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Process Parameter Selection for Micro Electric Discharge Machining of Inconel718

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Abstract - Micromachining of advanced engineering material such as ceramics and alloys are currently gaining interest from multi-disciplinary researchers. Inconel 718 is one of the most promising Nickel-based superalloy known for its unique properties such as retaining high strength and stable behavior even at extremely high temperature, but the cutting process of this material is very difficult and at micromachining level, it is even more challenging which need to be studied and explored. Micro Electric Discharge Machining (µEDM) with proper selection of input parameters can be found to be most effective in the creation of complex shapes, the profile of different shapes, contour machining with considerable good surface finishing and accuracy. In the present work, an experimental investigation on µEDM is proposed in order to study and validate the effect of different process parameters obtained from literature reviews such as voltage, capacitance, spindle speed, and feed rate on machining of Inconel 718 with tungsten carbide electrode. The effect of these process parameters on responses such as Material Removal Rate, Tool Wear Rate, Overcut and Taper angle of the work piece have been studied. The experiments were conducted by varying one variable at a time to find out a suitable range of values of the input variables with regard to responses.

Index Terms - µEDM.

BACKGROUND

Today, though the manufacturing industry is adopting advanced manufacturing techniques still facing challenges from hard-to-cut materials viz. superalloys, ceramics, and composites which require high precision and surface quality thereby increasing machining cost. Electrical Discharge Machining (EDM) is a non-traditional machining process that has become a well-established machining option in manufacturing industries throughout the world.

This rapidly developing technology aims to develop products in miniaturized compact volumes with more functions are embedded in the products. This created the demand for advancement in micro-manufacturing, so industrial research on micro-machining has become an important area widespread. µEDM, a recent development is found to be a cost-effective process for the fabrication of micro-tools, micro-components, and micro-features with good dimensional accuracy and surface quality. Though various researchers have studied the performance of EDM, the problems related to low material removal rate, tool wear, and surface integrity remain unsolved.

INTRODUCTION

µEDM works on the same principle of Macro Electric Discharge Machine, differing only with the tool dimensions, sparking energy, and the size of the plasma at micro-level developed for its use in precision and accurate machining of micro-structures. The selection of the most appropriate input parameter combination to provide the optimum values for various responses is very important in µEDM. In the last few years, µPMEDM has gained popularity due to its enhanced process capabilities. This is an attempt of presenting the study of the effects of various process parameters on output measures for optimizing multiple quality characteristics viz material removal rate, tool wear rate, and surface roughness and surface integrity to enhance the quality of micromachining.

LITERATURE REVIEW

Param Singh et al (2018) used the self-developed unique setup of micro EDM with the provision of ultrasonic vibrations generator unit for workpiece vibration in sinking configuration for making through-holes without rotating the tool electrode. Tungsten Carbide (WC) electrode of 500 µm was proposed as a tool material for drilling high aspect ratio micro drills in Inconel 718 using the OVAT approach. The accuracy and quality in the micro-hole drilled were observed along with better results in terms of MRR and TWR [1].

Bhosle et al. (2017) performed the micro-EDM drilling of Inconel 600 alloy to find out the optimum parameter setting using grey relation analysis using tungsten carbide tool and the optimum results for MRR, minimum taper, diametral variation and overcut were observed for 175 V voltage, 1000 pF capacitance, feed rate of 20 µm/s 15 µs pulse duration and 50 µs pulse interval [2].

D'Urso G. et al. (2015) used three different tabular electrodes of 0.3mm i. e. tungsten carbide, copper, and brass for the micro-hole drilling of stainless steel (AISI304) plate of 3mm thickness, and accounted response for Material removal rate, tool wear ratio, Diametric overcut and Taper Rate. Tungsten carbide exhibited the best micro-hole geometrical characteristics compared to brass and copper electrodes [3].

D'Urso G. et al. (2014) experimentally carried the drilling of stainless steel using tubular electrodes of tungsten and copper by varying several process parameters such as peak current, voltage, and frequency the material removal rate and tool wear was investigated. For both the electrodes MRR and TWR increases for increasing values of peak current and voltage, observed almost linear behavior for both the parameters [4].

Jun Liewa et al. (2013) performed the micro EDM operations on reaction bonded silicon carbide using carbon nanofibers in dielectric and observed the significant improvement in the electro-discharge frequency resulted in better MRR and spark gap. Electrode wear was dropped, and the lowest surface roughness was achieved at a fiber concentration of 0.02–0.1 g/L [5].

M. S. Azad et al. (2012) optimized process performances of µEDM drilling of titanium alloy based on the Taguchi method. The MRR improves with discharge energies. The end wear of the electrode is a source of errors for the assessment of the electrode length. The side wears influence the form of the hole created. The voltage is the most important parameter in µEDM. Based on the experiments performed voltage 80 V, current 50 (index value), Frequency 150 kHz, pulse on-time 1 µs is found to be optimum cutting parameters [6].

