Investigation and optimization of inconel-718 during dry EDM

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ABSTRACT

Keywords:
Dry Electrical Discharge Machining (Dry EDM),
Material Removal Rate (MRR),
Surface Roughness (Ra),
Tool Wear Rate (TWR),
Taguchi Method,
Analysis of Variance.

Dry electric discharge machining (EDM) is a new process in which the liquid dielectric is replaced by a gaseous as a medium. The flow of high velocity gas through hollow pipe tool electrode into the gap provides removal of debris and prevents excessive heating of the tool and work piece at the discharge spots. Keeping literature review into consideration and trial experiment in this paper, an attempt has been made by selecting compressed air as a dielectric medium, with Inconel – 718 as a work piece material and copper as a tool electrode. Experiments are performed using Taguchi DoE L_{27} *orthogonal array to observe and analyze the effects of different process parameters to optimize the response variables such as material removal rate (MRR), tool wear rate (TWR) and surface roughness (Ra). In the current work, a unit has been developed to implement dry EDM process on existing oil based EDM machine.*

1. Introduction

Electric discharge machining (EDM) is one of the most popular non-traditional machining processes being used today. This process appears by a perfect reproduction of the shape of the tool on the work piece. It uses thermal energy to generate heat that melts and vaporizes the work piece by ionization within the dielectric medium. The electrical discharges generate impulsive pressure by dielectric explosion to remove the melted material. Thus, the amount of removed material can be effectively controlled to produce complex and precise machine components. Apart from its advantages, environmental issues are associated with the process have been a major drawback of EDM [1]. Hydrocarbon oil based dielectric fluids provides major sources of pollution in EDM process and other effects. To make this process environment-friendly and effective liquid dielectrics are altered by gases.

Dry EDM is a new EDM technique in which the liquid dielectric is replaced by a gaseous as a dielectric medium. Tubular pipe tool electrodes are used and as the tool advances, high velocity gas is supplied through it into the machining zone. The flow of high velocity gas into the gap provides removal of debris from machining zone and prevents excessive heating of the tool and work piece at the discharge spots. It is an environment–friendly process, and apart from that it provides other advantages such as low tool wear, lower discharge gap, lower residual stresses, smaller white layer and smaller heat affected zone [5]. The process holds the potential to be a viable alternative to conventional liquid dielectric EDM for precision oriented machining applications. This technique provides simplicity in its implementation compared to conventional EDM method.

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2. Literature review

Kunieda and Yoshida [2] attempted dry EDM machining with air as medium. MRR in dry EDM is higher with negative polarity tool electrode as compared one with positive polarity for steel work piece with copper as tool. But above trend gets reversed in the case of EDM in a liquid which gives higher MRR with positive polarity of the tool electrode. They also compared machining characteristics of EDM in air with a negative tool electrode and EDM in oil with a positive tool electrode. They reported less tool wear ratio for negative the polarity of the tool electrode as compared to positive polarity of the tool electrode.

Nimo Singh Khundrakpam et al. [3] described the impact of the various process parameters viz.

Pulse On Time, pulse off Time, discharge current, Gap voltage and tool rotating velocity across near dry-EDM various surface roughness values Ra, Rt, Rsm, Rsk, Rku, etc. It was noted that discharge current was the most significant parameter followed by Pulse On Time. The other parameters of the method were not important. The ideal experimental outcome was discovered very close to the optimally expected consequence, thus validating the entire research.

Macedo et al. [4] made an investigation of the tool wear fundamentals in dry EDM for different electrode polarities. The results suggested that the point-type cathode tool concentrates the current to a hot anode spot, leading to the formation of discharges similar to anode dominated vacuum arcs. Thus, the active anode and passive cathode electrodes are probably the main reasons for relatively large workpiece erosion and very small tool wear. The inverted polarity, applying the tool as anode, provides time dependent erosion of anode and cathode electrodes. It occurs due the plane cathode geometry, which was not able to concentrate the discharge to a limited anode spot. Therefore, anode and cathode were active, leading to the distribution of the discharge energy over both electrodes. It was observed with the smaller workpiece material removal and larger tool electrode wear for point anode tool and plane cathode work piece in dry EDM.

