OPTIMIZATION OF DRILLING PROCESS PARAMETERS OF ELECTRICAL DISCHARGE MACHINING IN INCONEL 718 MATERIAL

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Abstract-

Electrical Discharge Machining is becoming an important machining process in the fields of manufacturing 3D complex shapes and using a simple shaped electrode tools. The present work deals with the experimental investigation of Electrical Discharge Spark machining on Inconel 718 material. The holes of 1.5mm deep were machined using EMS3050 Manual EDM with various combinations of input parameters such as pulse current and pulse on time (Ton). The Material removal rate and Surface roughness are taken as the output parameters as more focus is given to the dimensional accuracy of the machined components. The Taguchi method of optimization is used. The result shows the effect of input parameters on material removal rate and surface roughness. Also the optimum values are estimated.

Key words: *EDM, electrode, material removal rate, surface roughness, Taguchi method*

1. INTRODUCTION

Nickel based super alloy, Inconel 718 is one of the most difficult-to-machine material which attributed to its ability to maintain hardness at elevated temperature and consequently it‘s very useful for hot working environment. Formation of complex shapes by this material along with reasonable speed and surface finish is not possible in traditional machining. This alloy is characteristically difficult to machine due to its poor thermal properties, high toughness, high hardness, and high work hardening rate. Usually, a nonconventional machining method like electrical discharge machining (EDM) is chosen for machining Inconel 718 in order to overcome such limitations. However, due to the great physical properties of Inconel 718, the cutting process for this material is become an issue in order to improve the speed of machining process. This alloy has attracted many researchers because of its increasing applicability and the machining ability of aerospace alloys will continually decline as service demands increase in order to satisfy the demand for higher temperature capability for structural engine alloys. The Fig. 1 shows the working principle of Spark EDM. Spark erosion EDM, also called cavity type EDM or volume EDM consists of an electrode and work piece submerged in an insulating liquid such as, more typically, oil or, less frequently, other dielectric fluids. The electrode and work piece are connected to a suitable power supply. The power supply generates an electrical potential between the two parts.