EXPERIMENTAL PROCEDURES FOR DRILLING

µEDM drilling is performed on nickel-based superalloy, Inconel 718 with tungsten carbide tool electrode of 500 µm to study the various aspects of machining to find out best possible combinations of input parameters responsible for better output in terms of MRR, TWR, and Overcut. The experiments were conducted with OVAT (One variable at time) approach. The aim of this experimentation is to find out the range of values of the input variables concerning responses. Measurements of response parameters as well as the detailed characterization will be carried out using Video Measuring Machine (VMM), SEM (Scanning Electron Microscope).

Material Removal Rate and Tool Wear Rate and Overcut are selected as output responses of the µEDM Drilling process. In EDM the metal is removed from both the workpiece and the tool electrode. The material removal rate depends not only on the workpiece material but on the material of the tool electrode and the machining variables such as pulse conditions, electrode polarity, voltage, capacitance, feed, spindle speed, and the machining medium [7]. The MRR, TWR, and Overcut for each variable at different levels were calculated from experimental data.

A. Experimental Machine Setup

For the experimentation Hyper -10 EDM, Sinergy Nano Systems setup is used. Hyper 10 is the tabletop miniature machine tool performing multiple machining processes such as Micro turning, Micro milling, Micro EDM, Micro ECM, Micro EDM Drilling, and micro wire EDM with its various optional accessories. The machine has been used for conducting micro-EDM experiments.

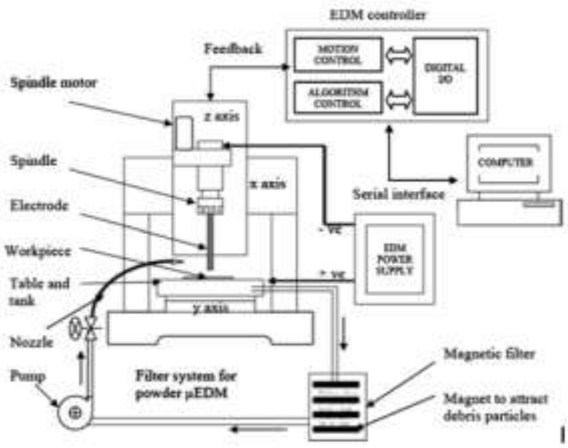

Fig.1: Schematic diagram of the experimental setup [8]

B. Work piece and Tool Material

Nickel based super alloy, Inconel 718 is selected for this experiment as it 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 [9]. A solid Tungsten Carbide (WC) of 500µm diameter is selected as tool material as it is an important tool and die material mainly because of its high hardness, strength, wear resistance and high melting point.

C. Selection of the Factor Levels and Ranges

Factors that are most influencing in the µEDM process were taken into account for experimentation. Considering the previous literature, factor levels are selected whereas workpiece material, tool material, and polarity were kept constant throughout the experiment. The following parameters were selected.

Table 1: Input parameters and their levels

Input Parameter	Unit	Level1	Level2	Level3	Level4	Level5
Voltage	V	80	100	120	140	160
Capacitance	pF/nF	100pf	1000pf	10nf	47nf	
Feed rate	µm/s	10	20	30		
Spindle Speed	Rpm	0	500	1000		

Work piece- Inconel718

Electrode- Tungsten Carbide Ø500 µm

Polarity – Tool electrode (+), work piece (-)

Dielectric fluid- Total EDM-3

Scheme of Experimentation

To study the effect of individual input parameters on output measures the OVAT (one variable at a time) is used as a design of the experiment.

Table 2: Experimental runs and their results

Expt. No.	Voltage	Capacitance	Feed	Spindle Speed	Overcut	MRR	TWR
Set-1							
1	80	10nf	20	500	0.095	0.010	14.441
2	100	10nf	20	500	0.104	0.016	7.615
3	120	10nf	20	500	0.093	0.022	6.102
4	140	10nf	20	500	0.093	0.041	2.303
5	160	10nf	20	500	0.154	0.093	5.492
Set-2							
6	120	100pf	20	500	0.125	0.004	32.282
7	120	1000pf	20	500	0.123	0.005	14.587
8	120	10nf	20	500	0.093	0.022	6.102
9	120	47nf	20	500	0.059	0.005	22.111
Set-3							
10	120	10nf	10	500	0.098	0.033	6.430
11	120	10nf	20	500	0.093	0.022	6.102
12	120	10nf	30	500	0.097	0.047	6.910
Set-4							
13	120	10nf	20	0	0.011	0.004	38.004
14	120	10nf	20	500	0.093	0.022	6.102
15	120	10nf	20	1000	0.095	0.028	2.879

