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Optimising Parameters for Dry EDM Machining of Inconel 800 Through OFAT Approach

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ABSTRACT

The paper presents an experimental investigation and optimisation of process parameters while performing dry edm of inconel 800, superalloy. The process parameters viz, discharge current, gap voltage, pulse on-time, pulse off-time, tool rotation, air flow rate are selected as the initial investigations, and their levels are chosen to finalize the optimized parameters and levels for main experimentation. Inconel 800 a supernally is work material in this study. Five levels of each parameter are selected for trials. The impact of parameters against the responses viz, material removal rate, tool wear rate surface roughness are recorded for all five levels settings. The results so obtained are plotted for each parameter, it was found that the discharge current at parametric settings of 8 A, 12 A, 16 A, gap voltage at parametric settings of 40 V, 50 V, 55 V, pulse on-time at parametric settings of 60 µs, 90 µs, 120 µs, pulse off-time at parametric settings of 30 µs, 60 µs, 90 µs, tool rotation at parametric settings of 120 N, 160 N, 240 N and air flow rate at parametric settings of 15 l/min, 20 l/min, 25 l/min gives better results in improving the responses. Scanning electron microscopy was also performed to investigate the effects of parameters on the machined surface of inconel 800. A better surface with minimum cracks wasproduced as compared to conventional edm at the same parametric settings.

Keywords: Dry EDM; Material removal rate; Tool wear rate; Surface soughness, SEM

1. INTRODUCTION

The machining of hard-to-cut material is a challenge in processing intricate and complex geometries in most of the modern manufacturing industries like aerospace, heat exchanger units etc. With the growing demand of material-specific parts with irregular shapes (turbine blades) it is challenging to machine such shapes with superalloys by conventional methods[1]. Electric Discharge Machining is a non-conventional process based on the principle of melting and vaporizing of material can produce complicated shapes with greater accuracy.

Dry EDM is a machining process in which the liquid dielectric used in conventional EDM is replaced with compressed air. In the present study, the cavities are produced on the surface of Inconel 800, a nickel-based superalloy. 30 cavities of 0.6 mm depth are machined with Dry EDM. Although conventional EDM is efficient in producing similar cavities, the dielectric fluid can impact the environment by producing a better surface finish when compared with conventional EDM. Dry EDM can also produce better surface finish no hydrocarbon waste, and hydrogen fumes because of dielectric ionization with no toxic fumes and less workshop space utilisation[2]. Researchers optimised the process parameters of conventional EDM using the OFAT (one factorat a time) approach in which the variables are screened and their levels are finalised[3].

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2. EXPERIMENTATION

2.1 Work Material

Inconel 800, a superalloy is chosen as a workpiece material for the current study as it has a wide range of applications in aeronautical, heat exchangers, oil gas, and cryogenics industries. This material retains its superior mechanical properties at high temperatures and hence can be used in high heat interaction areas. The Nickel-based superalloys have excellent fatigue resistance and creep performance at high temperatures on the other hand these alloys have low thermal conductivity, and excessive heat generation between the workpiece and tool interface resulting in work hardening and poor machinability when machined using conventional methodsand excessive tool wear results in the high tooling cost and low precision[4].

Table 1. Chemical composition of Inconel 800 (After web, Specialmetals.com)

Element	C	Mn	S	Cr	Ni	Al	Ti	Fe
%	.056	.62	.008	19.86	32.68	0.4	0.38	46

2.2 Tool Electrode Material

In the present study, a copper hollow tubular electrode is selected as tool material. A tubular electrode of cylindrical internal shape is selected so that an accurate circularity of cavity is obtained while performing EDM with electrode rotation. In the fabricated setup the High-velocity air passes between the tool and workpiece gap using tubular electrode. The attachment will also experience rotational motion as air passes past it. In this instance, gas is a significant dielectric medium during the machining process. When the gas is allowed to flow continuously through the tubular tool, the air pushes the debris particles out of the gap. The process is more stable and there is less arcing between the electrodes when the tool rotates.From the literature, it is found that copper has a minimum wear ratio as compared with other tool electrode materials[5].The central holes uniformly distributed will be drilled into solid copper electrodes. Air will be supplied through the tool electrode at different pressures and flow rate.

