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Research Article

EXPERIMENTAL INVESTIGATION OF ELECTRICAL DISCHARGE MACHINING (EDM) OF INCONEL 750

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ABSTRACT

This paper investigates spark electrical discharge machining (EDM) on super alloy Inconel 750. The tool used is copper electrode. The process performance is measured in terms of material removal rate, tool wear rate and also surface roughness (Ra). The input parameters like current, pulse-on time and pulse-off time are varied for each reading. Readings are taken as per Box Benhken experimental design. The tool wear and material removal rate are measured by using weight reduction method. Surface roughness is measured using surface roughness tester (MahrSurf GD120) machine. The result shows that the MRR is directly proportional to the current. While tool wear rate is highly affected by current variation and low surface roughness is obtained at low current levels. When pulse on time and current are kept constant the MRR changes according to pulse off time. Using Minitab software quadratic regression equations denoting relation between various parameters are obtained. Optimum levels for the process parameters for achieving high MRR, low TWR and low surface roughness (Ra) are studied.

INTRODUCTION

The spark electrical discharge machining (EDM) process is most widely used machining process in all non- traditional machining processes. It is a controlled material removal technique in which electric spark is used to cut the material. The shape formed on the material is opposite to that of electrode or cutting tool. Spark EDM involves the removal of electrically conducting material by starting of continuous spark between electrode and workpiece separated by a very small gap. The electrode and workpiece setup is immersed in dielectric fluid. The fluid gets ionized when the sparking starts thus allowing the current to flow from workpiece to electrode. The spark EDM process is mainly implemented to shape tough metals & create deep as well as different shaped holes by erosion various types of the electro conductive materials.

In spark EDM process the main influencing factors of machining are pulse ON time (T_{on}), current and pulse OFF time (T_{off}) which shows greater impact on parameters like surface roughness (Ra), tool wear rate and material removal rate. Currently, there is not much data available on spark EDM of Inconel 750 using copper electrode [P. Karthikeyan and J. Arun, 2014]. The main objective in spark EDM is to achieve high rate of material removal and low TWR to increase the productivity.

It was concluded that the electrode tool with negative polarity performs better in terms of MRR & lesser tool wear. Authors also concluded that higher the discharge current more is the MRR & surface roughness & vice versa (Harpinder, Vidhata, Jatin and Gurpreet, 2015).

The MRR, Ra, EWR are mainly affected by pulse ON time (Ton) and current while spark EDM of Inconel 718 (Maheshwari, Bharti and Sharma, 2010). Analysis of the effect of pulse ON time, flushing pressure, current & tool- workpiece gap on MRR was carried out. It was found that the current and pulse ON time influence the machining of Inconel 718 (Sharma, Rajesha and Kumar, 2011). Better MRR & good surface finish with magnetic force assisted spark EDM was obtained (Karthik, Arun, Soundararajan and Palanisamy, 2009). The MRR is directly related with current and pulse duration. Maximum MRR of 28.37 mm3/ min at 40 A of peak current & 400 µs pf pulse duration was achieved. EWR is directly proportional to peak current but it reduces gradually with rise in pulse duration. Better surface roughness (Ra) value can be produced by using lower peak current along with higher pulse duration (S. Ahmad and Lajis, 2015). Analysis of performance of EDM on W-300 die steel work material on adding aluminium metal powder to the distilled water was done. The polarity has major role in powder mixed EDM. High MRR for positive polarity while better surface roughness was achieved at negative polarity.

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Positive polarity could be selected for rough machining but for better surface roughness negative polarity is selected (Khalid and Kuppan, 2012). According to study carried out on comparative analysis of the performance of machining on stainless steel, it was found that material removal rate (MRR) increases with voltage and current. Also, while machining of carbide, electrode wear was higher than that of machining of stainless steel (Shankar, Boopathi and Prabu, 2015).

Experimental Setup

Inconel 750 specimen was used for machining under different conditions to study the influence of a current and pulse on time on material removal rate (MRR), electrode wear rate (EWR) and surface roughness (Ra). The experiments are performed by using die sinking EDM (spark erosion) machine, where hydrocarbon used as a dielectric fluid. The workpiece Inconel 750 wasqa cut into rectangle specimen of 40*60*8mm size. The specimen was machined with 9mm diameter, copper electrode. The chemical composition of specimen is shown in table 1. The parameters varied are current, pulse on time (T_{on}) and pulse-off time (T_{off}). Machining time is fixed as 10 minutes.

