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Effects of Die-Sinking Electro-Discharge Machining Parameters on Surface Roughness in Inconel 825 Alloy

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Abstract

Objective: The objective of this paper is to find the optimal machining parameters of Die-Sinking Electro-Discharge Machining on Inconel 825 alloy with nickel coated copper electrode for improving the process response. **Methods:** The effects of different parameters were studied on the machining responses. The machining parameters considered for this work were applied current, pulse on time and pulse off time and their effect on surface roughness response was studied. **Findings:** Taguchi optimization technique was employed to find the effect of machining parameters on Electro-Discharge Machining process responses. Besides, analysis of variance statistical method has been employed to predict the importance of individual machining parameters in the responses. The result of this research reveals that the proper selection of the input variables plays an important role in die-sinking EDM process. **Applications:** Ni base alloys are widely used in aviation, ship building and defense industries because of their better properties such as good impact strength, high ultimate tensile strength, high yield strength, high resistance to corrosion, retaining the strength even at high temperatures and fatigue resistance.

Keywords: Analysis of Variance, Die-Sinking EDM, Surface Roughness, Taguchi

1. Introduction

Die-Sinking Electro-Discharge Machining (DS-EDM) is a standard and flourished non-traditional machining process which is employed to machine conductive but hard to cut materials and also to machine insulating materials with good surface finish. DS-EDM is recognized as a widely accepted machining process in industries like aerospace, aviation, defense, ship building etc. for machining tough materials such as maraging steels, difficult to cut modern composite materials, Ni alloys, Ti alloys and even highly brittle ceramic materials[1]. DS-EDM is a complex technique consists of several synthesizing process parameters and any slight variation in the variables can affect the output such as Material Removal Rate (MRR), Tool Wear Rate (TWR) and surface roughness (R_a) etc. The efficient strategy is to be developed for determining the optimal cutting parameters in DS-EDM for obtaining the good surface finish in Inconel alloy. In[2] have suggested Taguchi technique with fuzzy logics for optimizing the responses like MRR and TWR by altering process parameters in Electro-Discharge Machining (EDM). In[3] have achieved the optimal surface roughness (R_a) using regression analysis by varying the process parameters in EDM for $BaTiO_3$ and have also validated the results using Genetic Algorithm (GA). In[4] have carried out an investigation on EDM. They have varied the variables like current density, duty cycle and pulse on time and have obtained the optimal responses like MRR, Electrode Wear Rate (EWR) and R_a and have mentioned that when pulse on time (T_{on}) increases, R_a also increases and EWR increases when Duty Cycle (DC) is increases slightly. In[5] have determined the MRR

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and EWR in Silicon Carbide (SiC) by varying the EDM parameters such as intensity of current, DC, T_{on}, flushing pressure and open circuit voltage. They have found that the MRR increases when the current intensity and open circuit voltage is kept at maximum and the flushing pressure of the electrolyte should be kept at minimum, to reduce the TWR. In[6] have carried out a research on the effect of EDM machining variables in AISI 1040 carbon steel and the cylindrical copper have been selected as an electrode. They have found that TWR and MRR increase, when pulse duration increases. In[7] carried out the research work for determining the effect of EDM variables in R_a. They have reported that the R_a increases when the discharge duration in EDM increases as this happens because of the expansion of the discharge channel as more energy is released at this juncture. In[8] have made a research on EDM process in EN31 tool steel by altering the electrodes used such as cylindrical copper and brass. They have also varied the process variables like intensity of current, T_{on} and pulse off time (T_{off}) and they have reported that high current gives high MRR with copper electrode and brass electrode gives better surface finish with moderate MRR. In[9] have investigated the effects of electrodes (tools) such as tungsten (W), silver tungsten (AgW) and copper tungsten (CuW) on the tungsten carbide (WC) material, in EDM process and have analyzed the different performance responses such as MRR, TWR and R_a. They have concluded that CuW electrode helps in attaining better MRR, while AgW electrode achieves good surface finish and tungsten tool produces lowest TWR while compared with other tool electrodes. In[10] have studied the process with multi-objective optimization technique in AISI D2 die steel. They have altered the variables like current, Ton, Toff and constant gap voltage on the responses such as EWR, MRR and Ra and have concluded that MRR will be maximum at highest current and EWR will be minimum while increasing T_{on} and T_{off} and R_a will be minimum, while keeping the current at lowest levels. In[11] have studied the Powder Mixed EDM (PMEDM) by optimizing the input parameters like T_{on}, current and T_{off} on MRR and TWR by employing Taguchi techniques and have revealed that the current contributes more for MRR as well as TWR, whereas T_{on} and T_{off} has the least significant on the responses. In[12] have utilized Taguchi technique to optimize the parameters such as servo voltage, pulse duration and peak current on the output like R_a by employing copper tungsten electrode in high carbon high chromium die steel and have reported that the current affects the response, significantly. In[13] have studied by varying several EDM parameters in EN24 tool steel and have utilized Taguchi techniques to optimize the output such as TWR and MRR and have concluded that when the values of the parameter increases, MRR increases, thereby TWR decreases and have also provided the effect of individual parameters on output. From the literature study, it has been observed that many experiments and researches were carried out using steels but hardly ceramic and Nickel (Ni) base alloys were employed on determining the performance responses in EDM. As the materials manufactured from Ni base alloys are broadly used in aerospace, aviation, ship building and defense industries because of their good mechanical properties such as good impact strength, high yield strength, high resistance to corrosion, retaining the strength even at high temperatures and fatigue resistance. But, because of the poor thermal conductivity, they become highly tough to machine by employing the traditional processes. Therefore, this study is based on optimizing the machining variables (applied current, T_{on} and T_{off}) for obtaining minimum R_a on Inconel 825 in DS-EDM.

