Effect of SiC Particles in Dielectric on Geometrical and Surface Characteristics during Micro-EDM Drilling

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Abstract
Nickel-based superalloys owing to their high strength, excellent corrosion resistance, thermal stability and supreme thermal fatigue properties find a wide range of applications in the aircraft industry, high-temperature turbines, etc. Due to excessive tool wear, low productivity, etc. it is unsuitable to machine these materials using the conventional techniques. Electrical discharge machining (EDM), owing to its inherent characteristic of zero process forces and ability to machine any electrically conductive material irrespective of its mechanical properties, is an excellent alternative in the machining of the difficult to machine alloys. Overcut and taper are the major geometrical defects associated with EDM drilling. Studies have shown that the surface roughness reduces on using conductor/semiconductor powder particles in the dielectric during EDM. In this paper, the emphasis is given to study the geometric characteristics associated with powder mixed µ-EDM drilling of Inconel 718. An external dielectric circulation setup was made, and experiments were done with gap voltage, electrode rotation speed (ERS), feed rate and powder concentration (SiC) in the dielectric as the factors with overcut and diameter difference between entry and exit (DDEE) as responses. The Box-Behnken design for four factors with each varied in three levels was taken for the experiment. The obtained results were analyzed using Alicona 3D optical profiler, and it was observed that gap voltage and powder composition in dielectric were influential for both responses. The obtained results were compared with those of normal drilling experiments, and it showed a remarkable improvement.

Keywords: Electric Discharge Machining, Electrode Rotation Speed, optical profiler, Box-Behnken Design

1. INTRODUCTION

The need of the hour is high precise miniaturized goods which can give better performance than their predecessor. To keep up with the needs of the society, the manufacturing industries are in the pursuit of developing processes which can manufacture such products at low cost with high precision. Micromachining is one of the key methodologies to achieve this goal. Micromachining can be defined as the manufacture of components in the range of 1-500µm. With advancements in the electronics industry more precise machine tools are made which has enabled the scaling down of the conventional and non-conventional machining processes to perform micromachining operations. Electrical Discharge Machining (EDM) is an important non-conventional machining process which has large-scale applications in die and mould making industry, aerospace, marine industry, etc. The EDM process is based on the thermoelectric energy created between workpiece and tool electrode both submerged in a dielectric fluid. When the workpiece and the electrode are separated by a specific small gap, a pulsed discharge occurs which removes material from the workpiece through melting and vaporization. Micro-EDM is the scaled down version of EDM which can do the same operation at a micro level.

The advent of smart materials, composites, super alloys, etc. has prompted the manufacturing sector to find suitable techniques for machining them. These materials have superior properties like very high hardness, high stiffness, high-temperature resistance, high wear resistance and high corrosion resistance. They find a large number of applications in aerospace, marine, semiconductor industries, etc. Even with these advantages, the machinability of these materials is very poor. So using conventional methods of machining like milling, turning, drilling, etc. is not advisable owing to high cutting forces, high tool wear and the difficulty associated with the manufacture of the required tools for machining. The alloys of titanium, nickel, etc. which has widespread applications in the aerospace industry come in this category of difficult to machine materials. Micro-EDM owing to its inherent ability to machine any electrically conductive material irrespective of their mechanical properties serves as an ideal methodology for the machining of such materials. Micro-EDM drilling produces holes by giving rotation to the tool electrode. The research findings show that rotation of electrodes help in improving the MRR and eject the debris from the discharge zone more effectively by creating a turbulence effect in the dielectric. Furthermore, it improved the machining stability by providing a cooling effect to the electrode surface and avoiding the repeated occurrence of discharge in one location [1].Micro-EDM drilling has been adapted to various applications including the cooling holes in turbine blades, jet engine nozzles, fibre nozzles, etc. Jahan et al. [2] observed that the RC type pulse generator gave better surface quality during micro-hole machining of the tungsten carbide by micro-EDM drilling process compared to transistor type. Although there are a large number of advantages associated with using EDM for machining, there are some disadvantages which cannot be neglected. The major disadvantages are overcut, taper and lower surface finish. Adding semi-conducting powder into the dielectric has been proven to be an important methodology to improve surface characteristics. This hybrid variant is called powder mixed electric discharge machining (PMEDM).

