Journal of Scientific & Industrial Research
Vol. 79, August 2020, pp. 691-695

Electrical Discharge Machining of Inconel 718 using Cryo-Processed Rotary Cu-Electrode

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Received 12 February 2018; revised 22 May 2019; accepted 5 May 2020

This paper focuses on the impact of machining factors on surface quality in electric discharge machining (EDM) of Inconel 718. Drilling has been performed by a cryogenic treated copper tool. Experiments were accompanied by dissimilar machining factors viz. tool diameter, discharge current, pulse on time pulse off time, tool rotation and hole depth. The thickness of work piece material remains constant. Surface roughness is measured by optical surface profiler. Taguchi based L_{18} orthogonal array of experimental design was employed to accomplish machining. Analysis of variance (ANOVA) has been employed to find out optimum factors for minimum surface roughness (SR). It was found that pulse off time, pulse on time and tool rotation are greatest affecting factors that affects SR for cryo-treated Cu tool electrode. Tool diameter is least affecting factor that affects SR. A linear regression model has been developed to find out optimum combination for SR of Inconel 718 work piece.

Keywords: ANOVA, Optical Surface Profiler, Regression, Surface roughness, Taguchi

Introduction

The heat produced in EDM causes metal removal by melting the work-piece material, but an unwanted layer i.e. recast layer (RCL) is also deposited, responsible for lower surface quality.[1] Surface texture improvement of machined sample is done via several practices in EDM such as provision of adequate power resource, addition of silicon carbide powder in dielectric fluid etc.[2]

Surface texture of Be-Cu is enhanced via multi-diameter tool and deionized water and kerosene as dielectrics without changing the process duration in EDM.[3] Investigators found for Inconel 600 that negative polarity leads toward lower SR.[4]

Rotary EDM is a technique primarily employed to machine harder metals by using rotation of tool or work-piece alloys.[5,6] Rotary EDM, machining firmness could be enhanced via providing rotation to tool since rotation improves the flushing of remains of materials from the machining area, constraining repetitive happening of extraordinary frequency electrical sparks at lone location.[7]

A number of investigators have functioned with EDM progression and strained to narrate the process factors with performance characteristics practically and theoretically.[8] Researcher invented a novel technique for enriching the tool electrode lifespan, which is the foremost concern in budget perspective in an industry. Cryogenic action methodology leads better tool electrode lifespan in comparison to other methods from continuing research.[9] Some studies have conducted for finding in what way cryogenic action affects tool electrode lifespan of brass tool electrode in EDM machining.[10] Influence of EDM input factors on response factors in Inconel 718 and 625 have been studied and second-order polynomial charts have been plotted.[11] Certain Investigators enhanced SR of Inconel 718 magnificently via numerous optimization techniques.[12–14]

This experimental investigation has stressed on the EDM of Inconel 718 through cryo-processed Cu tool having helical grooves upon its surface. An effort is performed to obtain optimum set of machining factors for least possible SR using Taguchi methodology.

Materials and Methods

The experiments on Inconel 718 were conducted with an EDD set-up (Fig. 1). Experimentations are accomplished through die sinking EDM Machine. For experimentations, kerosene was engaged as dielectric fluid.

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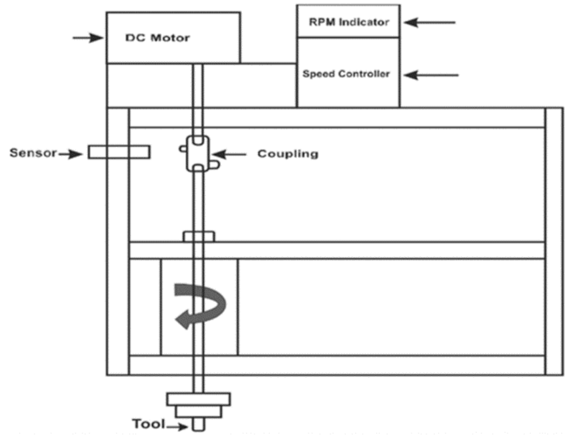

Fig. 1 — EDD Experimental Setup

Experimental study aimed to attain optimum arrangement of machining factors resulting in Minimum SR. This experimental setup comprises of a Mild steel structure, DC motor, RPM meter and tool holder. Solid copper tool electrode of diameters 4 mm & 6 mm with helical groove and helix angle of 10 degree have been employed in investigational studies of EDD process. Tool of 4 mm diameter having pitch thread and flute depth as 3 mm and 0.5 mm respectively was used. Tool of 6 mm diameter used had pith thread and flute depth of 3 mm and 1 mm respectively. Helical groove has been employed for enhancing machinability.[15] Depth of 1, 1.5 & 2 mm holes have been machined on Inconel 718 for cryo-processed tool electrode.

