

Analysis and Optimization of Surface Integrity Characteristics of EDMed Work Surface Inconel 718 Super-Alloy Using Grey-Based Taguchi Method



Md. Ghaus Ali, Rahul, Dipraj Banik, Akshansh Yadav, B. C. Rautara and Ashok Kumar Sahoo

Abstract The aim of this research work is to find the optimum combination of input process parameters such as peak current (I_p), open voltage (V_g), pulse-on-time (T_{on}) and duty factor (τ) for machining of Inconel 718 on EDM. The output response parameters studied were metal removal rate (MRR), electrode wear rate (EWR) and surface roughness (R_a). L_{16} orthogonal array of input parameters was created as the design of experiments (DOEs) with the help of Minitab software. Grey relational analysis (GRA) method is used to get a single domain of multiple output response parameters. After that Taguchi optimization method was applied to find out the optimal parameter setting for higher MRR, lower TWR and lower R_a .

Keywords EDM · Inconel 718 super-alloy · Copper tool · GRA · Taguchi method

1 Introduction

Several machining processes involving the application of very intense local heat have come into use in recent years. In these processes, material is removed by erosion and evaporation at the surface of the work piece.

Mishra et al. [1] has presented the importance of EDM in today's industrial world. EDM is widely used as non-traditional machining process in manufacturing process. The advantages of EDM are as follows: EDM can be used effectively for machining of complex shapes, EDM machining process is independent of material's mechanical properties, and EDM machining can result in high accuracy. When both the tool and electrolyte are placed in a dielectric medium and a very high electric potential is applied, a high impulse electric spark is generated. The spark dissipates a huge amount of heat (8000–12,000 °C), resulting in melting of the work piece [2, 3]. Ezugwu et al. [4] has presented a typical problem as the cost of electrode becomes high during machining of Inconel 718 due to high EWR. It has become a crucial issue during machining of Inconel 718. Sudhakara et al. [5] has presented the

Md. Ghaus Ali · Rahul (✉) · D. Banik · A. Yadav · B. C. Rautara · A. K. Sahoo
KIIT (Deemed to Be University), Bhubaneswar, Odisha, India
e-mail: rahulkumar589@gmail.com

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experimental investigation of machining of Inconel 718 on die-sink EDM. Various EDM parameters such as I_p , T_{on} , τ were taken during the machining of work piece. The output responses that were measured were metal removal rate and surface roughness. He showed the influence of I_p , T_{on} and τ on MRR, R_a and hardness. Ahamad and Lajis [6] in their work has analysed the electrode wear rate (EWR) of copper electrode during the machining of Inconel 718 by taking I_p and T_{on} high on EDM. They found that T_{on} is the most significant factor for TWR. Higher T_{on} can decrease TWR, but higher I_p can increase TWR. Rahul et al. [7] also conducted an experiment over the optimization of parameters on Inconel 601, Inconel 625, Inconel 718 and Inconel 825 super-alloys through electro-discharge machine based on 5-factor–4-level L_{16} orthogonal array and calculated the optimum results using the TOPSIS and Taguchi method for it. Rahul et al. [8] experimentally investigated machinability aspects of machining of Inconel 718 with copper tool. They conducted the research work based on L_{25} OA by taking various parameters such as V_g , I_p , T_{on} , τ and Flushing pressure F_p and various responses such as tool wear rate (TWR), surface roughness (R_a), surface crack density (SCD) and white layer thickness (WLT). Lin et al. [9] in his research work of optimizing EDM parameters used grey relational analysis in conjugation with fuzzy-based Taguchi method to find the optimum parameters.

In the present work, multilevel process parameter optimization of Inconel 718 super-alloy is done when machined with copper tool in EDM. Here, peak current, voltage, pulse-on-time and duty factor are taken as the variable parameters and MRR, TWR and R_a as machine responses.