PMEDM has a different machining mechanism from the conventional EDM. In this process, a conducting material in the powder form is mixed with the dielectric fluid. A stirring system is employed for better circulation of the powder mixed dielectric. The spark gap is filled up with powder particles. When a suitable voltage is applied between the electrode and the workpiece separated by an optimum gap, a high electric field is created. The powder particles get energized and behave

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ISBN: 978-93-80689-28-9

in a zigzag fashion (Fig. 1). These charged particles which are accelerated by the electric field become conductors. These conductors promote a breakdown in the gap and increase the spark gap between the tool and the workpiece. Under the sparking area, the particles come close to each other and arrange themselves in the form of chain-like structures between the electrodes. The interlocking between the different powder particles occurs in the direction of flow of current. The chain formation helps in bridging the discharge gap between both the electrodes. As a result of this bridging effect, the insulating strength of the dielectric fluid decreases and short circuit takes place, which causes an early explosion in the gap. At the same time, the added powder modifies the plasma channel. The plasma channel becomes enlarged and widened. The sparking is uniformly distributed among the powder particles; hence the electric density of the spark decreases. Due to uniform distribution of sparking among the powder particles, shallow craters are produced on the workpiece surface. This results in improvement in surface finish.[3]

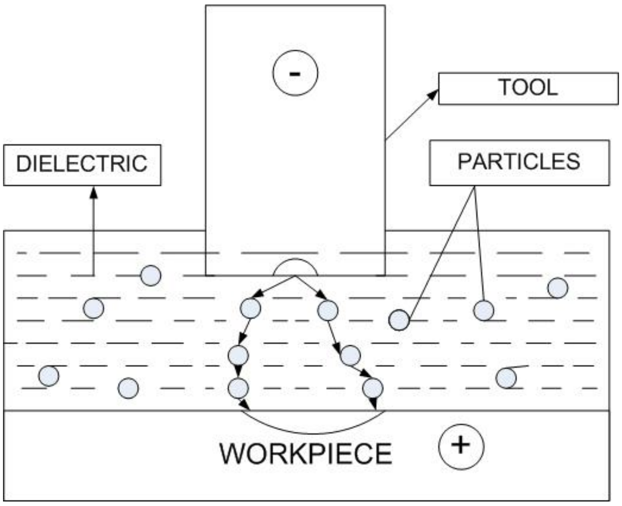

Fig. 1 Schematic of Powder mixed EDM

Kibria et al. [4] addressed the issues of micro- EDM by testing out different types of dielectrics such as kerosene, deionized water, boron carbide (B4C) powder suspended kerosene, and deionized water to explore the influence of these dielectrics on the performance criteria such as material removal rate (MRR), tool wear rate (TWR), overcut, diameter variance at entry and exit hole and surface integrity during machining of titanium alloy. Kumar [5] reported the results of an experimental study to develop mirror-like surface finish on the surface of AISI-D2 die steel by electric discharge machining (EDM) using carbon nanotubes (CNTs). The experimental results indicated that the CNTs concentration and peak current were the most influential variables. The obtained experimental results also showed significantly improved performance of Nano Powder Mixed EDM (NPMEDM) over EDM. Kuriachen et al.[6] studied the effects of major electric discharge milling process parameter like voltage, capacitance, and Silicon carbide powder concentration in a dielectric on material removal rate (MRR) and tool wear rate (TWR). From the results, it was recommended to use powder concentration of 5 g/L, the capacitance of 0.1 µF, and voltage of 115V for achieving high material removal and low tool wear. It was also concluded that PMMEDM could also be used for surface coating based on the Si deposits observed using the EDS analysis. Ekmekci et al. [7] used Hydroxyapatite (HA) powder suspension in deionized water as a dielectric liquid during Electrical Discharge Machining of Ti-6Al-4V. The powder particles in the dielectric liquid extensively migrated and formed an HA-rich layer on the work material surface under specific machining conditions. The results suggested the process as a practical alternative for producing biocompatible interfaces or coatings for medical applications.