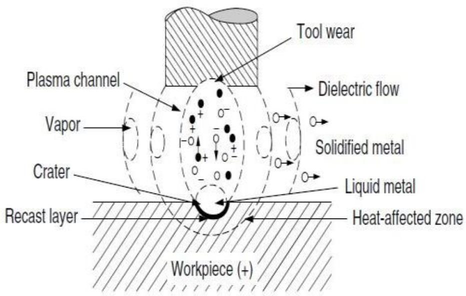

Figure 1 Working of spark EDM

2. LITERATURE REVIEW

Carbon or Silicon carbide is mixed into the dielectric fluid in the same tank or in a separate tank. The powder particles filling the spark gap get energized and are accelerated by the electric field and act like conductors forming chains which bridge the gap between the tool electrode and the workpiece leading to an early explosion [1]. The wire electrical discharge machining (WEDM) is a widely accepted non-traditional thermo-electrical material removal process used to manufacture components with intricate shapes and profiles. WEDM utilizes a continuously travelling wire electrode made of thin copper, brass, molybdenum or tungsten of diameter 0.05–0.3 mm, which is capable of achieving very small corner radii. The machining principle is based on erosion of the work-piece material using a successive discrete discharges occurring between the electrode (wire) and work piece [2]. The Material Removal Rate (MRR) is the rate at which material is removed from the workpiece. MRR depends not only on the workpiece material and electrode qualities, but also on the parameters applied in EDM and the characteristics of dielectric fluid [3]. The influence of machining parameters on electrical discharge machining of managing steels concluded that MRR increases with increase in current and decreases with increase with pulse-on time [4]. An almost positive linear relationship between material removal rate and pulse-on time [5]. An experimental investigation to determine the main EDM parameters which contribute to recast layer formation in Inconel 718 and found that average recast layer thickness increased primarily with energy per spark, peak discharge current, and current pulse duration [6]. The MRR increases proportionally with increase in current, voltage and pulse-on time. They reported an almost linear relationship for peak currents of 3 and 12A with MRR ranging from 3 to 40 mm^3/min [7]. The EDM process uses thermal energy to erode the tool and the workpiece immersed in a dielectric fluid through a series of current discharges subject to an electric voltage. When a voltage of 35 – 320V is applied between the tool electrode and the workpiece placed close to each other, an electric field in the range of 10^5- 10^7 V/m is generated [8]. The performance of Copper electrode when EDM of Nickel Based Super Alloy, Inconel 718 is at higher peak current and pulse duration. The results shows that the highest material removal rate (MRR) with value 34.94 mm^3/min, whereas machining at a peak current of 20A and pulse duration of 400µs yields the lowest electrode wear rate (EWR) with value -0.0101 mm^3/min. The lowest surface roughness (Ra) is 8.53 µm achieved at a lowest peak current used of 20A and pulse duration of 200µs [9]. Wire EDM is a specialized thermal machining process capable of accurately machining parts of hard materials with complex shapes. Parts having sharp edges that pose difficulties to be machined by the main stream machining processes can be easily machined by WEDM process [10]. An experimental investigation of Wire-EDM of titanium alloy to investigate the effect of seven process parameters including pulse width, servo reference voltage, pulse current, and wire tension on process performance parameters (such as cutting speed, wire rupture and surface integrity) and found that the cutting speed increases with peak current and pulse interval. Surface roughness was found to increase with pulse width and decrease with pulse interval [11]. The material removal characteristics of the EDM process. The results were supposed to be helpful for material removal mechanism of EDM [12].

3. MATERIAL AND METHODS

During the drilling operation in electrical discharge machining there may be a chance of getting surface disintegration and less material removal rate and the time factor which mainly affects the structure of the machined area. To minimize this objective machining was carried out using the input parameter such as input current, time on (Ton) and the output values are calculated to these input parameters. The main objective of the project is to minimize and maximize the various output parameters for the given input by keeping inconel 718 material as the work piece and copper as the electrode. Tab.1 shows the composition of inconel 718 material. Tab. 2 shows the properties of the inconel 718.

Table 1 Composition of inconel 718

Element	Content
Ni + Co	50-55%
Cr	17-21%
Fe	Bal
Nb + Ta	4,75-5,5%
Mo	2,8-3,3%
Ti	0,65-1,15%
Al	0,2-0,8%

Table 2 Properties of inconel 718

S. No.	Properties	Value
1	Density	8,19 g/cm^3
2	Melting point	1336°C
3	Co-Efficient of Expansion	13 µm/m°C (20 - 100^o C)
4	Modulus of rigidity	77,2 kN/mm^2
5	Modulus of elasticity	204,9 kN/mm^2

In the presence of EDM oil as the electrolyte by minimizing the output such as surface roughness leads of making of perfect die. The constraints are the MRR- maximum, SR –

minimize and T - minimize. The experiment is carried in Spark EDM for drilling operation with various input parameters such as pulse on time and pulse current. Taguchi Optimization technique is used to optimize the value of various input parameters like pulse on time and pulse current.

4. EXPERIMENTAL WORK

The experiment is conducted as per design matrix using EDM machine (Make EMS5030). Fig. 2 shows the spark EDM experimental setup with the following specification. Mechanism of process Controlled erosion (evaporation and melting)through a series of electric sparks; Maximum work piece height 175 mm; Main table traverse (X, Y) 280, 200 mm; Electrode diameter range 0,25 mm to 15 mm; Generator EMS 5030; Interpolation Linear and circular.

