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OPTIMIZATION OF µ - WIRE ELECTRICAL DISCHARGE MACHINING PARAMETERS OF INCONEL 718

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ABSTRACT

Micro-wire electric discharge machining (µ-WEDM) is growing at highly accelerated rate owing to its capability of achieving great dimensional accuracy and good surface finish with contour generation on features at micro scale. Due to widespread applicability in industry, manufacturing engineers require suitable parameters for the prediction of output performance of this process. This study highlights the significance of process parameters on surface roughness of the micro slots produced in Inconel 718 alloy using micro-WEDM. It is very difficult to determine optimal parameters for obtaining minimum surface roughness (SR) is a challenging task in µ-WEDM for improving performance characteristics. The process parameters, namely wire feed velocity, gap voltage, capacitance, feed rate and wire tension are optimized by considering performance characteristics as SR. Analysis of variance (ANOVA) was used to study the significance of process parameters which showed gap voltage and wire tension were be the most significant factors. To improve the machinability of the Inconel 718 alloy, optimum process parameter combination has been identified. This approach showed improved machining performance in the µ-WEDM process.

Keywords: *µ-WEDM, Inconel 718, Taguchi Method, Surface Roughness.*

1. Introduction

Inconel 718 is a nickel based super alloy which has excellent strength at elevated temperatures and resistance to oxidation and corrosion. It has a wide range of applications in manufacturing of aircraft engine parts such as turbine disks, blades, combustion and castings, extrusion dies, hot work tools and dies [1]. Due to the improved mechanical properties and heat resisting capacity, nickel based alloys are found to be difficult to machine in conventional machining process. It is also found that cutting tools result in the formation of built up edge and large crater wear thereby the surface defects such as surface drag, material pull out/cracking and tearing surfaces take place while machining of nickel alloys in conventional machining [2]. The surface integrity of the machined surfaces is also an important factor which significantly influences the performance of components during the actual performance. Hence, the advanced manufacturing processes are one of the solutions to machine nickel based alloys with improved efficiency.

Rapidly developing demand for miniaturized components made micro manufacturing (1-500µm) as an important technology, especially in the areas such as aerospace, nuclear, automotive, biomedical, etc.

Therefore, micromachining has become a hotspot in manufacturing industry. There is a growing need for fast, direct and mass manufacturing of miniaturized products from super alloys in aerospace, automotive, biomedical and military applications. To machine these materials and to meet the demands of micro-manufacturing industry, many non-traditional micro machining methods have been developed in the recent years [3]. Wire electrical discharge machining (WEDM) is one of the non-conventional machining processes which uses the thermal energy generated due to the controlled discrete sparks occur between the tool electrode and work piece. A suitable dielectric is continuously supplied into the inter electrode gap.

Micro wire electrical discharge machining (micro-WEDM) is a variant of WEDM technique, in which, a continuously travelling wire (Φ20-100µm) made of thin copper, brass or tungsten is used as electrode. The wire movement is controlled numerically to obtain the desired complex three dimensional shapes on difficult to machine materials such as super alloys. [4-5]. with the advantages of micro - WEDM over the other micromachining methods, it has been widely accepted in aerospace and nuclear space industry to machine difficult to machine materials. Due to its

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complex and stochastic nature and the increased number of variables involved, achieving the optimal performance measures of micromachining of super alloys is still a challenging task in manufacturing industry. Hence, the machinability of micro -WEDM process on Inconel 718 needs to be explored. Only a few researchers have been reported, on the machining of Inconel 718 using micro-WEDM.

Rajurkar et al. [6] developed a WEDM sparking frequency monitor to detect the thermal load for on-line control to prevent the wire from rupture and carried out an extensive experimental investigation to determine the process performances such as machining rate and surface finish. Spedding and Wang [7] modeled the WEDM process using RSM and ANN to investigate its effect on surface roughness, cutting speed and surface waviness. Both models were compared for goodness of fit and are found to be effective. Puri and Bhattacharya [8] analytically studied the effect of wire vibration on the machining characteristics of the wire-EDM.