Kansal et al. [8] conducted studies on the effect of mixing silicon powder into the dielectric fluid of EDM on machining characteristics of AISI D2 die steel. It was observed that the peak current and concentration of silicon powder were the most influential parameters for causing the material removal and the suspension of silicon powder into the dielectric fluid of EDM appreciably enhances the material removal rate. Pecas and Henriques [9] observed that use of PMEDM conditions promoted the reduction of surface roughness, crater diameter, crater depth and the white-layer thickness. Powder-mixed dielectric significantly reduces surface heterogeneity thus contributing to increased process robustness. Talla et al. [10] attempted to fabricate and machine aluminum/alumina MMC using EDM by adding the aluminum powder in kerosene dielectric. Results showed an increase in MRR and decrease in surface roughness (Ra) compared to those for conventional EDM. The survey conducted points out that still lot of work needs to be done in this area. The studies on powder mixed micro-EDM are very few, and since it has proven to be an excellent methodology to improve the geometrical characteristics, more research in PMMEDM is required.

In this paper, the effects of Voltage Feed rate, Electrode rotation speed and powder concentration in the dielectric on Diametrical Overcut and Diameter Difference between Entry and Exit (DDEE) are examined.

2. EXPERIMENTAL PROCEDURE

The experiments were carried out on DT-110 Micromachining centre with Inconel 718 sheets of thickness 2mm as workpiece and tungsten carbide of diameter 0.4mm as the tool electrode. Silicon Carbide (SiC) was used as the powder media mixed in the dielectric (Total EDM3 oil). SiC is a semiconductive powder, widely used in powder mixed EDM. Images for SiC powder particle were taken using the scanning electron microscope. The average size of the particles was around 500nm.An external dielectric circulation system was developed for doing the experiments (Fig. 2).

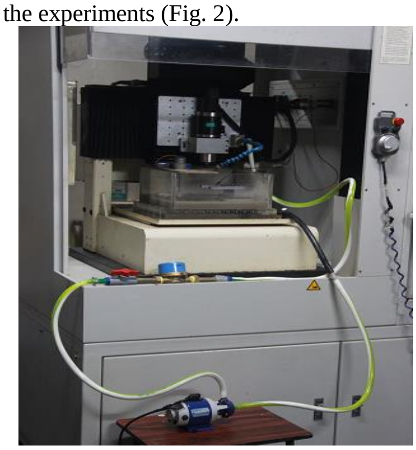

Fig. 2 External Dielectric Circulation setup

Using the water meter and the control valve the flow was adjusted to a constant value throughout the experiments. The stirrer avoids the settling and maintained a uniform concentration by its continuous stirring action. Box-Behnken design was used for performing the experiments. They are formed by combining two-level factorial designs with balanced incomplete block designs. The number of experiments for four factors, each varied in three levels with three centre runs equals 27. Additional experiments were conducted to compare the surface quality obtained via conventional micro-EDM and Powder Mixed micro-EDM. The process parameters and their various levels are as in Table 1.

Table 1
Process parameters and their levels

	Parameter	-1	0	+1
A	Voltage	80V	115V	150V
B	ERS	800RPM	1600RPM	2400RPM
C	Feed Rate	8μm/s	16μm/s	24μm/s
D	Powder concentration	2g/l	4g/l	6g/l

3. RESULTS AND DISCUSSIONS

The experiments were conducted and the results were analysed using ANOVA. The variation of each response with respect to every factor within the design space was studied.