The plate to be machined is cleaned thoroughly and then the plates are fitted to the fixture. The tool and workpiece are shown in Fig. 3. The fixture is used to provide support for the plates and to restrict the deformation of plate during welding due to axial pressure. It also exerts some back pressure on the plate when pressure is applied during welding. The work piece plate is placed in the fixture and firmly clamped on the machine table of Electric discharge machine. One of the important factors in a successful EDM operation is the removal of debris (chips) from the working gap. Flushing these particles out of the working gap is very important, to prevent them from forming bridges that cause short circuits. EDMs have a built-in power adaptive control system that increases the pulse spacing as soon as this happens and reduces or shuts off the power supply. Flushing – process of introducing clean filtered dielectric fluid into spark gap. The Fig. 4 shows the flushing of dielectric during machining. The electric spark is concentrated between the electrode and work piece for maximum metal removal, and minimum scattering and energy loss that may lead to overheating and premature oxidation. The Fig. 5 shows the Spark erosion during drilling process. EDM oil as a result, provides extended service life with minimum power consumption.

Figure 2 Spark EDM experimental setup

Figure 3 Tool and workpiece fixed

Figure 4 Flushing of dielectric during machining

4.1 Input parameters

The various input parameters like pulse on time and pulse current are consider for this study.

Pulse on time (s):

Metal removing process that takes place when current is allowed to flow is called Pulse on Time. Material Removal is directly proportional to the amount of energy applied during this time. This energy is really controlled by Pulse Current and the length of Pulse on time

Pulse Current (A):

Pulse Current is the amount of power used in discharge machining, measured in units of amperage. The maximum amount of amperage is governed by the surface area of the cut. The greater the amount of surface area, the more amperage is applied. Higher amperage is used in roughing operations and in cavities with large surface areas.

4.2 Calculation of Output parameters

The output parameters like Time (T), Material Removal Rate (MRR) and Surface Roughness (SR).

Time (T)

Time is one of the most important criteria during the machining of material. The machining time is calculated using stopwatch. Material removal rate may varies depending on the machining time.

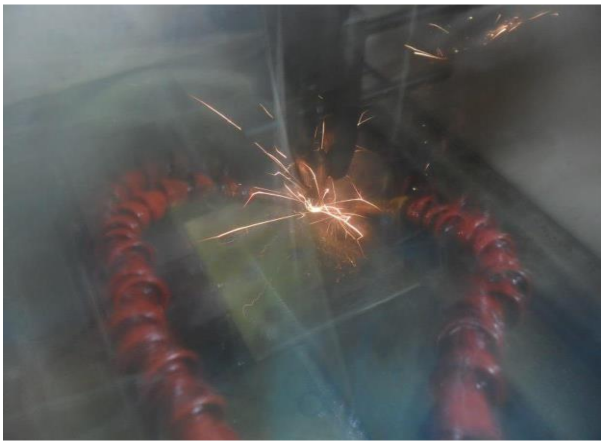

Figure 5 Spark erosion during process

Material Removal Rate (MRR)

MRR is used to evaluate machining Performance. MRR has increased when electrodes have been used with Positive polarity in all cases of semi-sintered electrodes. In case of the copper Electrode, EDM cannot be used when positive polarity has been selected. The material Removal Rate is expressed as the work piece removal rate. Under a period of machining time in minute (t), after machining, the Material Removal Rate has been estimated by using the following equation.

$$MRR = \frac{W_i - W_f}{\rho \, x \, t}$$

Where, W_f is the final machining weights of work piece material and W_i is the Initial machining weight of the work piece material respectively and 't' is the machining time and 'ρ' is the density of the material. The weight of the work piece materials are calculated in electronic weighing machine.

Surface Roughness (SR)

Surface Roughness has an increasing trend with the increase of pulse on time and at the same time it decreases with the increase of pulse off time. The surface roughness is most affected by the amount of discharge energy, which increases with the increase in pulse on time. Surface Roughness depends on the size of spark crater.

Figure 6 Work piece after drilling

Fig. 6 shows the work piece of nine holes with 1.5 mm deep is drilled in the spark EDM. The material removal rate are estimated for three different pulse time such as 29, 38, 47. The estimated MRR is tabulated in Tab. 3. Fig. 7 shows the work piece of nine holes with 1.5 mm deep is drilled in the spark EDM. The surface roughness are estimated for two trials and the average of the two trials is taken for study. The estimated surface roughness is tabulated in Tab. 4.