Eckart Uhlmann et al. [6] explained a comparative analysis of dry-EDM with two different gases as dielectric (oxygen and argon) and conventional EDM (deionized water) to manufacture micro holes in Si3N4-TiN ceramic. The results showed that the axis displacement y, voltage u0, and current iL differ for the processes. It was observed that dry-EDM has higher effective pulse frequency fe and shorter relative motions between workpiece and tool electrode than the conventional EDM process.

Shailesh S. Shirguppikar and Uday A. Dabade [7] implemented dry EDM method on existing oil-based EDM machine. They carried out dry EDM experimentation, with hollow copper electrode, shiny mild steel as a workpiece and oxygen as dielectric medium. Design of experiment was carried out by using taguchi technique with current, pulse on time and oxygen gas pressure as process parameters. Statistical analysis results showed that MRR and TWR are considerably influenced by current and POT.

Govindan and Joshi [8] attempted dry EDM machining with slotted electrodes Experimentation was carried out with copper as tool electrode, SS304 as work piece and oxygen as dielectric medium. They performed experimentation with different number of specific dimension slots on electrode and came out with four slots as a optimum number of slots to improve the material removal rate (MMR). They reported highest average material removal rate (MRR) of 1.497 mm^3/min under this study. They reported that use of slotted electrodes improves the debris flushing effectively and improves material removal rate (MRR).

Govindan and Joshi [9] attempted experimentation in dry electrical discharge drilling for material removal characterization. Experimentation was carried out with copper as tool electrode, steel as work piece material and oxygen as a medium. They reported with two phenomenon concerned to tool wear rate (TWR) that is erosion of electrode material and deposition of work piece eroded material on the electrode. They reported with tool wear rate (TWR) was almost close to zero and none of the input parameter influencing tool wear rate (TWR).

Tao et al. [10] investigated the dry and near dry EDM process with two phase gas-liquid mixture as a dielectric medium in near dry EDM. The effect of constant values of gas pressure and tool rpm along with process parameters such as, pulse-duration, pulse interval, discharge current, gap voltage and open circuit voltage was investigated. It was found that for rough machining copper tool and oxygen gas dielectric with a @ high current and low pulse off time were suitable with a high material removal rate (MRR). The highest material removal rates (MMR) of 1.8 mm^3/min have been reported using kerosene-air mixture used as dielectric.

The literature review above indicates that most of the researchers have investigated influence of a limited number of process parameters on the performance measures of dry EDM process. Also the influence of machining parameters on Inconel-718 has not been fully explored using dry EDM machining with copper as electrode. As Inconel-718 (nickel-based super alloy) is a high strength temperature resistant (HSTR) material which is extensively used in aerospace applications, such as gas turbine, rocket motors, and spacecraft as well as in nuclear reactors, pumps and tooling. The analysis of effect of different machining parameters on Inconel-718 is thus very essential. Hence in this paper attempts are made to see