2. Objective

- To obtain the best performance characteristics, (i.e.) to lessen the surface roughness (R_a) in Inconel 825 alloy;
- To examine the significance of variables like applied current, T_{on} and T_{off} in Inconel 825 alloy.

3. Operational Details

3.1 Experimental setup

The trials were handled on V5030 GRACE EDM machine. The machine consists of servo feed mechanism for controlling the movement of the electrodes, dielectric circulation system for circulating the electrolyte used in this process, which can also be used for the lubrication purpose and the control panel for governing the variables. The work has been done with single polarity. The feed rate has been kept constant.

3.2 Selection of Work Piece, Tool and an Electrolyte

Inconel 825 alloy has been chosen as the work piece material with 55 mm x 55 mm x 12 mm as its dimensions. The chemical composition of Inconel 825 alloy has been given in Table 1. The mechanical properties like density and hardness are found to be 8150 kg/mm^3 and (135–165)

HRB, respectively. Nickel coated copper electrode has been chosen as the tool. The tool has to be connected with the negative terminal and the work piece material with positive terminals in the machine. Kerosene oil has been chosen as an electrolyte, which acts mainly as lubrication purposes and also to remove the unwanted materials from the machining.

3.3. Selection of Machining Variables and their Levels

In this work, three manageable parameters viz. applied current, T_{on} and T_{off} with four levels each has been selected for machining Inconel 825 alloy and is shown in Table 2.

3.4 Taguchi Technique

Genichi Taguchi proposed an approach to examine how different variables affect the performance output in various processes. The main aim of this method is to produce quality goods thereby incurring less cost to the producers. This method employs an Orthogonal Array (OA) model, which organizes the process variables with their levels in a proper manner in order to obtain the quality outputs. This method possesses different Signal to Noise (S/N) ratio, which includes "Larger the Better (LB), "Nominal the Better (NB)" and "Smaller the Better (SB)"[14]. Usually, MRR should be higher for any given materials, therefore LB should be considered. Accordingly, for R_a and Tool Wear Rate (TWR), SB or NB should be considered, as these responses have to be minimized during machining conditions. In this study, L_{16} has been selected as per the Design of Experiments (DOE) and Smaller the Better (SB) response has been considered, as the intention of this experiment is to lessen the surface roughness. The formula for obtaining the SB S/N ratio has been given below as Equation (1) and the analysis has been done using Minitab 14 software[12].

$$\text{S/N ratio} = -10 \log [\Sigma (X^2/n)] \quad (1)$$

Table 1. Composition of Inconel 825 alloy

Ni	Fe	Cr	Mo	Cu	Ti	C
38–46	22.0	18.5	3.0	2.25	1.0	0.05

Table 2. Parameters with their levels

Coding	Parameters/Levels	I	II	III	IV
A	Current (A)	20	30	40	50
B	Pulse on time (μs)	45	50	55	60
C	Pulse off time (μs)	7	10	13	16

4. Results and Discussions

The trial have been carried out on Inconel 825 alloy based on L_{16} OA in EDM to compute the effect of the most important process variables namely, current (A), pulse on time [T_{on}] (μs) and pulse off time [T_{off}] (μs) on surface roughness (R_a). The experimental output was given in Table 3, with their respective S/N ratio.