Figure 7 Testing surface roughness

Table 4 Calculated Surface Roughness (SR)

S. No.	Pulse Time	Peak Current	Trial - 1	Trial - 2	Average SR (µm)
1	29	0,05	2,567	2,970	2,768
2	29	0,15	3,507	3,826	3,666
3	29	0,25	4,301	4,672	4,486
4	38	0,05	3,065	3,191	3,128
5	38	0,15	3,876	4,012	3,944
6	38	0,25	4,427	4,621	4,524
7	47	0,05	3,125	2,976	3,251
8	47	0,15	4,568	4,829	4,698
9	47	0,25	5,012	5,365	5,180

5. OPTIMIZATION OF PROCESS PARAMETERS

Taguchi method is an efficient problem solving tool, which can improve the performance of the product, process, design and system with a significant slash in experimental time and cost. Taguchi method employs a special design of orthogonal arrays to study the entire process parameters space with small number of experiments. The optimal result could be generated out of Taguchi method by means of systematic analysis of data and the dominant factor involved in optimization. The two fundamental terms are used in Taguchi methods (i) orthogonal arrays (ii) Signal to noise ratio (S/N) and Mean Squared Deviation (MSD). Taguchi method utilizes orthogonal arrays from design of experiments theory to study a large number of variables with a small number of experiments. Taguchi recommends the use of signal to noise ratio (S/N) as opposed to simple process optimizing process parameters. S/N ratio selection is based on Mean Squared Deviation (MSD) for analysis of repeated results. For selection of orthogonal arrays, the actual combinations of input process parameters are shown in Tab. 3 and 4. The two factors and their levels are shown in the Tab. 5.

Table 5 Factors and Levels

Factors	Levels		
	1	2	3
A (Pulse on time)	29	37	48
B (Pulse Current)	0,05	0,15	0,25

Samples are prepared with same dimension according to the L_9 orthogonal array which is given in the Tab. 6. The pulse on time and input current values are given in the machine and the hole diameters and hole depth are fixed in the tool. The MINITAB is used for analyzing the parameters in the Taguchi design. The figure 8 shows the various parameters considered for optimization process and entered in the MINITAB worksheet. The Taguchi orthogonal array design has been done. The optimum value of MRR and Surface Roughness are evaluated based on the Pulse ON current and Pulse on time.

Table 6 Experimental Layout of L_9 Orthogonal array

Experimental Run	**Input Parameters**	
	A	**B**
1	1	1
2	1	2
3	1	3
4	2	1
5	2	2
6	2	3
7	3	1
8	3	2
9	3	3

The result of the above designed experiment is listed in the table 7. The Signal to Noise ratio for the outputs is also provided in it. The approach of Smaller the betters is applied for Surface Roughness and the approach of Larger the better is used for Material Removal Rate.

6. RESULTS AND DISCUSSION

The experimental investigation of spark EDM drilling process in inconel 718 material has been carried out in a plate of nine holes of deep 1.5 mm. And also the Taguchi method is used for optimization of process parameters in this study. The results obtained are discuss as bellow: Fig. 9 shows the relationship between Pulse on time and Peak current on Material Removal Rate (MRR) in the drilling process of spark EDM in Inconel 718 material. From the graph it is understood that the MRR will be maximum at Level 1 of Pulse on time and level 3 of peak current. Fig. 10 shows the relationship between Pulse ON time and Peak current with Surface Roughness (SR) in the drilling process of spark EDM in Inconel 718 material. It shows that, the Pulse ON time decreases with increase in the Surface Roughness. The peak current also exhibits the same effect. The Surface Roughness will be minimum whenever the Level 1 of Pulse on time and Level 1 of Peak current is used. Fig. 12 shows the relationship between Peak current and Surface Roughness (SR) in the drilling process of spark EDM in inconel 718 material. It shows that, the peak current increases With increases in the Surface Roughness. It reveal that the peak current is also directly proportional to the Surface Roughness of the machined part. From the experimental study it is observed that the pulse time and peak current are increases with increase in the surface roughness. An increase in the pulse time with decrease in MRR and increase in peak current with increase in MRR in the spark EDM drilling process in inconel 718 material.

