_{on}	τ
1	0.05933	0.09367	0.11656
2	0.11856	0.12600	0.13689
3	0.19533	0.15356	0.11978
Delta	0.13600	0.05989	0.02033
Rank	1	2	3

Experiment with Coated Electrode: In order to carry out the experiment with the ceramic coated tool, the worst case of the result obtained in the usual copper tool was found, the machining parameters were set for that parameter, to find whether any significant decreases in the tool wear rate was there. In addition that the current 2A pulse on time 150µs and duty factor of 80 % will be resulted in poor material removal rate. The current 5A pulse on time 100 µs and duty factor of 80 % it can produce higher tool wear. Further particularly 8A and pulse current 150 µs and duty factor 70 % will be resulted in worst overcut. At this junction we repeat the experiment by considering the current of 5amps, pulse on time 100 and duty cycle of 80% and are mentioned in Table 4.7.

Table 4.7: Results of the experiment

Tool material	I_p	T_{on}	τ	MRR	TWR	OC
Al_2O_3-TiO_2 Coated copper	5	100	80	0.34256	0.042311	0.04400

CONCLUSION

An extensive experimental study has been conducted to investigate the effects of the machining parameters on machining characteristics in EDM of Ti6Al4V with copper and Al_2O_3-TiO_2 coated copper electrode. Based on the experimental result and Taguchi method of optimization the following conclusion is drawn:

- While machining copper electrode, optimal combination of process parameters for obtaining maximum MRR is peak current: 5 A, pulse on time: 150 µs, duty factor: 60 % and the optimal combination of process parameters for obtaining minimum TWR is peak current: 5 A, pulse on time: 50 µs, duty factor: 70 %.
- Furthermore the optimal combination of process parameters for obtaining minimum OC is peak current: 2 A, pulse on time: 50 µs, duty factor: 60 %.
- The most significant factor was found to be peak current followed pulse on time and lastly the duty factor.
- On the other hand based on the experiment done with Al_2O_3-TiO_2 coated copper electrode there will be 92% saving in electrode wear and 62.5 % reduction overcut is observed while machining Ti6Al4V alloy.

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