D. Effect of response parameters

In experiments of set-1, capacitance, feed rate, and spindle speed were kept constant at 10 nf, 20µm/s, and 500 rpm respectively, and voltage was varied from 80V to 160V with an increment of 20V. In set-2, voltage, feed rate, and spindle speed were kept constant at 120V, 20µm/s, and 500 rpm respectively and the capacitance is varied from 1pf to 47nf as per available levels in the machine. Whereas in set-3, voltage, capacitance, and spindle speed were kept constant and feed rate was varied in the range of 10µm/s to 30µm/s with an increment of 10µm/s. And finally, in set-4, voltage, capacitance, and feed rate were kept constant at 120V, 10 nf**,** and 20µm/s respectively and spindle speed was varied from 0 to 1000 rpm with an increment of 500rpm at each level. The effect of each input parameter and their levels on material removal rate; tool wear rate and overcut are explained below.

a) Material Removal Rate: Values of MRR as contained in table 2 against various values of the input parameter, as well as the graph in figure 4 (a), show the effect of it on material removal rate. It is seen that for lower values of voltage, the MRR is small and it increases with the increase in increased value. At a value of 80V MRR is 0.010 mm3/min, which rises to 0.093mm3/min at a value of 160V, which is highest within and amongst all other parameters. The heat produced by the process is utilized to melt and vaporize work material and some heat is absorbed by machined components and surroundings. At higher values of voltage, more sparks and, in turn, more energy is produced. A substantial portion of the heat generated in the process is used to melt and vaporize the work material. This leads to an increase in MRR.

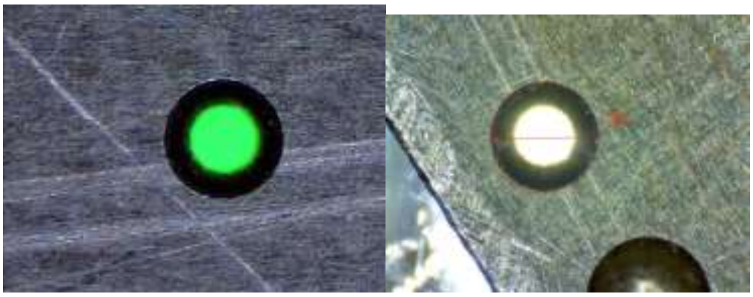

Fig.2 Microscopic images of work piece

b) Tool Wear Rate: Values of TWR as contained in table 2 against various values of the input parameter as well as the graph in figure 4 (b) show the effect of it on tool wear rate. It is seen that fat lower values of voltage i.e.80 V, the tool wear is very high (14.44) and it decreases with the increase in an increased value of voltage till 140V after this there is a sudden rise in tool wear occurs again. The lower capacitance of 100pf leads to very high tool wear as much as 32.28 and capacitance of 10nf created very low tool wear-reducing it to 6.10 and capacitance with 1000pf produces moderate results.

Fig. 3: Microscopic images of tool (a) before machining (b) after machining

c) Overcut (OC): Values of overcutting as contained in table 2 against various values of the input parameter as well as the graph in figure 4 (c) show the effect of input parameters on Overcut. It is seen that for lower values of voltage there is not much effect on overcut but it suddenly rises drastically at 16 V. At the same time in the case of capacitance the phenomenon is exactly reverse.

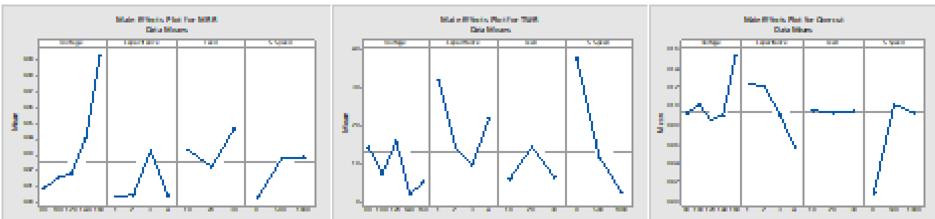

Fig.4 Main effect plot for (a) MRR (b) TWR (c) OC

CONCLUSIONS

The effect of input parameters on the MRR, TWR, and Overcut was investigated using the OVAT methodology. Conclusions based on the experiments are given below:

At the same time capacitance of 10nf gives the highest value of 0.022mm3/min. whereas feed rate of 30µm/s and 10µm/s gives better results compared to feed rate of 20µm/s and as you increase the spindle speed MRR increases.

The feed rate of 20µm/s performed the lowest TWR and feed rate of 30µm/s gives better result compared to feed rate of 10µm/s and as you increase the spindle speed TWR was found to be gradually reducing.

A very high Overcut value of 0.125 has been observed at 100pf compared to a lower value of 0.059 at 47nf. Whereas the feed rate shows a very little effect on overcut, again with a better result for 20μm/s and finally spindle speed exhibiting a gradual rise in overcutting with increased speed is observed.

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