Fig. 1 Actual setup of electric discharge machine (EDM)

Workpiece material

The work material used is Inconel 750, which is precipitation hardenable nickel-chromium alloy. Inconel 750 can be used to manufacture complex shaped components having high stress, good corrosion resistance and high heat resistance.

Table I Chemical composition of Inconel 750

Elements	Min. (%)	Max. (%)
C	-	0.08
Mn	-	1
Si	-	0.5
S	-	0.01
Cr	14	17
Ni	70	-
Nb/Cb	0.7	1.2
Ti	2.25	2.75
Al	0.4	1
Fe	5	9
Co	-	1
Ta	-	0.05
Cu	-	0.5

Also Inconel 750 has high creep resistance when subjected to high stress. The Inconel 750 is mainly used in aerospace and marine industries as well as in nuclear reactors, gas turbines and rocket engines.

Table 2 Physical properties of Inconel 750.

Density	8.28 g/cm3
Melting point	1430 °C
Coefficient of expansion	12.6 µm/m °C
Modulus of Rigidity	75.8 kN/mm²
Modulus of Elasticity	211 kN/mm²
Ultimate Tensile Strength	1120 -1250 MPa
Yield Tensile strength	760 -850 MPa
Electrical Resistivity	0.000122 ohmcm
Thermal Conductivity	12 W/mK
Specific Heat Capacity	0.431 J/g°C
Hardness	39 HRC

Electrode material

Copper is chosen as electrode material. Copper has good conductivity. It also has good strength, ductility and low magnetic permeability. It has resistance to corrosion, wear and shock. Copper finds its application in various fields.

Design of Experiment

The Box Behnken method is used for the design of experiment. Box-Behnken designs all design points fall within safe operating zone. In this method it is ensured that all factors are not at their highest level simultaneously. They are usually coded as -1, 0, +1. Here the design is carried out considering three factors, current, pulse-on time and pulse-off time. For the 3 process parameters L15 orthogonal array is obtained. Each and every experiment is carried out for 10 minutes. As per Box Behnken design of experiment total 15 holes are drilled. The current, pulse-on time and pulse-off time are varied for each reading as per experimental design. After EDM is performed on the workpiece, the following experimental methods are used to calculate MRR, TWR and surface roughness (Ra):

1. Weight reduction method: Calculating MRR and TWR by calculating the weight loss of specimen and tool (copper electrode) before and after machining process.
2. MarSurf GD 120 surface roughness tester is used to measure the surface roughness value (Ra). Principle of tester is based on stylus method. The cut-off length for each measurement trace is 0.25 µm and the transverse length is 1.75 mm for 15 holes.

The MRR is obtained using the equation,

$$MRR = ((Wb - Wa)\ 1000 / t)\ mg/min \qquad ……(1)$$

Wb = the initial weight of the Inconel 750 workpiece (gm)
Wa = weight of workpiece after carrying out machining (gm)
t = machining duration (10min)

The EWR was determined using the equation,

$$EWR = ((Eb - Ea)\ 1000 / t)\ mg / min \qquad …. (2)$$

Eb = the initial weight of the electrode (gm).
Ea = the weight of copper electrode after machining (gm). t = machining duration (10min)

Table 3 Experimental conditions and process parameter

Workpiece	Inconel 750
Electrode	Copper ø 9 mm
Voltage	40V
Machining duration	10 min
Peak current (A)	4 , 7 , 10
Pulse on time (µs)	60 , 80 , 100
Pulse off time (µs)	32 , 43 , 54
Dielectric fluid	Hydrocarbon oil
Flushing pressure	0.5 bar

EXPERIMENTAL RESULTS AND DISCUSSION

Experiments were conducted as per the experimental design and results were obtained as in table given below. Regression equation for parameters like MRR, EWR and Ra are calculated using Minitab software.