Machining factors, like tool diameter, discharge current, pulse on time, pulse off time, tool rotation and depth of hole have been altered to analyze their impact on responses characteristics i.e. SR for cryo-processed tool electrode. Factor has been retained same throughout drilling of holes in Inconel 718 as thickness of plate 3 mm, dielectric flow rate 7 LPM and power supply of 40 volts. SR of drilled surface has been recorded by optical surface profiler.

Design of Experiment (DOE)

Preliminary experimentations have been accomplished for selecting the process factors and their levels employed for analyzing through Taguchi technique and ANOVA. The process factors and their levels in existing investigation are listed in Table 1. Throughout trials, process factors viz tool diameter (d_t), discharge current (Ip), pulse on time (T_{on},) pulse off time (T_{off}), tool rotation (N_t) and hole depth (h) have been chosen via L_{18} orthogonal array (OA). Impact of process factors on response viz. SR, were studied for cryogenically treated Cu tool. Levels of input factors have been employed for developing the model for optimization of process factors for SR of drilled work-piece.

Table 1 — Several factors, their codes & levels

Control Factor	UNIT	CODE	LEVEL		
			1	2	3
d_t	mm	A	4	6	—
I_p	A	B	6	10	14
T_{on}	µs	C	20	30	40
T_{off}	µs	D	7	8	9
N_t	rpm	E	30	40	50
H	mm	F	1	1.5	2

To lowering process duration and expenditure, Taguchi practice has employed to achieve top consequences with a least amount of trials through employing OA of statically intended trials. Throughout the Taguchi practice, signal to noise (S/N) ratio has been employed for computing surface features. The smaller is better has been employed for evaluating SR. The ratio of S/N for DOE has been computed through Eq. (1).[10,16,17]

$$\frac{S}{N} = -10\log\left(\frac{1}{n}\sum Y_i^2\right) \quad \ldots (1)$$

Where i = 1, 2, 3 ……….n; Y_i = outcome of machining factors & n = number of recurrences.

The DOE is illustrated in Table 2 by employing L_{18} OA and linked values of SR along with equivalent S/N ration for cryogenically treated tool electrode.

Results and Discussion

Investigation of impact of individual machining factor on SR (for cryogenically processed tool electrode) has been conducted through S/N response analysis. Strongest impact has been applied by N_t followed by T_{off}, T_{on}, I_p, h and d_t for cryo-processed tool electrode. Response graphs of means of S/N ratios for SR of cryo-processed tool electrode are presented in Fig. 2. Optimum value of individual process factor could be effortlessly identified via "smaller the better'' performance characteristic. Therefore, grounded on S/N ratio, optimum level condition of particular process factors is, A2B2C3D2E1F2 for cryo-processed tool electrode.

Thermal conductivity, hardness and resistance to wear of Cu can be enriched through cryogenic process. Enhanced thermal conductivity of Cu causes more proficient heat transmission from tool throughout machining.[9] Surface quality is improved via tool rotation because of superior flushing-reduce formation of recast layer.[18]

Table 2 — DOE thru L18 OA and linked values of SR with equivalent S/N ratio for cryo-processed Cu tool electrode

