ELECTRICAL DISCHARGE MACHINING HOLES ON NICKEL-BASED ALLOYS

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Abstract

Electrical discharge machining is one of the advanced processing technologies widely used to machine micro-hole. However, advances in materials engineering that lead to the production of new nickel-based superalloys require the development of new machining technologies. In addition, new sustainable EDM conditions to achieve the desired geometric quality of manufacturing holes are needed. In this study, a series of experiments of EDM drilling of holes were performed. The influence of capacitor capacity, discharge time, and discharge break time on the geometry accuracy of manufacturing holes was investigated and described.

Keywords: EDM, electrical discharge machining, holes, geometry accuracy

1. INTRODUCTION

Effective manufacturing of long holes in difficult to cut materials is recently a key factor in producing a wide range of advanced components e.g., fuel atomizer, dies or aero-gas turbine engines. Many of these parts require materials with unique properties: high strength-to-weight ratio and corrosion resistance at high temperature and pressure. One of the modern difficult to cut superalloys that are widely used in the aeronautical industry is Inconel 718 [1-3]. Due to its properties, it finds particular applications for turbine blades. In the structure of blade the are many holes that must be effective produce. Currently, sustainable technological methods are sought to make high aspect-ratio holes in superalloys [4-7]. Due to the capabilities of electrical discharge machining which enables the processing of electrical conductive materials regardless of their hardness or chemical composition, much research is focused on manufacturing high aspect-ratio holes in superalloys with EDM. Predicting favorable machining conditions for the required dimensional and shape accuracy of manufacturing holes plays a key role [8-11]. The dimensional and shape accuracy of the holes also depends on the processing parameters: flushing pressure, discharge voltage and current, time discharge and interval [12-14]. Much research was focused on the improving surface roughness of manufacturing holes and MRR [15-16], however a relatively small number of research concerned the analysis of the dimensional and shape accuracy of the holes made. Therefore in this study the main attention was focused on the analysis of the obtained hole diameter and roundness deviation during EDM of Inconel 718. The main goal of this research is a better understanding of the relationship between the influence EDM process parameters: the main attention was focused on the analysis of the obtained hole diameter and roundness deviation.

2. MATERIALS AND METHODS

The present paper was focused on the analyses of the influence of EDM parameters on the geometric quality of manufacturing holes. Experimental studies were conducted on GF Machining Drill 20 machine. The holes were processed with the brass tube electrode - with a diameter of 2 mm. Through the electrode deionized water was delivered to the gap. Experiments were conducted with the following machining conditions: discharge time in the range t_{on} = 10 -90 μs, time interval t_{off} = 10 - 90 μs, and capacitor capacity C = 50 - 100 µF. Discharge voltage and rotation of electrode were constant and they were equal U = 30 V and S =300 rpm, respectively. The study was conducted with the design of experiment BoxBehnken, three-level, and three parameters. The fifteen samples were drilled with different EDM parameters (**Figure 1**).

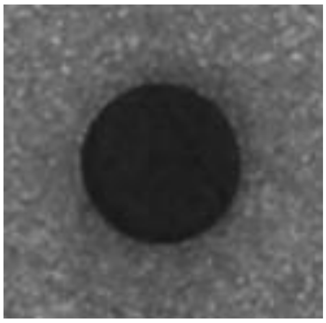


Figure 1 Hole after EDM

The diameter of manufacturing holes and roundness deviation were measured on a Carl Zeiss coordinate measuring machine. A measurement strategy was determined in the Calypso software - the head movement path and the number of points were determined. **Figure 2** shows the scheme of hole geometry. Measurement of the D1 - entrance diameter, D2 - exit diameter was performed on the 1 mm below the surface of workpiece. The roundness deviation Rd1 and Rd2 were measured on the section h1 - 3 mm below surface workpiece. employ reports on the performed measurements generated in Calypso and scheme of measuring procedure.

3. RESULTS AND DISCUSSION

An experimental investigation of the influence of the EDM process parameters on the geometric quality of manufacturing holes was carried out using response surface methodology (*RSM*). **Table 1** shows the levels of machining parameters carried out in the experimental design and observed values.