Table 4 Experimental results

Sr. No.	Current (A)	Ton (µs)	Toff (µs)	MRR (mg/min)	EWR (mg/min)	Ra (µm)
1	7	80	43	220.1	1.4	3.429
2	4	80	54	100.6	0.3	3.608
3	4	100	43	140.3	0.6	3.239
4	7	80	43	232.2	1.4	4.071
5	10	80	54	300.7	1.3	3.687
6	7	60	32	210.9	1	3.771
7	10	80	32	346.2	2.9	4.061
8	7	100	32	235.9	0.3	3.433
9	7	60	54	170.4	1.7	3.434
10	4	60	43	97.5	0.4	3.594
11	4	80	32	111.4	0.3	3.099
12	10	100	43	308.8	2.4	4.147
13	7	100	54	213.4	0.9	3.378
14	10	60	43	255.6	2.8	4.438
15	7	80	43	236.1	1.4	3.832

A. *Influence of current on material removal rate (MRR)*

The MRR increases with the peak current. Due to increase in value of peak current energy of the pulse increases. Intensity of the energy generated in the gap between electrode and workpiece is more at high values of peak current. High energy pulse removes more material thus increasing MRR. [8] The minimum value of MRR is 97.5 mg/min at current of 4 A, Ton of 60 µs and Toff of 43 µs. While maximum value of MRR obtained is 346.3 mg/min at 10 A, with Ton 80 µs and Toff 32 µs. The MRR increases with the peak current. Due to increase in peak current value energy of the pulse increases. Intensity of the energy generated in the gap between electrode and workpiece is more at high values of peak current.

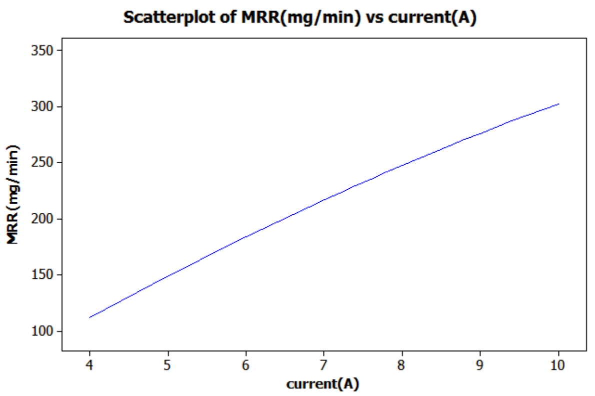

Fig. 3 Influence of peak current on MRR

High energy pulse removes more material thus increasing MRR. The minimum value of MRR is 97.5 mg/min at peak current of 4 A, Ton of 60 µs and Toff of 43 µs. While maximum value of MRR obtained is 346.3 mg/min at 10 A, with Ton 80 µs and Toff 32 µs. The average MRR at a current of 4 A was found to be around 112.375 mg/min. When current is increased to 10 A, the average MRR achieved is around 302.825 mg/min.

The regression equation for MRR is

$$MRR = -33.8 + 1.02\,Ton + 31.71I - 1.36\,Toff \ldots (3)$$

B. *Influence of current on electrode wear rate (EWR)*

The graph (fig. 4) shows effect of peak current on electrode (tool) wear rate (EWR). The high current leads to increase in electrode wear at all condition of Ton and T_{off}. High spark energy is generated due to high peak current which increases rate of material removal from workpiece which also leads to increase in electrode wear.[7] The average electrode wear at a current of 4 A is 0.4 mg/min. The electrode wear rate is maximum for the maximum peak current of 10 A and its average value is 2.35 mg/min. Maximum tool wear take place at a current of 10 A with T_{on} 80 µs and T_{off} 32 µs. Results indicate that machining should be done at lower values of peak current to keep tool wear low and thus increasing the tool life.

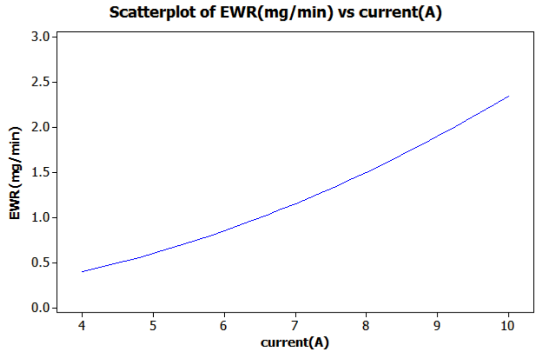

Fig. 4 Effect of current on EWR

The regression equation for EWR is

$$EWR = -0.01 - 0.0106Ton + 0.325\,I - 0.0034Toff \ldots (4)$$

C. *Effect of parameters on surface roughness (Ra):*

Using surface roughness tester following values of Ra is obtained.