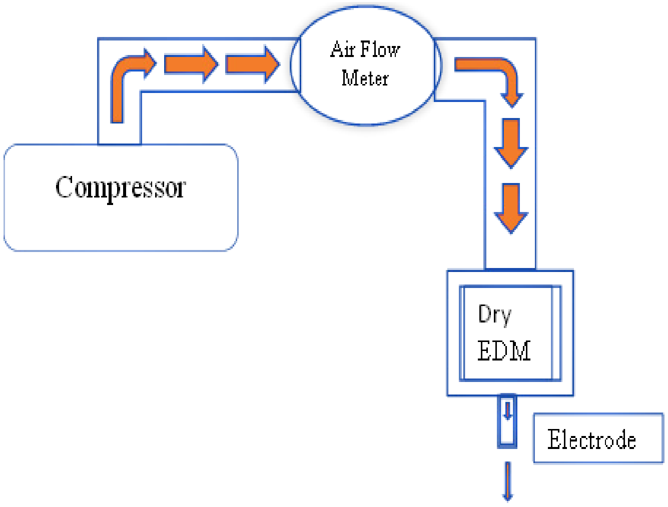


Figure 1. Schematic of air flow pattern.

A tube transfers this compressed air from the support cylinder channel into the shaft bore through the seal. The tube electrode will be mounted at the shaft end receiving this high-pressure gas. All the assembly are made in the workshop are the attachment is tested before the conduct of pilot experiment and also main experimentation.

An Oscarmax S 430 (EDM, Korean model, make S 430, Fuzzy controller) is utilized to conduct experiments in this study, which has motion capabilities along the X, Y, and Z axes with a resolution of one micron. The attachment is installed in the head of EDM as shown in schematic diagrams in Fig. 1. The air is supplied into the attachment through a compressor of 50 liters capacity. The air flow rate is measured by a rotameter of max capacity of 25 l/min. A Tool rotator is provided with the help of VFD (Variable Frequency Drive) motor shown in Fig 2. The reason for providing rotation and selecting a cylindrical hollow electrode is well explained in section 2.2.

2.3 OFAT-Based Pilot Experiment

To check the feasibility of attachment fabrication a pilotrun was conducted on an existing EDM machine (OscarmaxS 430) series and was finalised for conducting experiments.Again, trial runs are performed to finalise the feasible ranges and limits of process parameters for analysing various responses. Since not much work has been reported on Dry EDM in the recent past hence it is important to first study the effect of parameters on response.

An OFAT (One Factor At a Time) is designed to study each input variable on the machining of the workpiece, the minimum and maximum ranges are finalised for input variables viz, Current, Pulse ontime, Pulse Off Time, Gap Voltage, Rotation of tool electrode and Air flow rate.

