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Optimization of Process Parameters in Electric Discharge Machining Of Inconel 718 by Using Copper Electrode

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Abstract: *Electrical discharge machining, commonly known as EDM, is a process that is used to remove metal through the action of an electrical discharge of short duration and high current density between the tool and work piece. There are no physical cutting forces between the tool and work piece. This paper reports the results of an experimental investigation carried out to study the effects of machining parameters such as current, voltage and pulse on time on material removal rate in electrical discharge machining of Inconel 718, by using copper as an electrode. The process has been successfully carried by Response surface methodology (RSM) and model adequacy is carried out by using Minitab software. Finally an attempt has been made to estimate the optimum machining condition to produce best possible response within experimental constraints. It is observed that current is most affecting parameters for MRR, while voltage and pulse on time are less significant for MRR.*
Keywords: *Electrical discharge machining, current, voltage, pulse on time, response surface methodology, Inconel 718, material removal rate.*

I. Introduction

The EDM is one of the most promising and widely used non-conventional machining processes. the machining of super alloys, metal matrix composites, advance ceramics etc., with close precision and surface finish can be done by EDM satisfactory where the traditional machining fails. The EDM is thermo electrical material removal process, in which the tool and the Workpiece are connected to two electrodes and separated by a dielectric fluid A.K.khanra et.al (2006) [1]. The spark erosion of work material makes use of electrical energy, converting them into Thermal energy through a series of respective electrical discharges between tool electrode and work material electrode. Thermal energy generates a channel of plasma between two electrodes, at a temperature ranging from 8000^{0}C to 12000^{0}C and as high as 20000^{0}C Shankar Singh et.al (2004) [2].machining process is to be carried out in absence of oxygen so that the process can be controlled and oxidation avoided. Oxidation always leads to poor surface conductivity (electrical) of work piece hindering further machining. Hence dielectric fluid should provide an oxygen free machining environment N.Arunkumar et.al. (2012) [4].since long EDM is widely used in industry to machine ‘difficult to machine materials’ like HCHC steel (tool and die material) Inconel 718 is one of the alloy that have relatively poor machinability in the conventional machining processes, due to its work hardening nature, relation of high strength at high temperature (700 k) and low thermal conductivity for Inconel alloy, EDM is preferred material removal process due to advantages like reduced machining stresses, lesser work hardening effects and lesser metallurgical damage. Machining of material like Inconel through EDM processes is complex in nature. Inconel 718 is precipitation-hardened nickel-chromium alloy. it contain substantial levels of iron, molybdenum and nibonium and trace amounts of titanium and aluminum, processing high strength and temperature resistance combined together establishing the process capabilities of EDM for machining Inconel 718 and optimizing the process is important, since it has wide specialized engineering applications, like components of nuclear reactor, space craft, steam turbine and propulsion system M.Manohar et.al (2014) [8].studies show that selection of process variables and fixing the appropriate range of parameters to machine every product, decide the quality of the product and in turn design requirements Shankar sing et.al (2004) [2].considering the research done by others on different work materials and taking into account of the machining characteristics of Inconel 718 alloy, EDM experiments were carried out with copper electrode and analyzed for their adaptability to material.

II. Experimental Set Up And Material

2.1. Machine Tool & Die-Electric Medium

All the experiments where performed on die sinking ‘ZNC-50 ELECTRONICA EDM’ machine. For the experimentation purpose “RUST LICK-30” oil having dielectric strength 45 kW was used as a dielectric medium at a flushing pressure of 0.25 kg/cm^3. Fig.2.1 shows ZNC-50 electro discharge machine which is used for the experimental work and fig.2.2 shows Quill with side flushing system that is for tool holding and flushing the debris out of the working zone. The dielectric fluid should possess two conflicting properties that is the spark conductor that must ionize under the applied voltage at the same time it should not get break down in the spark gap. It should acts as flushing medium that carries away the melted material.