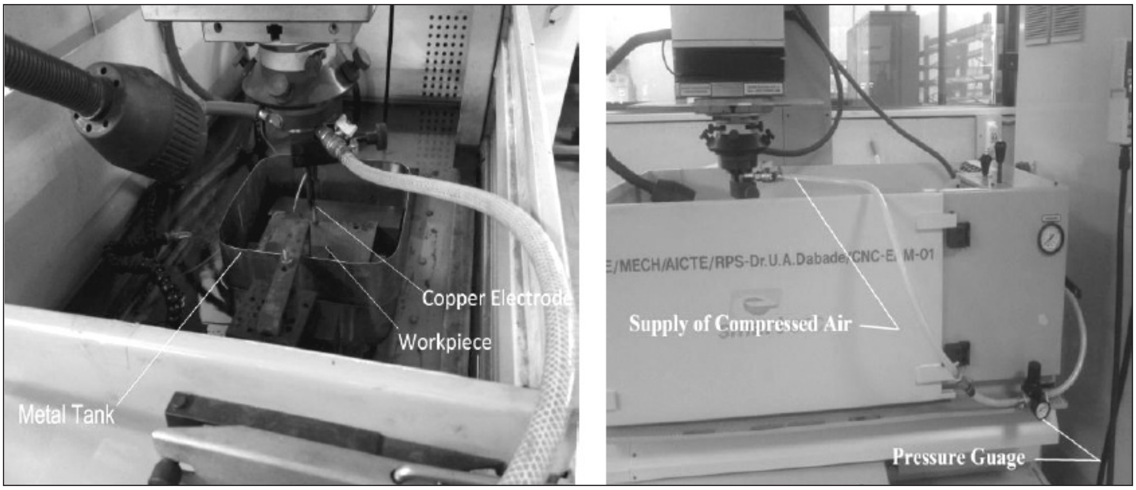

Fig.1. Experimental set-up.

Table 1
Experiment details.

SR. NO.	Experiment Details	Element
1	Machine	CNC EDM machine -S50 model of Electronica Machine Tools Ltd
2	Work piece Material	Inconel 718 as a work piece material (166 x 160 x 3 mm)
3	Tool Material	Copper hollow electrode as a tool material (Outer diameter = 7.5 mm, Inner diameter = 4.5 mm)
4	Dielectric Medium	Compressed air

Table 2
Process parameters and their levels.

SR. NO.	Parameters	Level 1	Level 2	Level 3
1	Gas Pressure, GP (Bar)	1	2	3
2	Current (I) Amp	13	16	19
3	Pulse on Time (POT) µs	100	150	200
4	Gap Voltage (V)	40	50	60

Table 3
L_{27} Orthogonal array with experimental parameters.

Exp. No.	Gas Pressure (Bar)	Current (I) Amp	Pulse on Time (POT) µs	Gap Voltage (V)
1	1	13	100	40
2	1	13	150	50
3	1	13	200	60
4	1	16	100	50
5	1	16	150	60
6	1	16	200	40
7	1	19	100	60
8	1	19	150	40
9	1	19	200	50
10	2	13	100	40
11	2	13	150	50
12	2	13	200	60
13	2	16	100	50
14	2	16	150	60
15	2	16	200	40
16	2	19	100	60
17	2	19	150	40
18	2	19	200	50
19	3	13	100	40
20	3	13	150	50
21	3	13	200	60
22	3	16	100	50
23	3	16	150	60
24	3	16	200	40
25	3	19	100	60
26	3	19	150	40
27	3	19	200	50

the effect of various process parameters on Inconel-718 with dry EDM process.

3. Experimental Setup and Procedure

As per Taguchi methodology, the characteristic such as material removal rate (MRR) is considered as the-larger-the-better type problem and smaller value indicates, such as tool wear rate (TWR), surface roughness Ra(µm) are considered as smaller the better type problem for better machining performance [11].

As it is dry EDM machining the new dry EDM machining attachment is developed on the existing CNC EDM machine (S-50 model) with following experimental details in table no 1.

Table 2 shows different process parameters and their levels used in experiments and table 3 shows L_{27} orthogonal array with experimental process parameters. Figure 1 shows the dry EDM machining setup on existing machine.

3.1. Response Variables

The response variable evaluation under these experiments is performed as below.

Table 4
Response variables measurement.

SR. NO	Response Variable	Formula	Elements
1	Material removal rate (MRR) is calculated in mm^3/min	$$MRR = \frac{\frac{\Pi}{3} * h * (R^2 + r^2 + R * r)}{t}$$	Where, R= EDMed hole radius at top side, r= EDMed hole radius at bottom side, h= Work piece thickness in mm and t = Machining time in minutes
2	The tool wear rate (TWR) was measured using the weight difference before and after machining by using equation in mm^3/min	$$TWR = \frac{1000 * (Wb - Wa)}{Density * Machining\ Time}$$	Where Wb=Weight before machining and Wa= Weight after machining
3	Surface roughness (Ra)	Average arithmetic surface roughness (Ra) was measured by using Mitutoyo surface tester in µm	

4. Results, Analysis and Discussion

In this attempt, twenty seven experiments based on Taguchi (L_{27}) experimental design methodology were conducted and results obtained for all the experimental runs were statistically analyzed using analysis of variance (ANOVA) and the effects of the selected variable were evaluated as shown in table 4 for material removal rate (MRR), tool wear rate (TWR) and surface roughness Ra (µm).