4.1 Effect of Input Variables on Surface Roughness in Inconel 825 Alloy

The optimal R_a appears at highest applied current and pulse off time but on lowest pulse off time, as given in Figure 1 and can found at A4–B1–C4 has significant effect

Table 3. Experimental output

Exp No	Input variables			Output	
	Current	T_{on}	T_{off}	R_a	S/N ratio
1	20	45	7	1.25	–1.93820
2	20	50	10	1.28	–2.14420
3	20	55	13	1.35	–2.60668
4	20	60	16	1.38	–2.79758
5	30	45	10	1.12	–0.98436
6	30	50	7	1.15	–1.21396
7	30	55	16	1.26	–2.00741
8	30	60	13	1.28	–2.14420
9	40	45	13	1.05	–0.42379
10	40	50	16	1.09	–0.74853
11	40	55	7	1.14	–1.13810
12	40	60	10	1.18	–1.43764
13	**50**	**45**	**16**	**0.55**	**5.19275**
14	50	50	13	0.75	2.49877
15	50	55	10	0.89	1.01220
16	50	60	7	0.95	0.44553

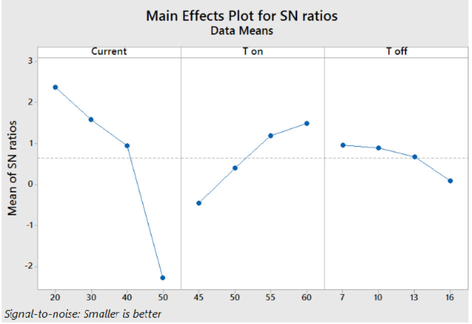

Figure 1. Effect of S/N ratio for R_a.

on the output characteristic. When the current increases, spark occurrence happens at regular intervals and smooth metal removal takes place, thereby good surface finish occurs. When the T_{on} increases, the content of the energy supplied to the work piece will be much higher, so deeper craters will be formed that leads to poor surface finish and also passivation effect increases gradually and this too leads to poor surface finish. Therefore, to prevent this occurrence, pulse off time has to be increased or kept at maximum levels. The response table of S/N ratio for R_a has been given in Table 4. This table proves that the current is an important parameter that affects R_a followed by the T_{on} and T_{off}.

4.2 Analysis of variance (ANOVA)

Analysis of Variance (ANOVA) table is a statistical tool, which is employed to find the reaction of the variables towards the performance output. To obtain the significance and percentage contribution of each variable on R_a, ANOVA table has to be generated and is shown in Table 5. The F-ratio determines the most effective variables as the value of F-ratio should be higher. The percentage contribution factor decides the significant variable, as the variations of these variables for applied current, T_{on} and T_{off} are 82.31%, 13.51%, 0.89%, respectively. The error value 3.29% represents the interaction between the variables. The optimal values of EDM of Inconel 825 alloy for surface roughness (R_a) was found to be 50 A (applied current), 45 (µs) pulse on time and 16 (µs) pulse off time, which is given in Table 6.

Table 4. Response table for S/N ratio of R_a

Levels	Current	T_{on}	T_{off}
1	−2.37166	0.46160	−0.96118
2	−1.58748	−0.40198	−0.88850
3	−0.93701	−1.18500	−0.66897
4	2.28731	−1.48347	−0.09019
(Max – Min)	4.65898	1.94507	0.87099
Rank	1	2	3

Table 5. ANOVA table for R_a

Source	DOF	Sum of Sq	Variance	F–ratio	Percent (%)
Current (A)	3	0.6244	0.2081	49.94	82.31
Pulse on time (µs)	3	0.1025	0.0342	8.22	13.51
Pulse off time (µs)	3	0.0067	0.0022	0.529	0.89
Error	6	0.025	$4.16^{*}10^{-3}$	––	3.29
Total	15	0.7586	––	––	100

Table 6. Optimal values of R_a

Variables			Optimal values
Current (A)	Pulse on time (µs)	Pulse off time (µs)	Surface roughness (µm)
50	45	16	0.55

5. Conclusion

Thus, the present work achieves the impact of different variables namely applied current, pulse on time and pulse off time on surface roughness in EDM of Inconel 825 alloy. It has been determined that current has been the most significant variable that affects the surface roughness profoundly, followed by the pulse on time and the pulse off time. The percentage contribution for these variables current, pulse on time and pulse off time was calculated through ANOVA table and was found to be 82.31%, 13.51%, 0.89%, respectively.

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