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Experimental Investigation and Optimization of Micro-Wire EDM Parameters in Machining of Inconel 718

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Abstract – Inconel 718 super alloy finds widespread applications in various industries owing to its superior properties like high strength, resistance to oxidation and corrosion at elevated temperature, and high fatigue endurance limit. However there are some inherent problems associated with machining of Inconel 718 using conventional machining processes. Therefore non-conventional machining processes such as micro-wire electric discharge machining (micro-WEDM) are becoming favourite for efficient machining of Inconel 718, especially, for micro-feature fabrication. This paper mainly presents the investigation of the effects and optimization of process parameters on Material Removal Rate (MRR) and Kerf width in micro-WEDM of Inconel 718 while fabricating micro channels. Initially the effects of three process parameters including gap voltage, capacitance, and feed rate were investigated on process performance. Then multi-objective optimization was performed using a genetic algorithm to obtain an optimum condition for maximizing the MRR and minimizing the kerf width. The experimental validation was performed to check the optimum solutions.

Keywords— Micro-wire electric discharge machining, Micro-channels, MRR, Kerf, Inconel 718

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1. INTRODUCTION

The Nickel-based super alloys are used in many areas like automobile, medical, aerospace, etc. due to their high fatigue endurance limit, creep-rapture strength, amazing resistivity to corrosion and oxidation. [1,2]. Among all nickel based alloys, Inconel 718 is widely used particularly in an aerospace application, medical devices, etc. Though, Inconel 718 causes significant amount of difficulty during its machining owing to its high working hardness, chemical affection, thermal conductivity, etc. Therefore nontraditional machining processes are favored for its processing as compared to traditional processes [3, 4].

Since last decade, micro-WEDM is considered as one of the best processes for fabrication of microfeature owing to its ability to machine any conductive materials regardless of its hardness. Micro-WEDM is given higher priority among all the nontraditional machining processes because of its high machining efficiency, precision, and low cost and hence has been widely used in industrial machining purposes.

In general the performance of WEDM is mainly affected by a combination of properties of the workpiece, electrical settings of the machine, physical properties of the wire electrode, machine intelligence, dielectric flushing method and its properties. Mahapatra and Patnaik [5] pointed out the effects of various machining parameters on the Surface Finish (SF) and Metal Removal Rate (MRR). They observed the behavior of the process under influence of different process parameters like dielectric flow rate, wire tension, wire speed, pulse duration, and discharge duration. They used a genetic algorithm for multi-objective optimization of WEDM. Sivaprakasan et al. [6] investigated the influence of various input parameters such as capacitance, voltage, and feed rate of micro-WEDM on the performance parameters including Surface Roughness (SR), MRR, and kerf width (KW) using response surface methodology with Central Composite Design (CCD) while machining Ti-6Al-4V. They pointed out that all input parameters have a significant influence on performance parameters. They also determined the optimal machining condition for best performance using the Multi-Objective Technique (MOT).

Kuriachen et al. [7] established a model to overcome the limitation of micro-WEDM. The effect of various input parameters like capacitance, gap voltage, feed rate and wire tension on the performance of the wire-WEDM of on Ti-6AL-4V was studied. They claimed that the predominant factor among all the factors is capacitance. They also proposed a fuzzy logic based model to give more accurate data and good dynamic quality of the system. Zhen et al. [8] investigated the

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effects of process parameters and optimized them in wire-EDM. They also observed the surface integrity in terms of crack density and white layer thickness. Brar et al. [9] analyzed the effect of pulse-on-time, pulse-off-time, and current on MRR and SR. They found that for MRR, pulse-on-time, and current were predominant factors. While for surface roughness, pulse-off-time and current have maximum effect.