In order to investigate the effect of machining parameters, statistical analysis using analysis of variance (ANOVA) has been performed. The ANOVA results (refer table 5) show that the gas pressure (GP), discharge current and pulse on time (POT) found to be significant factors at 95% confidence level that influences the MRR. ANOVA shows that discharge Gas pressure (GP) is the most significant factor affecting on MRR. The main effect plot indicates that the MRR increases with increasing gas pressure (GP) from 1 bar to 2 bar. As the air pressure increases it removes the debris particle attached to the electrode and improves the flushing efficiency. As the pressure changes from 2 bar to 3 bar there is slight reduction in MRR because the particles get attached to tool face. Discharge current (I) is the second significant factor affecting on MRR. The main effect plot indicates that the MRR increases with all levels of current. It is found that by increasing current the pulse energy increases and it transfers greater amount of thermal energy to the machining zone and erodes maximum amount of material. Pulse on time (POT) is the third significant factor affecting on MRR. As the POT increases deeper discharge craters are formed and more material is

Table 5
F and P values of ANOVA for response variables.

Source	DF	MRR (mm^3/min)		TWR (mm^3/min)		Ra (µm)	
		F	P	F	P	F	P
GP	2	67.33	0.000	0.77	0.477	0.53	0.600
Current-I	2	10.23	0.001	5.97	0.010	0.54	0.592
POT	2	4.16	0.033	1.07	0.365	3.75	0.044
Voltage-(V)	2	0.09	0.913	2.90	0.081	0.02	0.976
Error	18						
Total	26						
		R-Sq=90.09% R-Sq(adj)= 85.68%		R-Sq=84.53% R-Sq(adj)= 79.04%		R-Sq=81.95 % R-Sq(adj) =76.04 %	

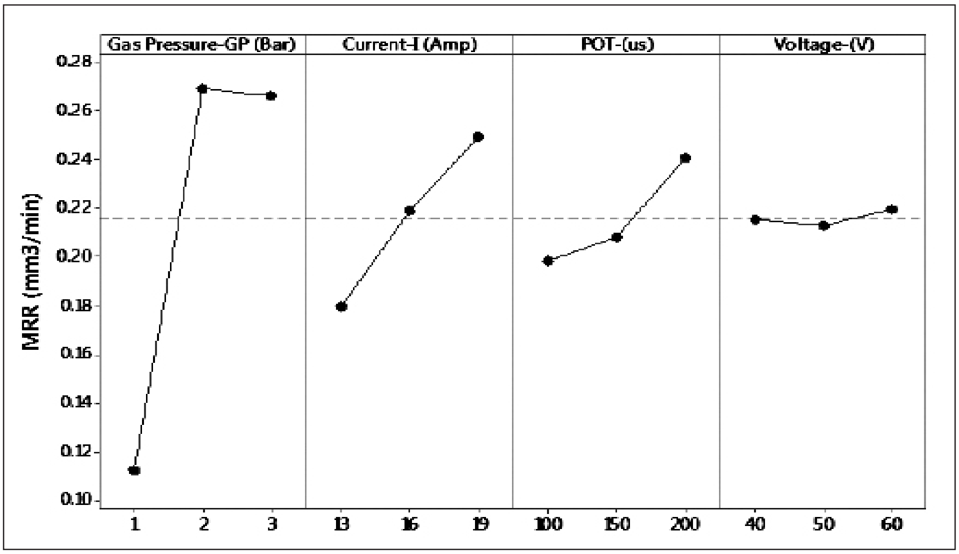

Fig. 2. Main effects plot of MRR.