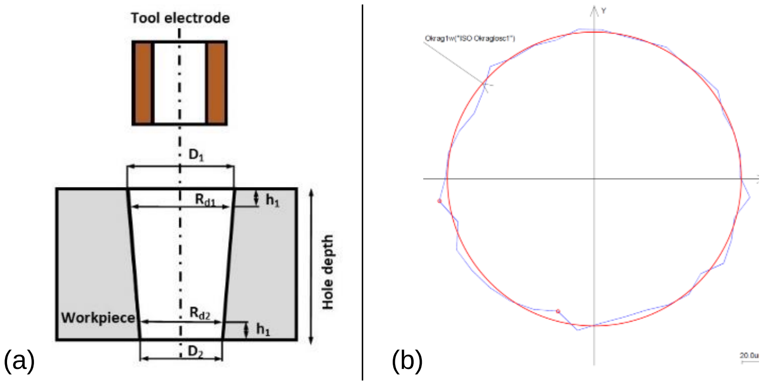


Figure 2 The scheme o measuring: (a) hole geometry, (b) graphical presentation of measured roundness deviation

Table 1 Design of the experimental matrix

No.	EDM paramters			Observed values			
	t_{on} (µs)	t_{off} (µs)	C (µF)	D_1 (mm)	D_2 (mm)	R_{d1} (mm)	R_{d2} (mm)
1.	10	10	68	2.1757	2.0871	0.0218	0.0266
2.	90	10	68	2.2825	2.0871	0.0297	0.0426
3.	10	90	68	2.1625	2.0585	0.0181	0.0158
4.	90	90	68	2.2589	2.1343	0.0254	0.0267
5.	10	50	51	2.132	2.0896	0.0157	0.014
6.	90	50	51	2.192	2.099	0.0245	0.0307
7.	10	50	90	2.1847	2.132	0.0138	0.0184
8.	90	50	90	2.2723	2.2141	0.0225	0.0397
9.	50	10	51	2.1955	2.1827	0.0292	0.0284
10.	50	90	51	2.198	2.1416	0.0253	0.0224
11.	50	10	90	2.2468	2.1934	0.0315	0.0335
12.	50	90	90	2.208	2.2156	0.0217	0.0278
13.	50	50	68	2.1557	2.13	0.0214	0.0254
14.	50	50	68	2.1432	2.1289	0.0213	0.0253
15.	50	50	68	2.1445	2.131	0.0216	0.0257

Response surface methodology was used to build empirical models of influence EDM parameters on the diameter and roundness deviation manufacturing holes. In the first stage, the analysis of different regression models was carried out. The best fit between prediction models and experimental data was found for the polynomial function of the second degree:

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum_{i=1}^{k} \beta_i i X_i^2 + \sum_{i=1, i \neq j}^{k} \beta_{ij} i X_i X_j + \varepsilon \tag{1}$$

In the next step, the analysis of variance (ANOVA) was used to estimate the regression models. The significance of each factor in the response function was checked at a 95 % coefficient level (**Table 2**). For each regression model the coefficient of determinationR2 and the adjusted coefficient of determination, R2-Adj were calculated. After removing nonsignificant factors following response function was obtained:

$$D_1 = 2.207 + 0.087 \cdot \mathrm{t_{on}} - 0.026 \cdot t_{on}^2 - 0{,}043 \cdot t_{off}^2 + 0{,}050 \cdot \mathrm{C} \tag{2}$$

$$D_2 = 2{,}136 + 0{,}044 \cdot \mathrm{t_{on}} + 0{,}044 \cdot t_{on}^2 + 0{,}060 \cdot \mathrm{C} - 0{,}043 \cdot C^2 + 0{,}037 \cdot \mathrm{t_{on}t_{off}} + 0{,}036\mathrm{t_{on}}C \tag{3}$$

$$R_{d1} = 2.207 + 0.087 \cdot t_{on} - 0.026 \cdot t_{on}^2 - 0{,}043 \cdot t_{off}^2 + 0{,}050 \cdot C \tag{4}$$

$$R_{d2} == 0.027 - 0.009 \cdot \mathrm{t_{off}} + 0.016 \cdot t_{on} + 0.006 \cdot C \tag{5}$$