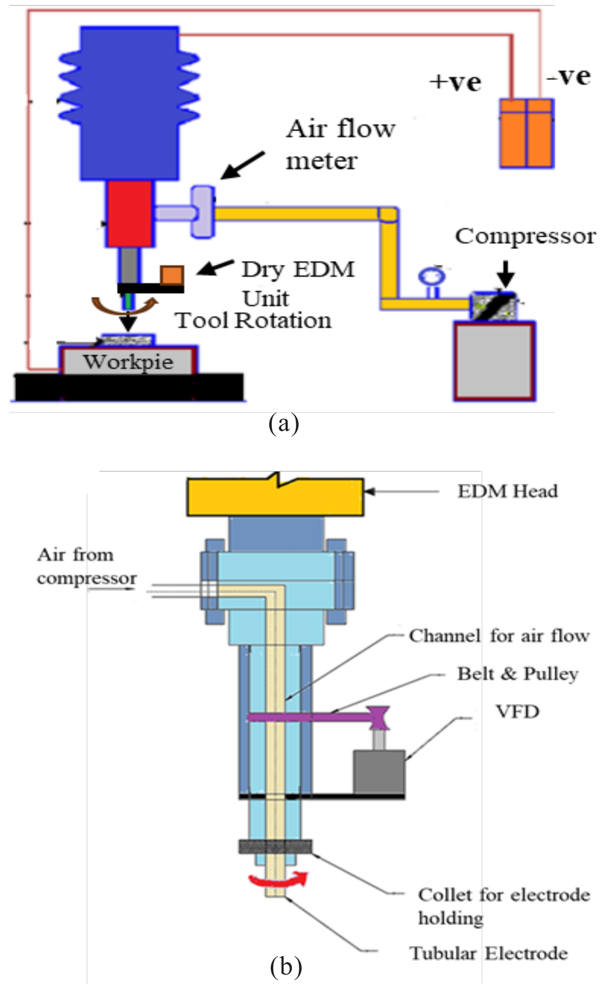
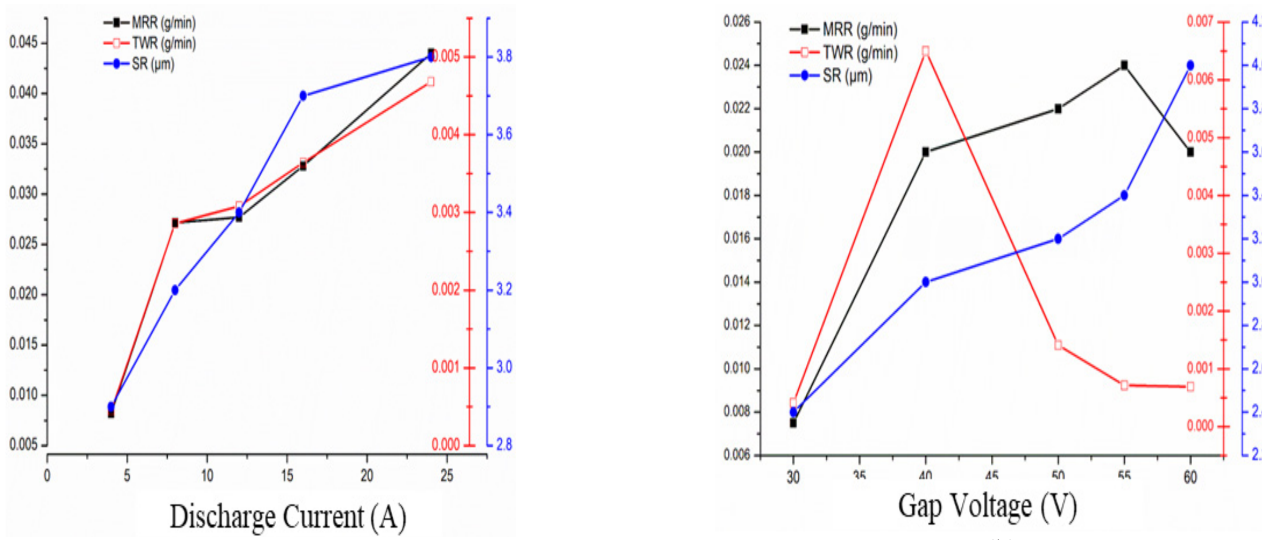


Figure 2. Schematic of dry EDM set up (a) setup with attachment, and (b) line diagram of attachment.

OFAT is used to select the potential parameters for final experiments, in this technique effect of each variable is studied while keeping other parameters constant, in this way a significant screening of the variable is performed. In Dry EDM of Inconel 800 due to the new field of research potential parameters for machining are not well known, so an OFAT is performed to select potential parameters. The parameter for OFAT in the present work is, current (A), T_{ON}(µs), T_{OFF}(µs), Gap Voltage (V), Tool Rotation (N) of the tubular electrode, and airflow rate (AFR). Two electrodes of the same outer (8mm) diameter and different inner diameters 2mm & 3mm) are used, and the experiments are performed for each electrode. After conducting OFAT parameters and their levels are finalized.