The influence of pulse discharge frequency on amplitude of wire vibration was also studied. It was also seen that higher the thickness of the workpiece greater the amplitude of vibration for a particular span of wire. Kuriakose et al. [9] conducted modeling based on data mining approach to find the significant factors affecting the cutting velocity and surface roughness. Tosun et al. [10] studied the effect of machining parameters on the kerf and MRR in WEDM operations and they found that open circuit voltage and pulse duration were the most significant factors.

In addition, micro WEDM is an electro-thermal process of material removal where the electrical and thermal properties of the work piece also plays an important role in the complexity of the machining. Therefore, the machinability of Inconel 718 in micro wire electrical discharge machining (RC based pulse generator) has to investigated extensively.

2. Experimentation

Experiments were carried out on DT110 multi-process micro machine (Fig 1) with µ-WEDM (Fig.2) attachment through resistance capacitance (RC) circuit.

Since RC circuit ensures low discharges at high frequency, it is suitable for micro scale electric discharge machining process. Hence it has been decided to use RC type pulse generator in this study.

Fig.1 DT110 Multipurpose Micro Machine

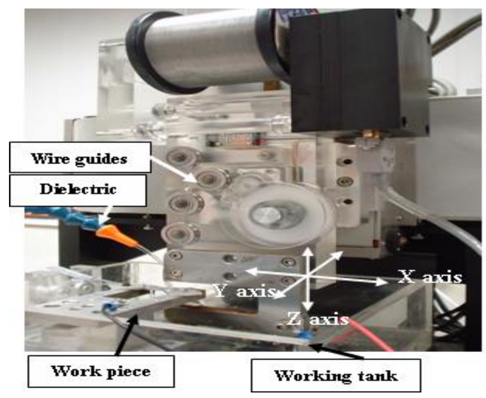

Fig. 2 Close view of µ-WEDM

2.1 Materials and measurement

Inconel 718 sheet of thickness 2mm and tungsten wire of diameter 70µm have been used as workpiece and wire/tool electrode respectively. The chemical composition of Inconel 718 is given in Table 1. EDM 3 synthetic oil has been used as the dielectric fluid for the present study.

Three replicates of 5mm slot in a single pass were obtained on the selected samples. The sidewall Surface roughness (Ra) value of the slot was measured using surface roughness tester (Surf test SJ210) with 2 µm stylus in interface with SURFPAK software.

2.2 Machining parameters and levels

Selection of appropriate parameter setting is one of the most important activities in µ-WEDM process. The typical input parameters like wire feed velocity, gap voltage, capacitance, feed rate, and wire tension were taken for measuring surface roughness based on the review of literature, cause and effect diagram and experience.

The parameters and their levels considered for the study are listed in Table 2.

Table 1. Chemical Composition of Inconel 718

Element	Ni	Cr	Fe	Nb	Mo	Ti	Al	Cu	C
Wt (%)	53.5	18.9	17.01	5.5	3.2	1.1	1.0	0.07	0.067

Table 2 Process parameters and their levels

Sl. No.	Factor	Parameter	Level		
			1	2	3
1	A	Wire Feed Velocity (μm/min)	60	100	---
2	B	Gap Voltage (V)	80	115	150
3	C	Capacitance (μF)	0.01	0.1	0.4
4	D	Feed Rate (μm/s)	3	6	9
5	E	Wire Tension (g)	4.125	8.25	12.375

3. Results and Discussions

Settings of selected combinations of the influential process parameters should be experimentally tested to achieve the optimum performance measures for surface roughness. The mean values of the results obtained for experiments done using Taguchi's L_{18} orthogonal array are as shown in Table 3.

Table 3. Experimental Results

Run order	A	B	C	D	E	SR (μm)
1	1	1	1	1	1	2.24
2	1	2	1	1	2	1.16
3	2	1	1	3	3	1.2
4	2	1	2	1	1	2.39
5	1	3	1	2	1	1.48
6	2	3	1	3	2	1.52
7	1	2	2	2	3	1.32
8	1	3	2	3	2	1.62
9	2	1	3	2	2	1.72
10	1	2	3	3	1	1.64
11	2	2	3	1	2	1.28
12	2	3	3	2	1	2.2
13	2	3	2	1	3	1.68
14	1	3	3	1	3	1.6
15	1	1	2	2	2	2.14
16	1	1	3	3	3	1.92
17	2	2	2	3	1	1.84
18	2	2	1	2	3	1.36

3.1 Effect of process parameters on Surface Roughness

The adequacy of the relationship among the parameters for Surface roughness is also checked by ANOVA. Table 4 shows the ANOVA, F-test values and % contribution showing the effectiveness of individual process parameter on SR. By checking F and p-value, it is seen that voltage and wire tension has the highest effect on SR followed by capacitance.