Table 5 Surface roughness values for different input parameters

Sr. No.	Current (A)	T_{on} (µs)	T_{off} (µs)	Ra (µm)
1	7	80	43	3.429
2	4	80	54	3.608
3	4	100	43	3.239
4	7	80	43	4.071
5	10	80	54	3.687
6	7	60	32	3.771
7	10	80	32	4.061
8	7	100	32	3.433
9	7	60	54	3.434
10	4	60	43	3.594
11	4	80	32	3.099
12	10	100	43	4.147
13	7	100	54	3.378
14	10	60	43	4.438
15	7	80	43	3.832

Surface roughness (Ra) value directly depends upon the magnitude of current. When current used is of low magnitude flattened and shallow crater formation takes place. As magnitude of current is increased for machining high amount of heat gets generated. Fast melting of metal takes place leading to formation of deeper and large crater thus affecting surface roughness adversely. [8] Best surface roughness value (Ra) value is obtained at low current of 4A with T_{on} of 80µs and T_{off} of 32µs.

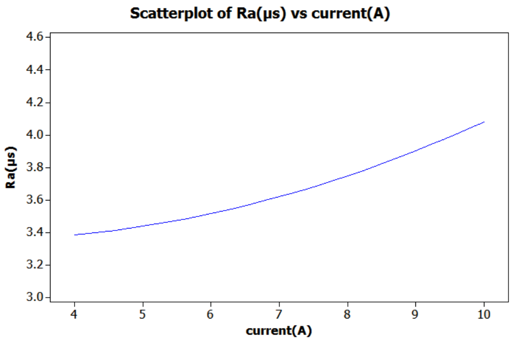

Fig. 5 Influence of current on surface roughness (Ra)

The regression equation for Ra is

$$Ra = 3.51 - 0.00650\,Ton + 0.116\,I - 0.00293\,Toff \quad ..(5)$$

D. Effect of T_{on} and T_{off} on MRR:

From analyzing the results of experiment it is found that T_{on} and T_{off} have influence on the MRR. MRR increased when Ton was increased. This is mainly because overall pulse duration, in machining time of 10 minutes, increases. MRR decreases with increase in T_{off}. At high value of T_{off} time gap between two consecutive pulse on time increases thus reducing the MRR. Compared to current effect of T_{on} and T_{off} on MRR is very less.

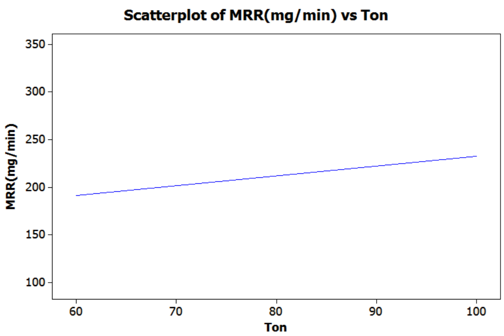

Fig. 6 Effect of Ton on MRR

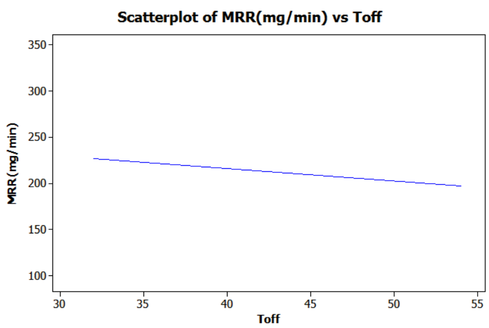

Fig. 7 Influence of MRR on Toff

CONCLUSION

Based on the results obtained following conclusion were made:

1. Maximum value of MRR is obtained at a current of 10A, T_{on} 80µs and T_{off} 32 µs. MRR is directly proportional to the magnitude of peak current (I).
2. Low EWR was achieved at a low current of 4A, T_{on} 80µs and T_{off} 54 µs. Tool wear increased with increase in peak current (I).
3. Surface roughness value (Ra) is lowest at low peak current (I) of 4 A, T_{on} 80 µs and T_{off} 32 µs. Value of the peak current should be kept low to attain a good surface finish.
4. During machining when peak current (I) and pulse on time (T_{on}) were kept constant the MRR was inversely proportional to the value of pulse off time (T_{off}).

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