2 Experimental Details and Data Collection

Inconel 718 super-alloy circular work piece having dimension (50 mm \times 5 mm) has been used as work material. The snapshot of EDMed Inconel 718 is shown in Fig. 1. Copper (20 mm diameter) has been used as tool electrode (Fig. 2). Research work has been done on EDM (Model: ELEKTRA EMS 5535 Machine, Pune, India) set-up (Fig. 3). EDM oil 30 is used as dielectric fluid. The viscosity of EDM oil is 36 ssu at 38 °C. Work piece polarity has been chosen as positive. The design of experiment is taken as per 4-factor–4-level L_{16} orthogonal array (OA) given in Table 1. Here, peak current, voltage, pulse-on-time and duty factor are taken as the variable parameters each varied at four different levels. The duration of machining for every experiment was taken as 30 min. Various responses such as surface roughness (R_a), metal removal rate (MRR), electrode wear rate (EWR) have been measured for every experiment given in Table 2.

Fig. 1 EDMed Inconel

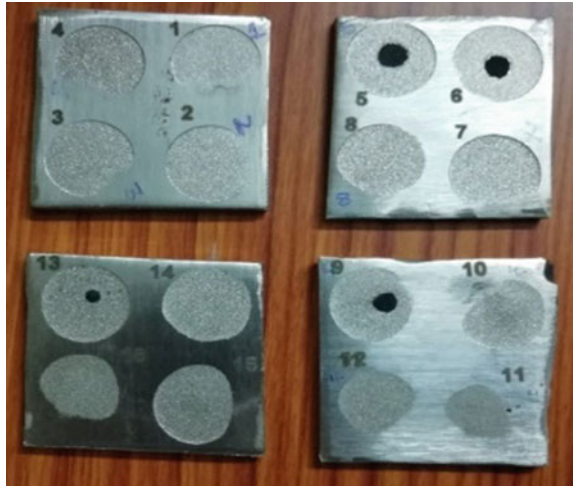


Fig. 2 Copper tool

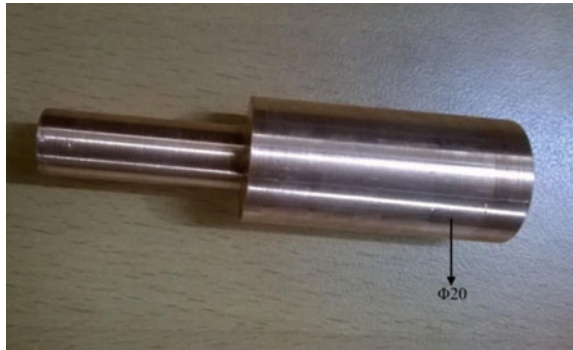


Table 1 Domain of experiments

Input parameters	Unit	Symbol	Levels of variation			
			1	2	3	4
Peak current (I_p)	A	A	8	10	12	14
Open voltage (V_g)	V	B	15	20	25	30
Pulse-on-time (T_{on})	μs	C	50	100	150	200
Duty factor (τ)	%	D	55	70	85	100

Fig. 3 EDM machine



Table 2 Design of experiments (DOEs): L₁₆ orthogonal array (collected data)

Exp. no.	Levels of parameters in coded form				Collected experimental data		
	A	B	C	D	MRR (mm ³ /min)	TWR (mm ³ /min)	SR (μm)
1	1	1	1	1	3.6621	0.0433	4.824
2	1	2	2	2	5.4932	0.0874	4.366
3	1	3	3	3	3.0518	0.1756	4.832
4	1	4	4	4	3.0518	0.1756	4.459
5	2	1	2	3	7.3242	0.0874	3.919
6	2	2	1	4	4.2725	0.1315	2.92
7	2	3	4	1	7.3242	0.1756	4.209
8	2	4	3	2	3.6621	0.2198	4.773
9	3	1	3	4	3.6621	0.0874	3.765
10	3	2	4	3	4.2725	0.0433	4.007
11	3	3	1	2	0.6104	0.0874	3.426
12	3	4	2	1	1.2207	0.1756	3.537
13	4	1	4	2	7.3242	0.0433	4.28
14	4	2	3	1	3.0518	0.0874	5.096
15	4	3	2	4	3.6621	0.1315	5.462
16	4	4	1	3	2.4414	0.1315	4.604

The output response parameters are explained below:

- MRR It is defined as the quantity of metal displaced from the job under a specific time. Unit was taken as mm³/min.
- TWR It is defined as the quantity of metal displaced from the tool under a specific time. Unit was taken as mm³/min.