Table 7 Experimental results and SN ratio

Pulse ON	Peak current	SR	SNRA1	MRR	SNRA2
29	0.05	2.7685	-8.844890557	9.82E-08	-8.844890557
29	0.15	3.6665	-11.28503379	1.1508E-06	-11.28503379
29	0.25	4.4865	-13.03815344	1.3889E-06	-13.03815344
38	0.05	3.128	-9.905334888	8.35E-08	-9.905334888
38	0.15	3.944	-11.91873813	9.097E-07	-11.91873813
38	0.25	4.524	-13.11045193	1.2628E-06	-13.11045193
47	0.05	3.0505	-9.687420587	6.84E-08	-9.687420587
47	0.15	4.6985	-13.43918462	9.764E-07	-13.43918462
47	0.25	5.1885	-14.30083642	1.1326E-06	-14.30083642

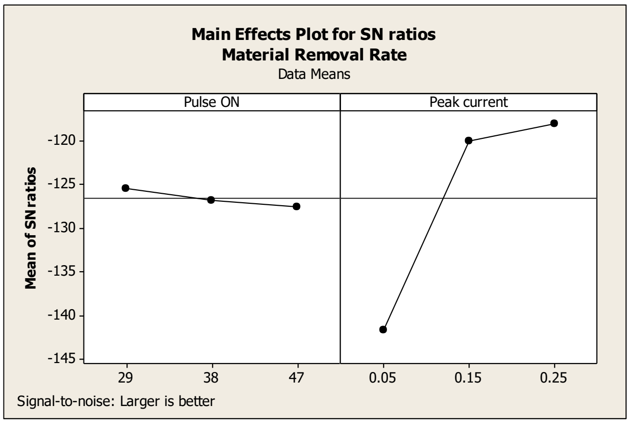

Figure 9 SN ratio plot for MRR

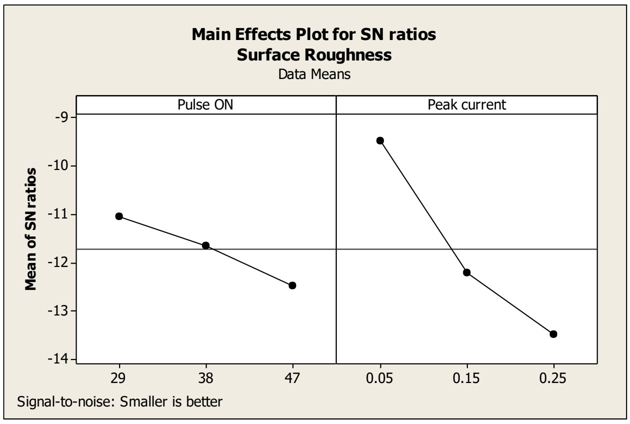

Figure 10 SN ratio for Surface Roughness

7. CONCLUSION

The following conclusions are arrived from the experimental work and optimization process is carried out in the Spark EDM drilling in Inconel 718 material.

- When pulse on time is increases, the MRR is decreased. The higher the pulse on time, intensity of spark is decrease due to expansion of plasma channel and results in less metal removal will takes place.
- When the current is increased, surface roughness is also increased. Because due to increase in current, the spark intensity is also increases. So the MRR per minute increases. Finally the surface roughness is increased.
- When the Pulse on time is increased, surface roughness is decreased, because due to increase in pulse on time, the spark intensity is also decreases. So the MRR per minute decreases. Finally the surface roughness is decrease.
- When current increases, the MRR also increases. The higher the current, intensity of spark is increased and results in high metal removal will takes place. The material removal rate (MRR) mainly affected by peak current (Ip). Pulse on time (Ton) has least effect on it.
- The surface roughness (SR) is mainly dependent on pulse current (Ip).Optimum parameters of input factors are as follows; Pulse Time: 38 μs, Pulse current : 0,05 Amp

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