Exp.no	(d_t)	(Ip)	(T_{on})	(T_{off})	(N_t)	(h)	SR (μm)				S/N ratio
							1	2	3	Avg	
1	4	6	20	7	30	1.0	5.13	5.17	5.13	5.143	-14.22
2	4	6	30	8	40	1.5	5.57	5.58	5.52	5.556	-14.89
3	4	6	40	9	50	2.0	5.26	5.28	5.31	5.283	-14.45
4	4	10	20	7	40	1.5	5.35	5.38	5.32	5.350	-14.56
5	4	10	30	8	50	2.0	5.57	5.52	5.57	5.553	-14.89
6	4	10	40	9	30	1.0	5.65	5.61	5.63	5.630	-15.01
7	4	14	20	8	30	2.0	6.09	6.19	6.15	6.143	-15.76
8	4	14	30	9	40	1.0	5.61	5.51	5.53	5.550	-14.88
9	4	14	40	7	50	1.5	5.46	5.56	5.66	5.560	-14.90
10	6	6	20	9	50	1.5	5.49	5.53	5.63	5.550	-14.88
11	6	6	30	7	30	2.0	5.48	5.38	5.28	5.380	-14.61
12	6	6	40	8	40	1.0	5.77	5.81	5.88	5.820	-15.29
13	6	10	20	8	50	1.0	5.57	5.55	5.51	5.543	-14.87
14	6	10	30	9	30	1.5	5.59	5.65	5.63	5.623	-14.99
15	6	10	40	7	40	2.0	6.15	6.03	5.91	6.030	-15.60
16	6	14	20	9	40	2.0	5.15	5.10	5.19	5.146	-14.22
17	6	14	30	7	50	1.0	5.22	5.28	5.25	5.250	-14.40
18	6	14	40	8	30	1.5	6.20	6.11	6.13	6.146	-15.77

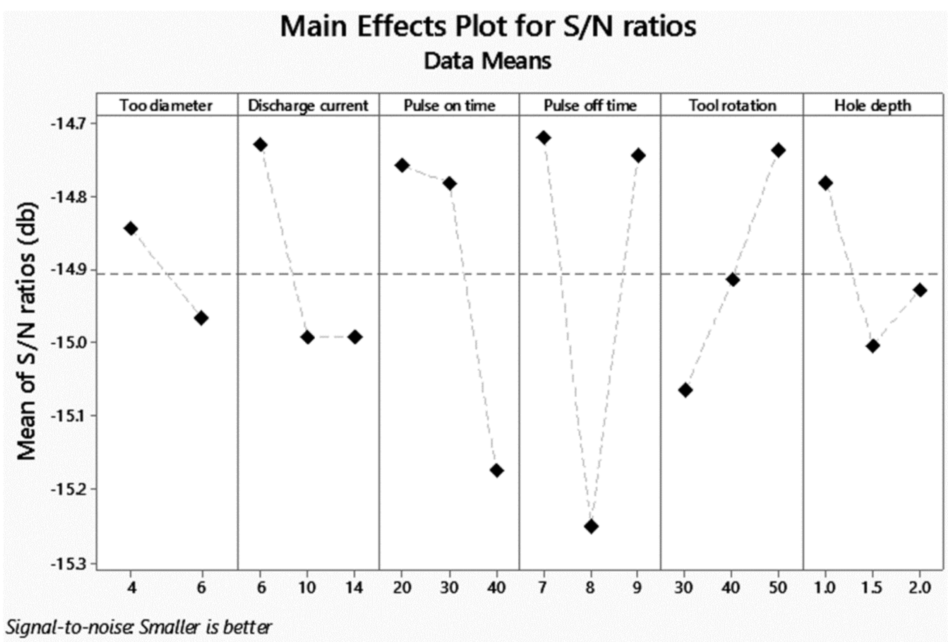

Fig. 2 — Response plots of S/N ratio of SR, for cryo-processed tool electrode

Analysis of Variance (ANOVA) for SR

Analysis of variance is a statistically based, objective decision-making tool for detecting any deviance in average performance of clusters of objects experienced. So, it has been employed to determine which machining factors expressively influence output characteristic.[19] The ANOVA of input factors on SR of Inconel 718 super for cryo-processed tool electrode is given in Table 3. It is perceived that at 95% confidence level, T_{on}, T_{off} & N_t are utmost noteworthy input factors that impacts SR cryogenically treated tool electrode whereas d_t, I_p & h are least noteworthy factors. T_{on} impacts SR more than other parameters because of the fact that with increase in T_{on} diameter of plasma enhances which minimize both energy concentration & impulsive force.[20]

Table 3 — ANOVA of S/N ratio for cryo-processed tool electrode (S = 0.285784; R^2= 68.87%; R^2 (adj)= 11.80%; R^2 (pred) = 0.00%)