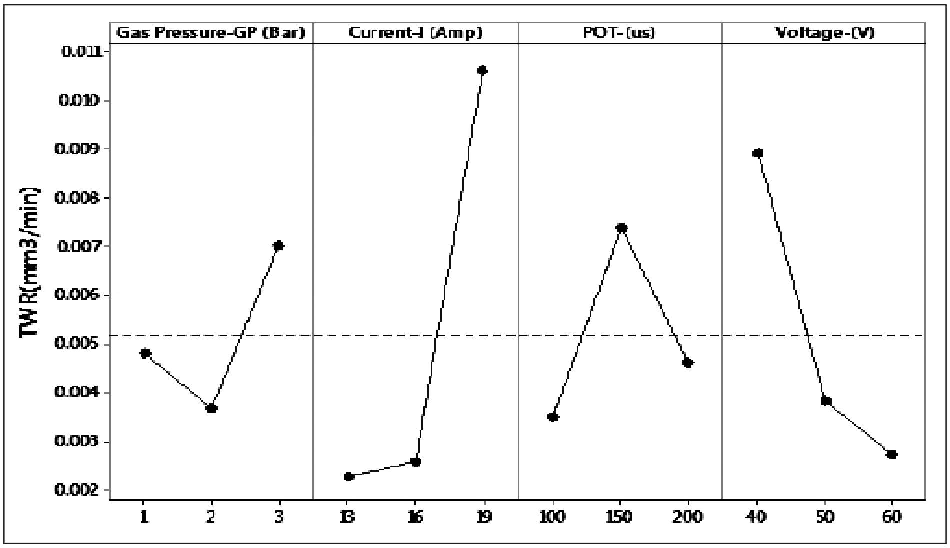

Fig. 3. Main effects plot of TWR.

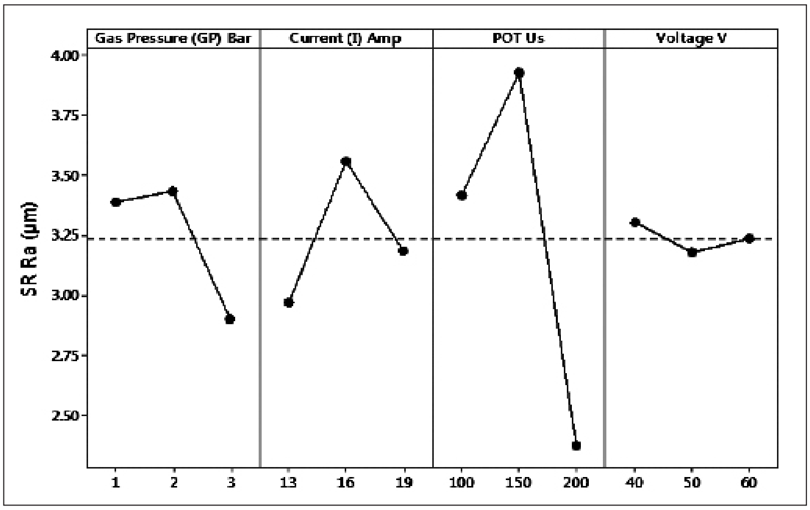

Fig. 4. Main effects plot of Ra (µm).

eroded from the surface because discharge energy is directly proportional to the POT.

The ANOVA results for tool wear rate (TWR) (refer table 5) show that the, discharge current found to be significant factors at 95% confidence level and gap voltage found to be significant at 90% confidence level. (ANOVA) shows that discharge current (I) is the most significant factor affecting on TWR. The main effect plot indicates that the TWR increases with all levels of current. It is found that by increasing current the pulse energy increases and it transfers greater amount of thermal energy to the machining zone and also to the tool surface and provides maximum wear to the tool material. The gap voltage (V) is the significant factor affecting on TWR at 90 % confidence level. It is observed that increase in gap voltage reduces the TWR. As the gap voltage increases the discharge energy also increases, but for dry edm E=V/d relation satisfies the condition. Discharge occurs when the gap voltage increases and the gap distance d increases because of which it reduces the spark energy on work piece surface and also on tool hence provides lower tool wear.