3.1 Analysis of Overcut

During EDM drilling a negative impression of the base area of the cylindrical tool is obtained on the workpiece. Ideally, the diameter of the hole should be equal to that of the tool diameter. Unfortunately owing to side sparking, improper flushing of the debris particles from the machining zone the obtained diameter will be greater than the expected one. This difference in inlet diameter of the obtained hole and the diameter of the tool electrode is defined as diametrical overcut. It is given by

$$Overcut\ (OV) = \frac{D_1 - D_2}{2} \qquad (1)$$

where D_1 is the hole inlet diameter and D_2 is the diameter of the tool electrode. ANOVA was done and the regression equation considering significant factors is given as

$$Overcut = +129.2 + 0.5579 \times A - 5.10 \times C - 21.95 \times D + 0.714 \times C \times D + 0.0753 \times C^2 + 1.648 \times D^2 \qquad (2)$$

The R-squared, Adj. R-squared and Predicted R-squared values are 0.938, 0.92 and 0.853 respectively. The variation of overcut with all the factors in the design space is given. (Fig. 3)

From Fig. 3 it can be seen that Voltage is the most significant parameter affecting overcut. The overcut varies linearly with Voltage. An increase in voltage means an increase in the discharge energy of spark. This results in more material removal and hence more overcut. ERS is almost constant in the design space. Feed rate also doesn't have much variation in the design space. It slightly decreases at first then increases. The number of sparks per unit time is increased with increase in feed rate resulting in more material removal, thus increased overcut. Powder concentration also behaves almost similar to that of feed rate, but the rate of increase of overcut is more in the second half. This may be due to the excess quantity of the powder particles in the tool proximity which also may lead to side sparking resulting in increased overcut.

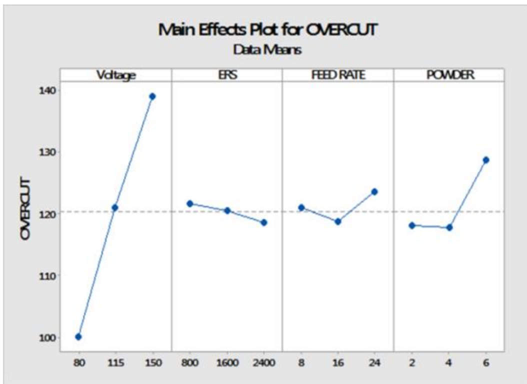

Fig. 3 Main effects plot for Overcut

3.2 Analysis of DDEE

The diameter difference at entry and exit is another major factor which has to be avoided during micro-EDM drilling. The expected final shape of the hole is a cylinder of diameter equal to that of the tool electrode but due to improper flushing of dielectric and side sparking the shape obtained will be similar to that of a frustum of a cone. It is calculated as

$$DDEE = D_i - D_e \qquad (3)$$

where D_1 is the inlet diameter of the hole and D_e is the exit diameter. The entry and exit diameters were measured using Alicona Infinite Focus non-contact 3D profiler and results tabulated are analysed using ANOVA. The regression equation regarding actual factors ignoring the insignificant terms is as follows

$$DDEE = 71.7 + 0.1445 \times A - 0.0318 \times B - 5.99 \times C + 28.96 \times D - 3.181 \times D^2 + 0.002362 \times B \times C + 0.507 \times C \times D \quad (4)$$

The R-squared, Adj. R-squared and Predicted R-squared values are 0.86, 0.81 and 0.75 respectively. The variation of DDEE with respect to each factor is explained using the main effects plot. (Fig. 4)