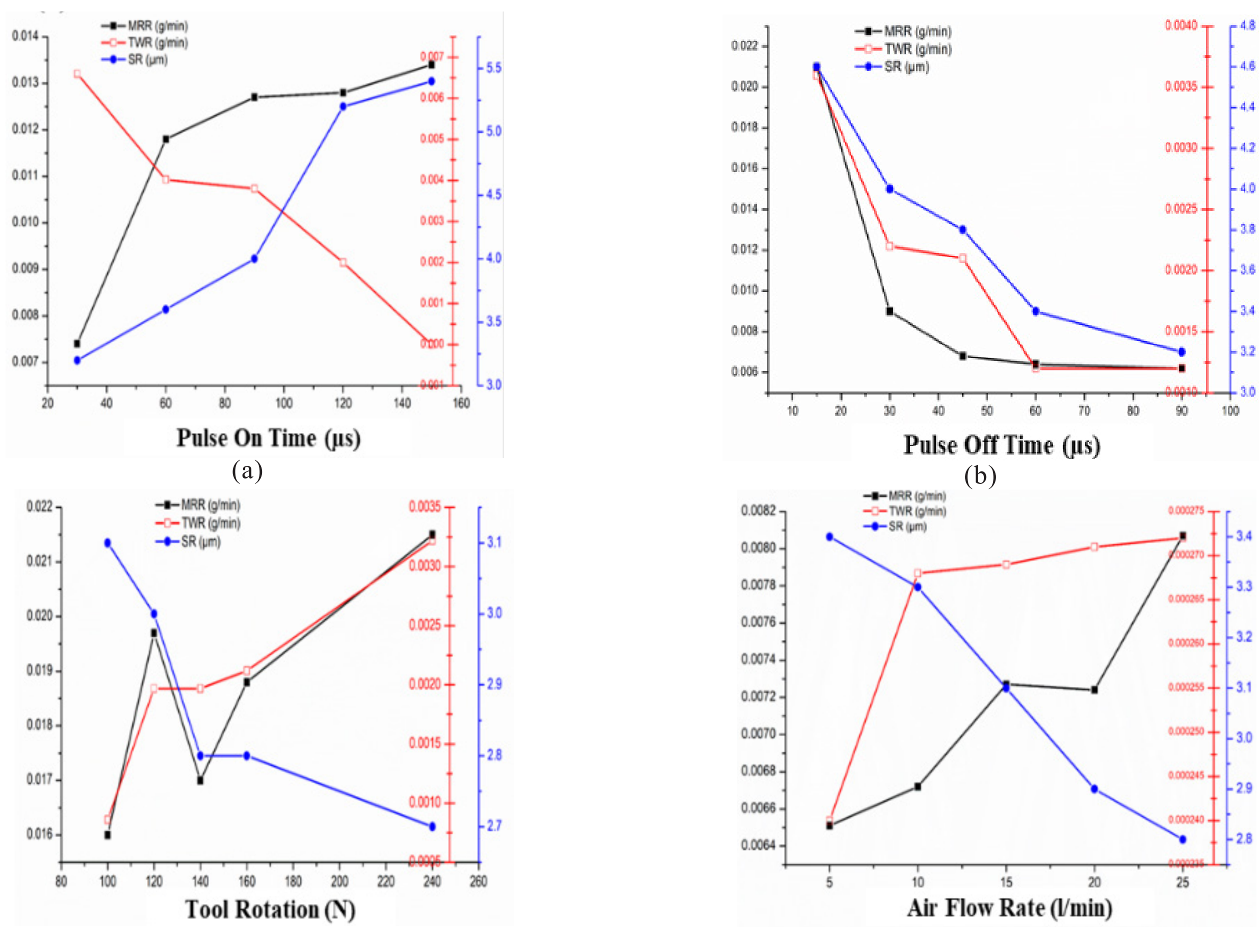
2.4 Experimental Results and Graphs of the Pilot Experiment for Dry EDM

The results of the influence of individual parameters on the response variable are plotted in the graph. At 4 A the value of surface roughness is 3.0 µm and tool wear rate is 0.00021 g/min which is very low and favorable but at the same time, the value of material removal rate is very low 0.008 g/min hence 8 A,12 A,16 A discharge current values was finalised. A similar



(a) (b)

Figure 3. Graph between (a) discharge current and responses, and (b) gap voltage and responses.