Hoang et al. [10] pointed out the new approach to controlling feed rate of the electrode by using a real-time estimation of MRR and identification of the workpiece height. Their results show that the proposed approach gives much better results than the conventional method in terms of stability and efficiency. Azam et al. [11] observed that pulse-on-time and wire speed to be the most significant factors influencing the thickness of recast layer. Recently, Unune and Mali [12] investigated a novel approach of a vibration assisted wire-EDM process. They investigated the effects of vibration on MRR and kerf width and claimed that vibrations significantly enhance the performance of the process due to effective removal of debris and reduced arcing.

The present work investigates performance of micro-WEDM of Inconel 718 for various input process parameters such as gap voltage, capacitance, and feed rate. The performance of input parameters has been analyzed on MRR and kerf width and input parameters have been optimized to obtain optimum process performance.

2. EXPERIMENTATION

2.1 Materials

The commercially available Inconel 718 was selected as a workpiece material. The workpiece specimens of size 25 mm thickness, 10 mm length and 3 mm width were prepared using diamond cutter. The dielectric fluid chosen was commercially available Total DIEL 7500IN. Zinc coated brass wire diameter 70 µm was used as an electrode material.

2.2 Experimentation

The experiments were carried out using the micro-WEDM setup on Mikrotools DT110 machine. The positive terminal was connected to workpiece while negative terminal was connected to the electrode. The schematic diagram of the experimental setup is shown in Fig. 1. The gap voltage, capacitance, and feed rate were designated as input parameters while Material Removal Rate (MRR) and kerf width as performance parameters. The experiments were performed varying one-factor at a time and keeping other variables constant. The machining conditions are displayed in Table 1.

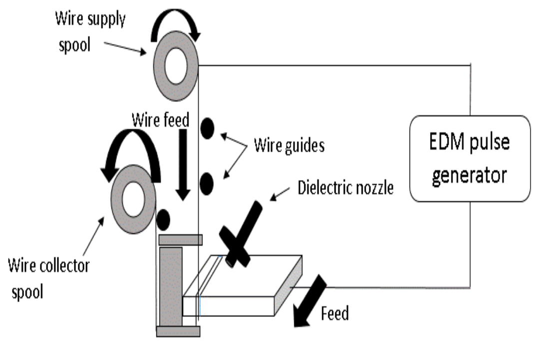

Fig. 1 Schematic diagram of micro-WEDM

TABLE II Machining conditions

Parameter	Values/Details
Workpiece	Inconel 718
Wire	Zinc coated brass (Ø70µm)
Dielectric	Total DIEL7500IN
Gap voltage (V)	80, 90, 100, 110, 120, 130
Capacitance (µF)	0.001,0.01, 0.1,0.2, 0.3, 0.4
Feed rate (mm/min)	0.1, 0.2, 0.3, 0.4, 0.5, 0.6
Wire tension (%)	0.35

2.3 Measurement

MRR was calculated by dividing weight difference of specimen before machining and after machining to machining time, using following equation.

$$\text{MRR} = \frac{\nabla M_{wp}}{t} \left(\frac{mg}{min}\right)$$

Where, ∇M_{wp}=Weight difference, and t=time

Kerf width was measured using a Digital Microscope (Zeiss Axio Cam). Kerf width was measured at five different points then their average was considered as the final result.

3. RESULTS AND DISCUSSION

This section presents the effects of input machining parameters, viz., gap voltage, capacitance, and feed rate on MRR and kerf width.

3.1 Effects of machining parameters on MRR

Fig. 2, 3 and 4 show the effects of gap voltage, capacitance and feed rate on MRR. It was observed that MRR increases with increase in capacitance and gap voltage. However for gap voltage, MRR increases initially after achieving an optimum value of 110 V. It starts to decline if further gap voltage is

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increased. The reason behind this observation is that with an increase in both gap voltage as well as capacitance, the discharge energy produced by RC circuit also increases. The discharge energy (DE) in RC circuit is the product of capacitance and gap voltage (DE=0.5*Capacitance*Voltage^2) [13, 14]. The capacitance regulated the amount of energy stored and therefore with an increase in capacitance, the amount of DE, pulse current and pulse interval also increases [7]. As higher discharge energy acts onto the workpiece, more material could be removed from the workpiece. Therefore MRR rises significantly at higher values of capacitance (Fig. 3). It is seen that MRR increases initially with an increase in gap voltage up to an optimum value and then decreases with further increase in gap voltage. It has been observed from Fig.4 that MRR increases linearly with the increase in feed rate. This is due to reason that with an increase in feed rate the cutting rate also increases.