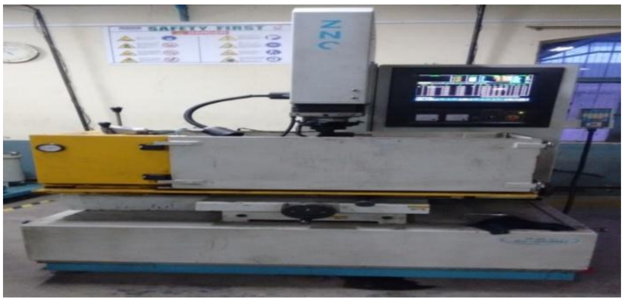


Fig. 2.1: EDM Machine

Fig. 2.2: Quill with side flushing

2.2. Work Piece Material

The work material chosen for the experimental purpose was Inconel 718. Total 20 holes are drilled of diameter 10 mm over 4 plates of size (90×20×4) mm. it has wide specialized engineering applications, like components of nuclear reactor, space craft, steam turbine and propulsion system. The chemical composition & Physical properties of Inconel 718 are listed in table.

Table 2.1: Chemical composition of Inconel 78

Element	Ni+Co	Cr	Fe	Nb+Ta	Mo	Ti	Al
Content	50-55%	17-21%	Bal	4.75-5.5 %	2.8-3.33%	0.65-1.15%	0.2-0.8%

Table 2.2: Physical Properties of Inconel 718

Coefficient of Expansion (^{0}C)	20-100
Melting point (^{0}C)	1336
Modulus of Rigidity (KN/mm^2)	77.2
Modulus of Elasticity (KN/mm^2)	204.9

2.3 Electrode Material

With the Advancement in EDM Copper becomes the metallic Electrode material of preferences. Again due to its tool making culture that is adverse to untidiness of working with Graphite, Copper is generally preferred as electrode of choice. For experimental purpose copper electrode of diameter 10 mm is employed. The physical properties of copper electrode are listed in table.

Table 2.3: Physical properties of copper electrode

Specific gravity (g/cm^3)	8.94
Melting range (^{0}C)	1065-1083
Thermal Conductivity (W/m-k)	388
Specific heat (J/kg-k)	385
Electrical resistivity (ohm-cm)	1.7×10^{-6}
Thermal expansion co-efficient (1/ ^{0}C)	16.7×10^{-6}

2.4 Machining Performance Evaluation

The material removal rate is expressed as the ratio of difference of weight of the work piece before & after machining to the machining time into density as shown in equation.

$MMR = (W_{tb} - W_{ta}) / T \times D$ … (2.1)

W_{tb}- Weight before machining of work piece (gm)

W_{ta}- Weight after machining of work piece (gm)

T - Time consumed for machining (min)

D- Density of work piece material (gm/m^3)

2.5 Theory of Experimental Design

The main objective of experimental design is studying the relations between the response as a dependent variable & various parameters levels. It provides opportunity to study not only the individual effects of each factor but also their interactions. Design of experiment is a method used for minimizing the numbers of experiments to achieve the optimum condition.

The design of experiments for exploring the influences of various predominant EDM process parameters (eg. Pulse on time, Pulse off time, Peak current, Average gap voltage, Dielectric fluid etc.) on the machining characteristics (eg. Material removal rate, Electrode wear rate, gap size, Surface finish etc.) Where modeled. In the present work experiments where designed on the basis of experimental design technique using Response surface method.

2.6 Response Surface Methodologies

Response surface methodology (RSM) is a collection of mathematical and statistical techniques useful for analyzing problems in which several independent variables influence a dependent variable or response, and the goal is to optimize this response. In many experimental conditions, it is possible to represent independent factors in quantitative form as given in equation 2.1. Then these factors can be thought of as having a functional relationship with response as follows

$$Y = \phi\,(x_1, x_2, x_3 \ldots\ldots\ldots\ldots x_k) \pm er \qquad \ldots (2.2)$$

This represents the relation between response Y and x_1, x_2… x_k of k quantitative factors. The function ϕ is called response surface or response function. The residual er measures the experimental errors. For a given set of independent variables, a characteristic surface is responded. When the mathematical form of Φ is not known, it can be approximated satisfactorily within the experimental region by a polynomial. Higher the degree of polynomial better is the correlation but at the same time costs of experimentation become higher.

2.7 Response Surface Design

The present article gives the application of the response surface methodology. The scheme of Carrying out experiments was selected and the experiments were conducted to investigate the effect of process parameters on the MRR. The experimental results will be discussed subsequently in the following sections. The selected process variables were varied up to three levels and face-centered central composite design was adopted to design the experiments as shown in figure 2.3. Response Surface Methodology was used to develop second order regression equation relating response characteristics and process variables.