(a) (b) (c) (d)

Figure 4. Graph between (a) pulse on time and responses, (b) pulse off time and responses, (c) tool rotation and responses, and (d) Air flow rate and responses.

trend was also noticed by reserchers[6-7]. Figure 3 shows the results of OFAT for Discharge Current and Gap Voltage.

From Fig. 3 it can be observed that at 55 V, and 60 V, very low values of surface roughness are recorded and on the other side at 30V the value of MRR is low due to poor flushing of debris[8]. Hence 40 V, 50 V, and 55 V values are finalised for Gap Voltage.

At 30 μs very low MRR is recorded whereas at 150 μs the value of MRR and TWR is high but the value of surface roughness is alsovery high (4.8 μm)[9]. Hence 60 μs, 90 μs, 120 μs are finalised.

At 15 μs, 30 μs very high value of SR is obtained (4.6 μm) and the TWR is also high[9]. As shown in Fig. 4(b). Hence 30 μs, 45 μs, and 60 μs pulse off time is finalised.

At 100 N and 120 N, the value of SR is high as the debris is not properly flushed out[11]. The graph between tool rotation and responses are shown in Fig. 4(c). Hence higher values of RPM are preferred. 140N, 160N, and 240N RPM values are finalised.

In Dry EDM at 5 l/min and 10 l/min the debris is not properly flushed out as the flow rate is low, the spark is also discontinuous at this flow rate. Hence higher values of AFR (15 l/min, 20 l/min, 25 l/min) are selected for study. Shown in Fig. 4(d).

3. PLANNING AND DESIGNING OF MAIN EXPERIMENTS FINALIZED AFTER OFAT BASED PILOT EXPERIMENTS

The fundamental principle underlying Design of Experiment (DoE) involves the deliberate manipulation of input variables (factors) to observe their effects on output response, aiming to optimize processes. For this study, one noise factor involving Electrode inner diameter (with two levels) and five process parameters namely, discharge current, gap voltage, pulse on time, pulse off time, and tool rotation have been chosen for air flow rate (l/min) is chosen for Dry EDM. The specific levels of these process parameters were determined after conducting pilot experiments. The L18 mixed orthogonal array is selected for the design of the experiment, A mixed orthogonal array is a design matrix that combines two or more types of factors within a single experimental setup. These arrays are constructed based on the principles of orthogonal arrays, which enable efficient experimentation by systematically varying factors while minimising the number of runs required for experimentation. A 12 degree of freedom or more than 12 degrees of freedom system is efficient for experimenting according to Taguchi's Philosophy[10], here in L18, 18 degrees of freedom is present hence it is a good experimental design for conducting experiments.

4. SURFACE MORPHOLOGY ANALYSIS OF DRY EDMED INCONEL 800

The SEM (Scanning Electron Microscopy) and EDS (Energy Dispersive X-Ray Spectroscopy) analysis (conducted at IIT Kanpur) revealed the elemental composition of the machined surface, shown in Fig. 5. Various experiments based on OFAT is performed using Dry EDM processes, employing a cylindrical copper rod as the tool electrode. A total of 30 experiments of each were carried out.

Iron (Fe), nickel (Ni), chromium (Cr), and carbon (C) constitute the primary elements detected on the machined surface.The rise in carbon content seen in Dry EDM process is due to the diffusion of carbon atoms[7]. High-value processing parameters generate increased energy, subsequently raising temperatures that facilitate the generation of carbonaceous atoms. There was an observed upward trend in oxygen in Dry EDM, the oxygen migration onto the machined surface can be observed. Copper migration from the tool electrode into the machined surface was noted in Dry EDM processes.

The migration of copper slightly increased with higher discharge current and pulse on time. Additionally, higher oxygen content was detected on the surface machined using the Dry EDM process. This observation aligns with the use of compressed air (mixture of gases) as the dielectric medium, resulting in a greater presence of oxygen in the surface produced via the Dry EDM process.