3.2 Analysis of Kerf

Fig. 2, 3 and 4 also show effects of machining parameters on kerf width. Kerf width increases with an increase in capacitance, feed rate, and gap voltage but their pattern is different, i.e., for capacitance and gap voltage are steep but for feed rate the curve is almost flat. It is observed that kerf width is more sensitive toward capacitance followed by gap voltage and least sensitive to feed rate.

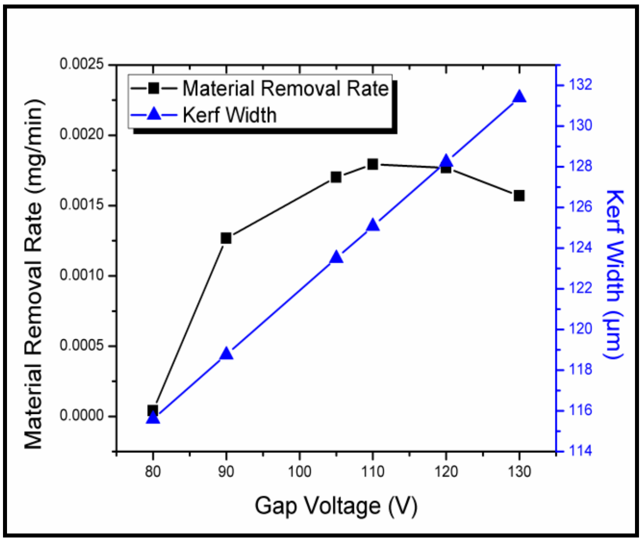

Fig. 2 Effect of gap voltage on MRR and kerf width

For achieving lower kerf width, the low gap voltage and low capacitance (i.e. low discharge energy) are recommended. As discharge energy increases kerf width also increases because of increased thermal energy acting on the workpiece. The increase in capacitance and gap voltage results in larger ionization effect.