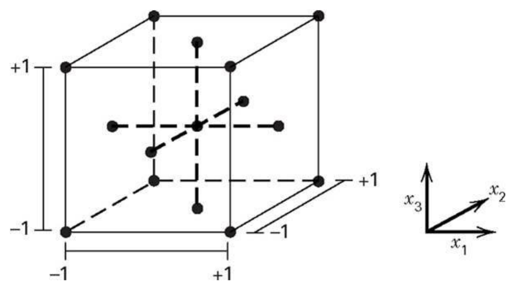


Fig. 2.3: Face centered central composite design for k=3

2.8 Machining Parameters And Their Levels

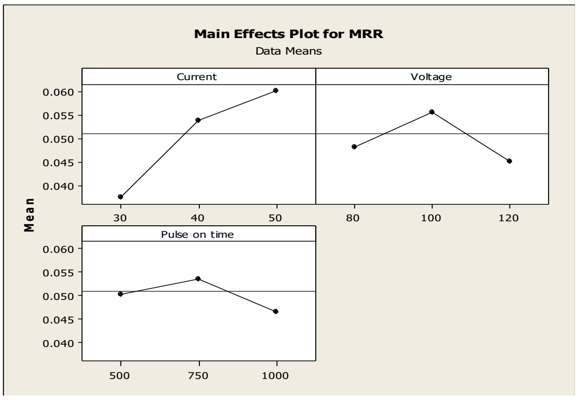
Table 2.4: Levels of operating parameters

Parameters	Levels		
	-1	0	1
Voltage (V)	80	100	120
Current (A)	30	40	50
Pulse-on time (µS)	500	750	1000

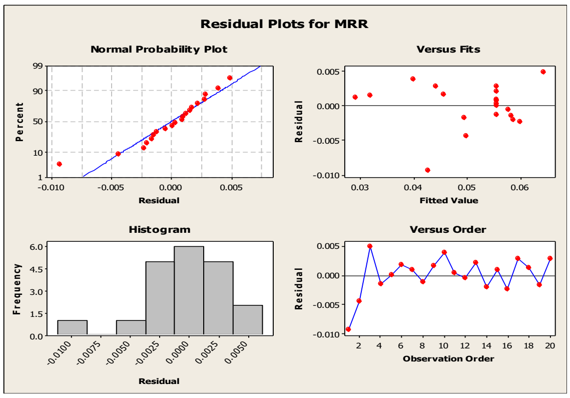
III. Result and Discussion

Table 3.1: Experimental results

Sr. No.	Current (A)	Voltage (V)	Pulse on time(µS)	MRR (mm^3/min)
1	30	100	750	0.03327
2	40	80	750	0.04539
3	50	100	750	0.06918
4	40	100	500	0.05679
5	40	100	750	0.05563
6	40	120	750	0.04733
7	40	100	750	0.0564
8	40	100	1000	0.05427
9	30	120	500	0.03322
10	30	80	1000	0.04369
11	40	100	750	0.05588
12	50	80	500	0.05719
13	40	100	750	0.05773
14	50	120	1000	0.05653
15	40	100	750	0.05653
16	50	120	500	0.05759
17	40	100	750	0.05842
18	30	120	1000	0.03026
19	40	80	1000	0.0477
20	30	80	500	0.04678



Graph 3.1: Main effect plot for MRR



Graph 3.2: Residual plots for MRR

In this study the machining parameters such as Current, Voltage and Pulse on time are studied to evaluate MRR.

The MRR is calculated as the work piece removal weight over the machining time, which is expressed as grams per minute. Main effects plots are drawn showing the effect of various input parameters on material removal rate. The Regression equation 3.1 is performed based on results by the design of experiments software, which is shown in graph 3.1. Here, The MRR acts as dependent variable, which has three independent variables.

$$MRR = 0.0201 + 0.00119\ Current - 0.000138\ Voltage - 0.000003\ Pulse\ on\ time \quad \dots (3.1)$$

IV. Conclusion

The hole-drilling experiments were successfully performed on Inconel 718 alloy using copper electrode and the material removal rate is evaluated. From main effects plots it is clearly observed that the MRR increases directly with increase in current and the maximum material removal rate is obtained at 50 A. but in case of voltage and pulse on time initially the MRR is increases and then decreases. So from the above results it is clear that the current is most affecting parameter for MRR. While voltage and pulse on time are less significant for MRR.

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