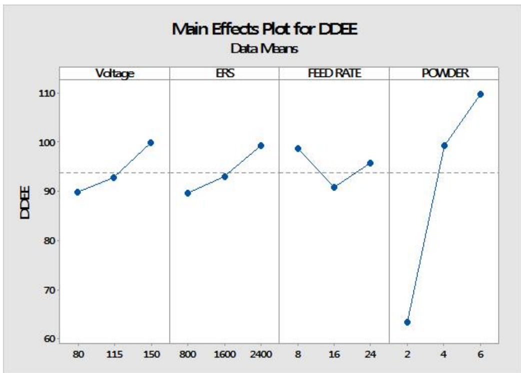

Fig. 4 Main effects plot for DDEE

Fig. 3 shows that overcut increases drastically with increase in the voltage. Since the input diameter is increasing the DDEE also increases (Fig. 4). DDEE tends to increase with an increase in ERS as better flushing results in better exit holes and thus the difference increases. Feed rate has its local minima in the design space. It may be due to the fact that the overcut reduces with an increase in feed rate and then increases (Fig. 3), this attributed to the change in DDEE as similar to overcut. The powder concentration has a negative effect on the DDEE, the increase in concentration leads to a rise in overcut due to side sparking, the inability for proper flushing. This in turn increases DDEE as the concentration increases.

3.3 Powder Mixed μ-EDM Drilling vs. μ-EDM Drilling

The overcut and DDEE were compared for normal micro-EDM Drilling and Powder Mixed μ-EDM Drilling at powder concentration 4g/l for the following conditions. (Table. 2)

Table 2
Run order for comparison

Sl no	Voltage	ERS	Feed Rate
1	115	1600	16
2	150	1600	24
3	80	800	16
4	115	2400	8
5	150	1600	8

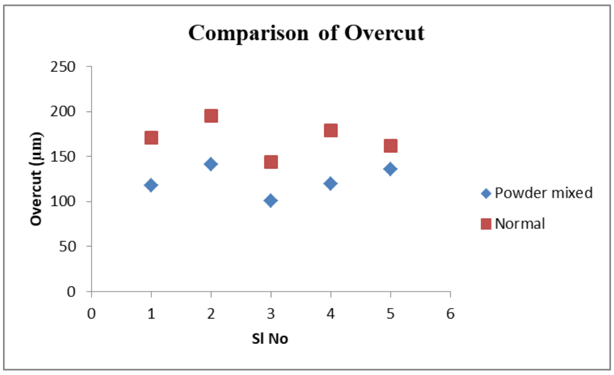

Fig. 5 Comparison of overcut for powder mixed (4g/l) and normal μ-EDM drilling

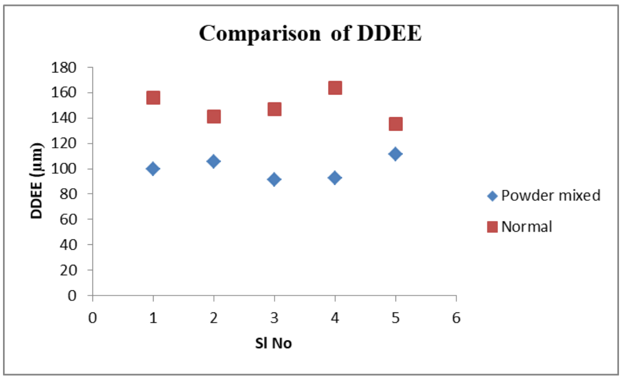

Fig. 6 Comparison of DDEE for powder mixed (4g/l) and normal μ-EDM drilling

We can see a drastic decrease in the overcut and DDEE when using powder mixed rather than normal μ-EDM drilling (Fig. 5 & 6).

4. CONCLUSIONS

- Voltage and Powder concentration are the most significant factors while calculating overcut and DDEE.
- The powder concentration reduces the overall overcut and DDEE, but too much increase in powder concentration negatively affects the process.

ACKNOWLEDGEMENT

Authors would like to sincerely thanks Department of Science & Technology (DST), Govt. of India & Center for Precision Measurements & Nanomechanical Testing, Department of Mechanical Engineering, National Institute of Technology Calicut, for providing support to carry out this work under the scheme 'Fund for improvement of Science & Technology' (No. SR/FST/ETI-388/2015).

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