Source	DF	Seq SS	SS Adj	Adj MS	F	P
d_t	1	0.02880	0.02880	0.02880	0.35	0.574
I_p	2	0.11824	0.11824	0.05912	0.72	0.523
Ton	2	0.27591	0.27591	0.13796	0.262	0.262
T_{off}	2	0.45086	0.45086	0.22543	2.76	0.141
N_t	2	0.14680	0.14680	0.07340	0.90	0.456
h	2	0.06345	0.06345	0.03173	0.39	0.694
Residual Error	6	0.49003	0.49003	0.08167		
Total	17	1.57410	1.57410			

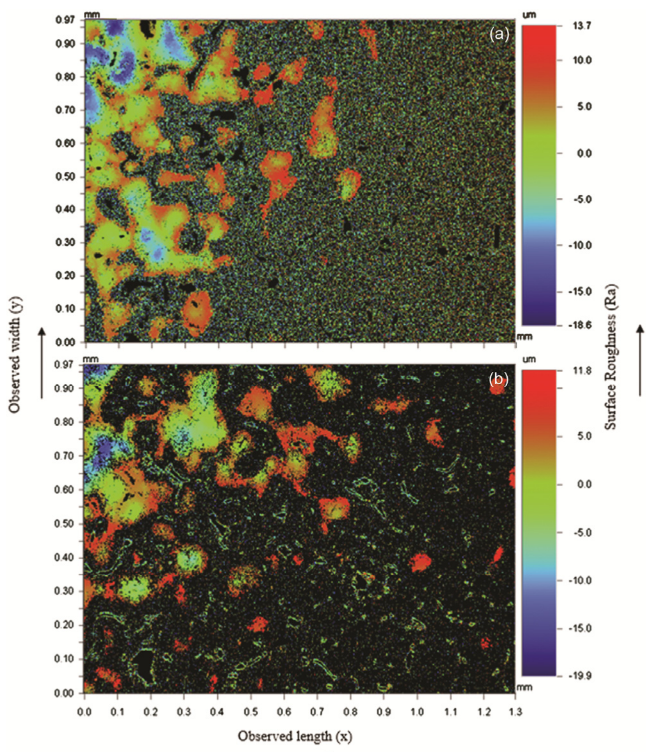

Fig. 3 — Micro structure of machined hole using optical surface profiler for (a) normal tool electrode having SR of 5.28 µm (b) cryo-processed tool electrode having SR of 5.17 µm

Regression analysis

Regression study has been engaged to know impact on SR.[21] Regression equation for cryo-processed Cu tool electrode is obtainable as in Eq. 2:

$$SR = 4.996 + 0.04\, d_t + 0.0221\, I_p + 0.01328\, T_{on} + 0.0058\, T_{off} - 0.01105\, N_t + 0.01\, h \quad \ldots (2)$$

From above expression, projected R^2 (68.87 %) value and adjusted R^2 value have been found more or less agreeing with investigational consequences. Adjusted R^2 find out amount of deviance about the mean which is pronounced through model.

Validation of experiments

It is clear from confirmation experiment that optimum projected value of SR (5.7181 µm) is differed from optimum trialed value (5.58 µm) by 2.41 % for cryo-processed tool electrode.

Microstructure analysis

Optical surface profiler analysis

The micro structure of machined surface using optical surface profiler for normal and cryo-processed Cu tool electrode respectively are displayed in Fig. 3 (a) and 3 (b). It is clear from these images that cryo-processed tool electrode have lesser SR (superior surface texture) than normal tool electrode.

Conclusions

The impact of machining factors on SR in EDM of Inconel 718 is deliberated. DOE and regression practices are employed for optimization of SR. Key deductions are as follows:

For cryo-processed tool electrode, factors of 6 mm d_t, 10 A I_p, 40 µs T_{on}, 8 µs T_{off}, 30 RPM N_t and 1.5 mm h have been identified as optimal setting. This setting of input factors will offer least SR. It is revealed that T_{on}, T_{off}, and N_t are utmost influential process factors that affects SR. Based on the result obtained it has been revealed that cryo-processed Cu tool electrode offers better surface quality (least SR) in comparison to normal Cu tool electrode. A linear regression model is developed for SR. This mathematical model has noteworthy impact on SR.

References

1 Holmberg J, Wretland A & Berglund J, Grit blasting for removal of recast layer from edm process on inconel 718 shaft: An evaluation of surface integrity, *J Mater Eng Perform*, **25** (2016) 5540–5550.