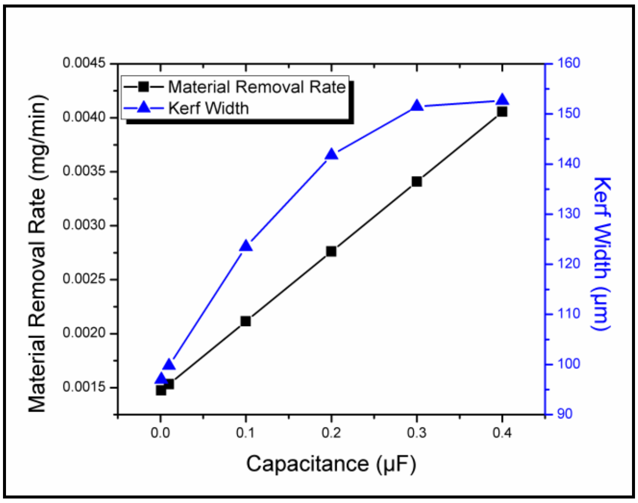

Fig. 3 Effect of capacitance on MRR and kerf width

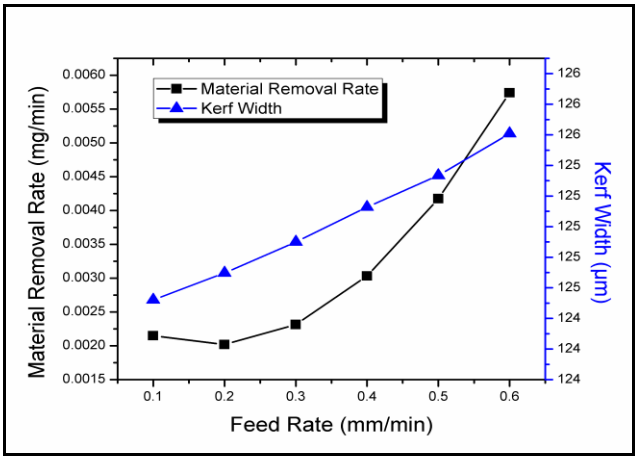

Fig. 4 Effect of feed rate on MRR and kerf width

The microscopic image of the fabricated microchannel in Inconel 718 using micro-WEDM is shown in Fig. 5.

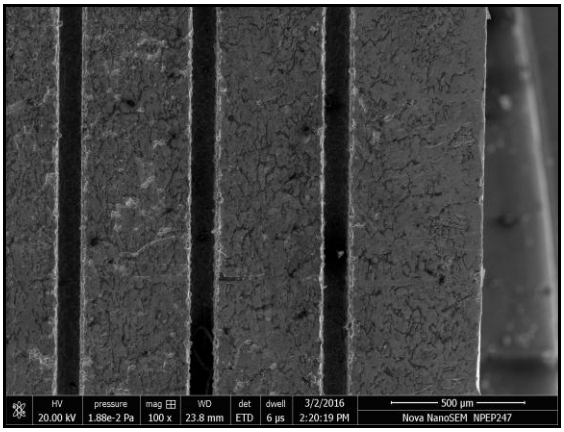

Fig. 5 Micro-channels fabricated using micro-WEDM in Inconel 718

3.4 Optimization using genetic algorithm (GA)

Genetic algorithm (GA) is a powerful tool to solve the optimizing problem in engineering. GA starts with initialization of parent population, and the fitness was defined in next step it began to reproduce under certain probability of crossover and mutation then come the evolution process in this step unit with higher fitness value will likely to survive but unit with low fitness value gets replaced with new higher fitness value when the fitness value reaches the termination criteria.

In this study our aim is to maximize MRR and minimize kerf width:

Objective Function,

Maximize MRR= f (Gap Voltage, Capacitance, Feed rate)

Minimize Kerf width = f (Gap Voltage, Capacitance, Feed rate)

Subjected to constraints,

80 ≤Gap Voltage≤130,

0.001≤ Capacitance ≤0.4

0.1≤ Feed rate ≤0.6.

MATLAB program is used for GA based optimization of micro-WEDM of Inconel 718. A number of generations: 500; population size: 20; crossover rate: 0.8; crossover mechanism: two points; and mutation rate: 0.01 were selected as GA parameters. The optimal parameters along with predicted and validated response variables are shown in Table 2.

Table IIII Optimum Machining conditions

Optimum values for parameters	**Predicated Response**		**Experimental Response**	
	MRR (gm/min)	**KW (µm)**	**MRR (gm/min**	**KW (µm)**
Gap voltage (116 V), Capacitance (0.1 µF), Feed rate (0.6 mm/min)	0.057	118.7	0.0568	117

4. CONCLUSIONS

This paper presented a multi-objective optimization of process parameters of micro-WEDM of Inconel 718 using a genetic algorithm. For the experimentation, input parameter viz. gap voltage, capacitance, and feed rate while performance parameter viz. MRR and kerf width were selected. From experiment work following conclusion were drawn:

- It was observed that with an increase in gap voltage, capacitance, and feed rate MRR in micro-WEDM increases.
- The kerf width found to be increasing with increase in gap voltage, capacitance, and feed rate.
- The optimization results showed that the optimum parametric combination of gap voltage of 116 V, the capacitance of 0.1 µF and feed rate of 0.6 mm/min can lead to for maximum MRR of 0.0568 mg/min and minimum kerf width of 117 µm.

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