3 Methodology

3.1 Grey Relational Analysis

In this analysis, the input parameters converted into normalized value in a scale range between 0 and 1. Since the response MRR is of larger-the-better type and TWR and R_a are of smaller-the-better type, then normalized value x_i^* for larger-the-better type, i.e. MRR, is expressed as:

$$x_i^* = \frac{x_i - x_{\max}}{x_{\max} - x_{\min}}$$

where i = experiment number, i.e. 1, 2, 3, 4, ..., 16, x_i^* = normalized value of MRR for i th experiment number, x_i = actual MRR value for the i th experiment number, x_{\min} = minimum actual value of MRR among all the 16 experiments done, and x_{\max} = maximum actual value of MRR among all the 16 experiments done. Normalized value $y_i^* = y_i - y_{\max} / y_{\min} - y_{\max}$ for “smaller-the-better” type, i.e. TWR and R_a , is expressed as:

where i = experiment number, i.e. 1, 2, 3, 4, ..., 16, y_i^* = normalized value of TWR or SR for i th experiment number, y_i = actual TWR or SR value for the i th experiment number y_{\min} = minimum actual value of TWR or SR among all the 16 experiments done, and y_{\max} = maximum actual value of TWR or SR among all the 16 experiments done.

Step I: Calculating deviation sequences (Δ) for the normalized data

After the normalization procedure, all performance values (MRR, TWR and R_a) will be scaled into [0, 1]. Deviation sequence aims to find the alternative whose normalized value is the closest to the reference value. Upon calculating the normalized value of MRR, TWR and SR for each experiment number, we calculate deviation sequences (quality loss function) with the help of normalized values of MRR, TWR and SR for each experiment number. Deviation sequence is denoted by Δ and mathematically calculated as:

$$\Delta_i = 1 - \text{Normalised Value of Response Parameters} \\ \text{(i.e. MRR, TWR and } R_a \text{) for } i \text{th experiment run.}$$

where i = experiment number, i.e. 1, 2, 3, ..., 16. Example: For $i = 1$, i.e. first experiment run, $\Delta_{MRR\ 1} = 1 - S_{MRR\ 1} = 1 - 0.4545 = 0.5455$

Step II: Determining grey relational coefficient (GRC) and grey relational grade (GRG)

The GRC is mathematically defined as follows:

$$GRC = \frac{\Delta_{\min} + \Gamma \Delta_{\max}}{\Delta_{ij} + \Gamma \Delta_{\max}}$$

where i = experiment number, j = refers to the response parameters, i.e. MRR, TWR and R_a , Δ_{\min} = minimum value of deviation sequence for j th response parameter among all the 16 experiments, Δ_{\max} = maximum value of deviation sequence for j th response parameter among all the 16 experiments, Γ = distinguishing factor (when all the response parameters are given the equal weightage, then usually its value is taken as 0.5). After finding GRC for each experiment run for every parameter, i.e. MRR, TWR and R_a , GRG was calculated for every experiment. GRG combines all the individual GRCs of parameters like MRR, TWR and R_a of a particular experiment run into one grade which can be compared with the other GRG of other experiment runs. GRG is mathematically found out by the relation given below:

$$GRG_i = (W_g \times GRC_{MRR_i}) + (W_g \times GRC_{TWR_i}) + (W_g \times GRC_{R_a_i})$$

where i = Experiment No., W_g = Weightage given to the response parameters = 0.33 (as $\Gamma = 0.5$).

Then, optimization of GRG function is done using Taguchi approach. As GRG is wished to be the maximum, so during signal-to-noise ratio calculation higher-the-better approach was used. The calculations of GRG and S/N ratio are given in Table 3.

4 Results and Conclusions

The machining responses obtained from the experiments were used to calculate S/N ratio plots, and the optimal parameter setting appears to be $A_2B_1C_4D_2$, i.e. $I_P = 10\text{ A}$, $V_g = 15\text{ V}$, $T_{on} = 200\ \mu\text{s}$ and $\tau = 66.67\%$.