The ANOVA results for surface roughness Ra (µm) (refer table 5) show that the pulse on time (POT) found to be significant factors at 95% confidence level that influences the Ra. As the POT increases deeper discharge craters are formed and more material is eroded from the surface which increases the values of Ra. As the Ra values are considered to be more sensitive to crater depth compared to crater impression.

Hence, as the POT increases the diameter of crater impression get more affected compared to crater depth so it will not provide direct effect on Ra values.

5. Conclusions

In this work attempt has been made to study the effect of process parameters on the response variables (MRR, TWR, surface roughness) of Inconel 718 during Dry EDM.

- For material removal rate (MRR) the gas pressure (GP), discharge current and pulse on time (POT) found to be significant factors and for this work maximum material removal rate (MRR) reported is 0.371413735 mm^3/min.
- For tool wear rate (TWR) discharge current found to be significant factors at 95% confidence level and gap voltage found to be significant at 90% confidence level and the minimum tool wear rate (TWR) obtained is 0.0001 mm^3/min.
- For surface roughness Ra (µm) pulse on time (POT) found to be significant factors at 95% confidence level that influences the Ra and the minimum surface roughness Ra (µm) obtained is 1.243.

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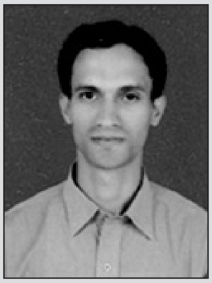
References

1. Leao, Fabio, N; Pashby, Ian R: A review on the use of environmentally friendly dielectric fluids in electrical discharge machining, 'Journal of Materials Processing Technology', 149 (1-3), 2004, 341-346.
2. Kunieda, M and Yoshida, M: Electrical Discharge Machining in Gas Tokyo University of Agriculture and Technology, Department of Mechanical Systems Engineering Tokyo Japan', 1996.
3. Khundrakpam, Nimo Singh; Brar, Gurinder Singh; Deepak, Dharmpal: Grey-Taguchi Optimization of Near Dry EDM Process Parameters on the Surface Roughness, 'ICMPC 2017', vol. 5, no. 2, 2018, 4445-4451.
4. Macedoa F T B; Wiessner, M; Hollenstein, C; Kuster, F; Wegener, K: Investigation of the Fundamentals of Tool Electrode Wear in Dry EDM, '7th CIRP Conference on High Performance Cutting (HPC VII)', vol. 46, 2016, 55-58.
5. Saha, S K & Choudry, S K: Multi–objective optimization of the dry electric discharge machining process, hal-00396875, version 1- 4, 2009.
6. Uhlmann, Eckart; Schimmelpfennig, Tassilo-Maria; Perfilov, Ivan; Streckenbach, Jan; Schweitzer, Luiz: Comparative Analysis of Dry-EDM and Conventional EDM for the Manufacturing of Micro holes in Si3N4-TiN, '18th CIRP Conference on Electro Physical and Chemical Machining (ISEM XVIII)', vol. 42, 2016, 173-178.
7. Shirguppikar, Shailesh S; Dabade, Uday A: Experimental Investigation of Dry Electric Discharge Machining (Dry EDM) Process on Bright Mild Steel, 'IMME17', vol. 5, 2018, 7595-7603.
8. Govindan, P and Joshi, S: Investigations into performance of dry EDM using slotted electrodes, 'International Journal of Precision Engineering and Manufacturing', vol. 12, no. 6, 2011, 957-963.
9. Govindan, P and Joshi, S: Experimental characterization of material removal in dry electrical discharge drilling, 'International Journal of Machine Tools & Manufacture', vol. 50, no. 5, 2010, 431–443.
10. Tao, J; Shih, AJ; and Ni, Jun: Experimental Study of the Dry and Near-Dry Electrical Discharge Milling Processes, 'Journal of Manufacturing Science and Engineering', vol. 130, 2008, DOI:10.1115/1.2784276.
11. Phadke M S : Quality engineering using robust design, Prentice Hall, Eaglewood Cliffs, 1989 ◘



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