2 Khan A A, Royani N N, Hazza M H, Daud M R & Mohiuddin A K M, Improvement of surface quality using

silicon carbide powder added dielectric fluid during EDM, Proc Int Conf Mech Auto Aeros Eng, *Mater Sci Eng*, **184** (2017) 012039.

3 Donga S, Wanga Z, Wanga Y & Liua H, An experimental investigation of enhancement surface quality of micro holes for Be-Cu alloys using micro EDM with multi-diameter electrode and different dielectrics, *Proc CIRP*, **42** (2016) 257–262.

4 Torres A, Luis C J & Puertas I, Analysis of the influence of EDM parameters on surface finish, material removal rate, and electrode wear of an INCONEL 600 alloy, *the Int J Adv Manuf Technol*, **80(1–4)** (2015) 123–140.

5 Pandey A & Singh S, Current research trends in variants of electrical discharge machining: A review, *Int J Eng Sci technol*, **2(6)** (2010) 2172–2191.

6 Yahagi Y, Koyano T, Kunieda M & Yang X, Micro drilling edm with high rotation speed of tool electrode using the electrostatic induction feeding method, *Proc CIRP*, **1** (2012) 162–165.

7 Singh A, Kumar P & Singh I, Process optimization for electro-discharge drilling of metal matrix composites, *Proc Eng*, **64** (2013) 1157–1165.

8 Ay M, Caydas U & Hascalık A, Optimization of micro-EDM drilling of Inconel 718 super alloy, *Int J Adv Manuf Technol*, **6** (2013) 1015–1023.

9 Shivnandan & Gill S S, Machinability evaluation of cryogenically tempered die steel in electric discharge drilling, *Int J Res Eng Technol*, **2(5)** (2013) 866–870.

10 Kapoor J, Singh S & Khamba J S, Effect of cryogenic treated brass wire electrode on material removal rate in wire electrical discharge machining, *Proc Inst Mech Eng C, J Mech Eng Sci*, **226(11)** (2012) 2750–2758.

11 Dhanabalan S, Sivakumar K & Narayanan C S, Analysis of form tolerances in electrical discharge machining process for Inconel 718 and 625, *Mater Manuf Process*, **29(3)** (2014) 253–259.

12 Tang L & Du Y T, Experimental study on green electrical discharge machining in tap water of Ti6Al4V and parameters optimization, *Int J Adv Manuf Technol*, **70(1–4)** (2013) 469–475.

13 Bhatia A, Kumar S & Kumar P, A Study to achieve minimum surface roughness in wire EDM, *Proc Mater Sci*, **5** (2014) 2560–2566.

14 Ahmad S & Lajis M A, An electrical discharge machining (EDM) of inconel 718 using copper tungsten electrode with higher peak current and pulse duration, *Int J Mech Mechatron Eng*, **15(5)** (2015) 39–47.

15 Plaza S, Sanchez J A, Perez E, Gila R, Izquierdo B, Ortegaa N & Pombo I, Experimental study on micro EDM drilling of Ti6Al4V using helical electrode, *Precis Eng*, **38** (2014) 821–827.

16 Kumar J & Ahmad H, Parametric analysis of rotary tool electrical discharge machining of metal matrix composite, *Int J Eng Res Technol*, **3(9)** (2014)1225–1229.

17 Gaur S & Bharti P K, Experimental study with rotating tool electrode of EDM for Ni alloy, *Int J Mod Eng Res*, **5** (2015) 15–22.

18 Dwivedi A P & Choudhury S K, Increasing the performance of EDM process using tool rotation methodology for machining AISI D3 Steel, *Proc CIRP*, **46** (2016) 131–134.

19 Rao S R & Padmanaban G, Application of taguchi methods and ANOVA in optimization of process parameters for metal removal rate in electrochemical machining of Al/5% SiC composites, *Int J Eng Res Appl*, **2(3)** (2012) 192–197.

20 Patel K M, Pandey P M & Rao P V, Understanding the role of weight percentage and size of silicon carbide particulate reinforcement on electro discharge machining of aluminium-based composites, *Mater Manuf Process*, **23** (2008) 665–673.

21 Tanikic D & Marinkovik V, Modelling and optimization of the surface roughness in the dry turning of the cold rolled alloyed steel using regression analysis, *J Braz Soc Mech Sci Eng*, **34(1)** (2012) 41.