The optimum process parameters found as $A_2B_1C_4D_2$ and the corresponding value found as -1.05155 are less than the corresponding values found in every experiment. Since the S/N ratio's need was higher-the-better, we found the highest corresponding value at the optimum setting showing the reliability of the Taguchi approach. The main effects plot for S/N ratios [$A_2B_1C_4D_2$] is shown in Fig. 4.

Table 3 Calculations

Exp. no.	MRR	TWR	R_a	Δ_{MRR}	Δ_{TWR}	Δ_{R_a}	GRC _{MRR}	GRC _{TWR}	GRG	S/N ratio	Predicted value
1	0.454	1.000	0.251	0.545	0.000	0.749	0.478	1.000	0.620	-4.152	
2	0.727	0.750	0.431	0.272	0.249	0.568	0.647	0.666	0.588	-4.612	
3	0.363	0.250	0.247	0.636	0.749	0.752	0.440	0.400	0.409	-7.765	
4	0.336	0.250	0.394	0.636	0.749	0.605	0.440	0.400	0.427	-7.391	
5	1.000	0.750	0.607	0.000	0.249	0.393	1.000	0.666	0.735	-2.674	-1.052
6	0.545	0.500	1.000	0.454	0.499	0.000	0.523	0.500	0.668	-3.504	
7	1.000	0.250	0.492	0.000	0.749	0.507	1.000	0.400	0.626	-4.068	
8	0.454	0.000	0.271	0.545	1.000	0.729	0.478	0.333	0.402	-7.915	
9	0.454	0.750	0.667	0.545	0.249	0.332	0.478	0.666	0.576	-4.791	
10	0.545	1.000	0.5724	0.4545	0.000	0.427	0.523	1.000	0.681	-3.337	
11	0.000	0.750	0.8009	1.0000	0.249	0.199	0.333	0.666	0.566	-4.943	
12	0.090	0.250	0.7573	0.9091	0.749	0.242	0.354	0.400	0.471	-6.539	
13	0.272	0.473	0.7916	0.0000	0.000	0.535	1.000	1.000	0.819	-1.734	
14	0.237	0.463	0.8301	0.6364	0.249	0.856	0.440	0.666	0.487	-6.249	
15	0.202	0.452	0.8686	0.5455	0.499	1.000	0.478	0.500	0.433	-7.270	
16	0.167	0.442	0.9072	0.7273	0.499	0.662	0.407	0.500	0.441	-7.111	

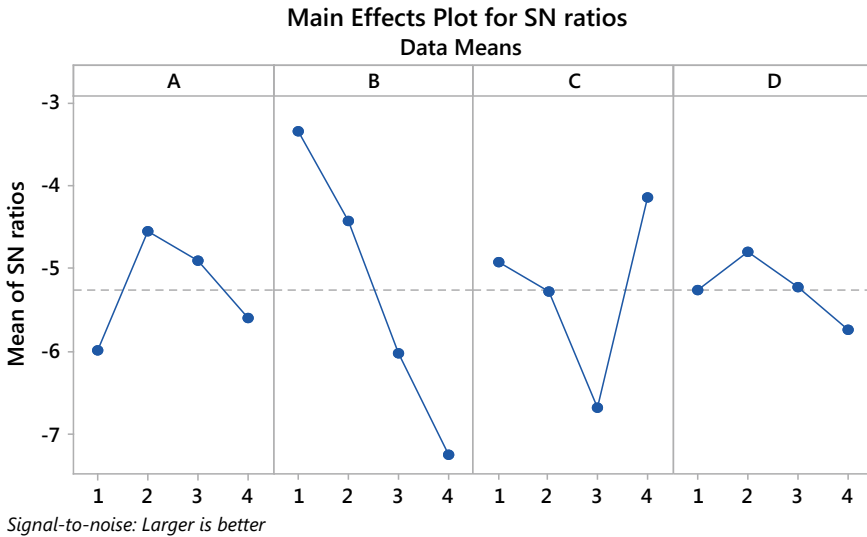


Fig. 4 Main effects plot for S/N ratios [A₂B₁C₄D₂]

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