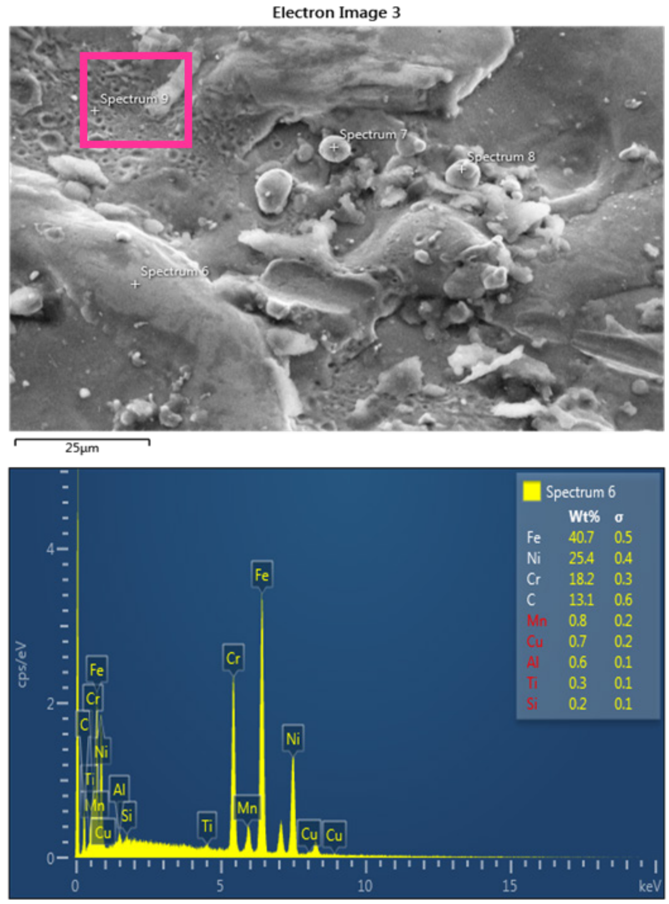


Figure 6. SEM and EDS image of dry EDMed surface of Inconel 800.

5. CONCLUSIONS

The experiments were conducted on Inconel 800 using Dry EDM process. A 0.6mm cavities are produced with tool rotation and compressed air is used as dielectric. During the investigations following conclusions are drawn.

- The material removal rate increases as the value of discharge current increases as the discharge energy increases with the increase in discharge current. A rising trend in Tool Wear Rate is also observed. Surface roughness also increases asdeeper craters are produced with increased current. The optimum values are selected for conducting main experiments. Hence OFAT is useful in scrutinizing the variable when process is quite new. 8A, 12A, 16A (three levels) Discharge Current values are selected
- With increase in gap voltage material removal rate increases as the more energy is supplied between the gap, but as it increases beyond 55 V the MRR decreases because of poor flushing between the gap as the distance between workpiece and tool increases the pressure of compressed air decreases[11]. As far as surface roughness concern the roughness value is quite low between 40 V to 55 V. Hence 40 V, 50 V, 55 V are selected for main experiments

- As pulse on time increases the sparking time increases leading to higher amount of energy concentration for longer time, resulting in more melting and vaporisation at workpiece and electrode[12]. Hence MRR increases with increase in pulse on time and decreases with increase in pulse off time as there is no spark during this period. Surface roughness also increase as the pulse on time increases[13]. Hence 60 µs, 90µs, 120 µs is best setting for pulse on time. 30 µs, 45 µs, 60 µs is best setting for Pulse Off Time
- When tool rotation increases the peripheral velocity also increases hence the flushing efficiency is also increases therefore at higher RPM much better surface finish can be obtained[14]. In case of Air flow rate more air will lead to better ionization phenomenon as the flow rate of air increases more oxygen will be available for ionization which will results in more material removal. Also when the flow rate increases the debris are flushed out efficiently[15].

The study aims to improve the machining of Inconel 800 using Dry EDM, with a focus on surface integrity and quality. This can also be tested by different dielectric gases, adjusting machining conditions, exploring hybrid machining technologies.

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CONTRIBUTORS

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In the present study he has conducted experiments, prepared corresponding set up, and analysed the results.

Dr Shankar Singh is a Professor of the Mechanical Engineering Department at Sant Longowal Institute of Engineering & Technology. He obtained his PhD from Delhi. His areas of interest are unconventional machining, material processing and material characterisation.
In the present study he has carefully edited the paper and included relevant references for its proper validation.