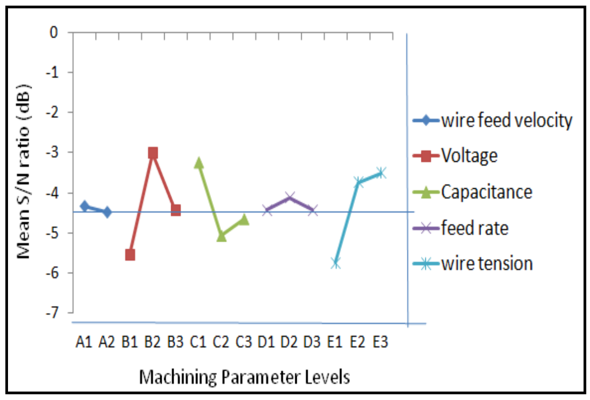

Fig. 3 S/N ratio (dB) by factor level for SR

The value of p less than 0.05 indicates that the model terms B, C and E are significant. From the % contribution it was found that voltage is the most influencing factor followed by wire tension and capacitance.

In Taguchi experimental design, S/N ratio is the ratio of signal to noise, where signal represent the desirable value (i.e. the mean for the output characteristic), and noise represent the undesirable value (i.e. the square deviation for the output characteristic), which is used to measure the quality characteristics that is deviating from the desired value. Therefore, the S/N ratio is the ratio of mean to square deviation.

For surface rougness lower the better (LB) S/N ratio is considered. The mean S/N ratio (dB) by factor level for Surface Roughness is shown in Fig 3. From that S/N response graph, it can be concluded that the optimal parametric combination for SR is A1B2C1D2E3.

With increase in gap voltage and capacitance, there is an increase in discharge energy ($0.5CV^2$) and more material are removed and increases the evaporation and recasting which alters materials surface morphology to a larger extnet and hence roughness increases [11].

With increase in voltage beyond the optimum value, high energy is dissipated which erodes more work material with stronger sparks. With this material erosion the unexpelled debris trapped in the machining zone causes secondary sparks. Thus high amount of discharge energy produced is wasted due the seconday sparks, thus work material is effectively removed by a small portion of discharge energy which results in lower average surface roughness.

Table 4. ANOVA for Surface Roughness

Sl No	Factor	SS	Variance	F-value	p-value	% contribution
1	A	0.0027	0.0027	0.164	0.6962	0.1356
2	B	0.7550	0.3775	22.74	0.0005	37.86
3	C	0.3598	0.18	10.84	0.0053	17.93
4	D	0.0344	0.0172	1.036	0.3980	1.714
5	E	0.722	0.361	21.74	0.0006	35.98
6	Residual	0.1328	0.0166			6.617
7	Total	2.0068				
	Model	2.21	0.4344	14.79	0.001	Signi ficant

As the capacitance increases, larger discharge energy is created. This greater discharge energy causes more energy to be conducted into the machining zone, which results in the formation of larger craters, which results in the increase of surface roughness.

As the feed rate increases, spark energy is more involved in material removal, but further increase in feed rate will not result in increasing surface roughness. With increase in wire tension, minimizes the wire bending and vibration [12] which leads to a dynamic stability condition of the diameterand the depth of the crater and improved the machined surface finish.

4. Conclusions

- This paper presents the experimental investigation of µ-WEDM on Inconel 718 alloy.
- Surface roughness (Ra) of the machined slot increased with increase in wire feed velocity, gap voltage, capacitance and feed rate. At the same time, increase in wire tension has improved the surface finish.
- The optimal process parameters for obtaining better surface finish based on S/N ration for the wire cut EDM of Inconel 718 were identified as A1(60 µm/min), B2 (115 V), C1 (0.01µF), D2 (6 µm/s) and E3 (12.375 g) combination.

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