Table 2 ANOVA summary

Investigated parameters	**ratio R^2**	**R^2-Adj**	**MS Residual**
Entrance diameter D_1 [mm]	0.90	0.85	0.0003457
Exit diameter D_2 [mm]	0.94	0.89	0.000246
Roundness deviation R_{d1} [mm]	0.97	0.96	0.000001
Roundness deviation R_{d2} [mm]	0.91	0.88	0.0000071

ANOVA results indicate that the values of the R_2 for the diameter D_1, D_2 and the roundness deviation R_{d1}, R_{d2} were over 90 %. Developed response functions provide a good explanation of the relationship between the pulse time, time interval, and capacitor capacity on the response *D* and *R*. For example in (**Figure 1**) are present plots of residuals for response function D_1. Expected normal value vs residuals shows that the correlation between predicted and experimental data is good. Experimental data is distributed approximately along a straight line (**Figures 1a**). The plots of residuals versus the predicted values (**Figures 1b**) and the residuals versus the case number values (**Figures 1c**) indicate that the residuals have a stochastic nature. Conducted residual analysis for each developed response function indicates that developed models were adequate from a statistical point of view.

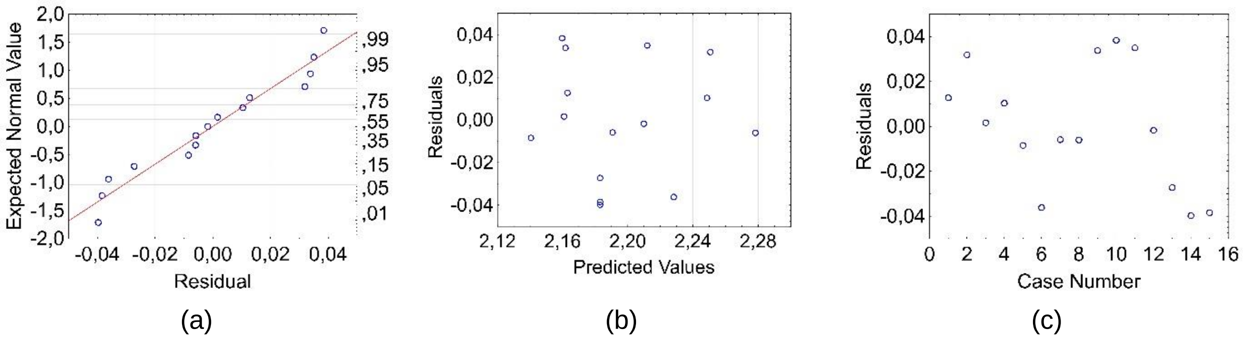
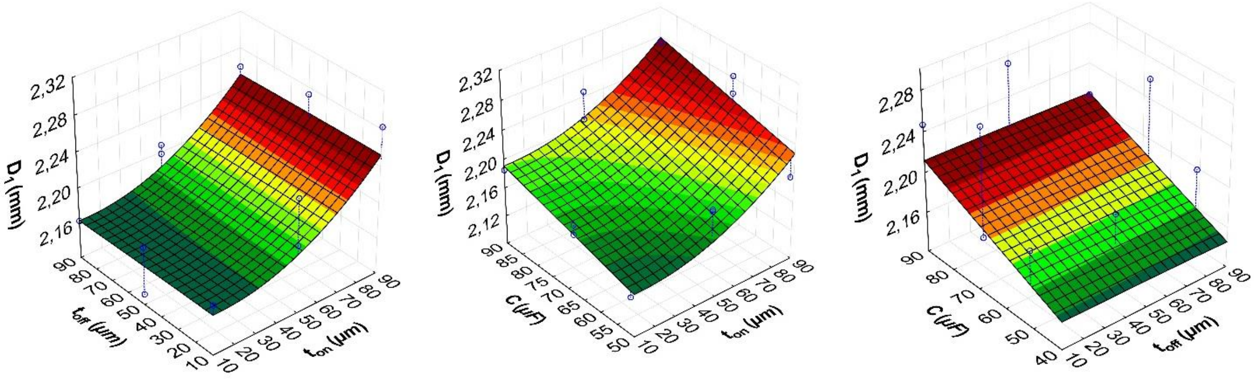


Figure 3 Plots of residuals for the entrance diameter D_1: (a) the normal plot of residuals; (b) the residuals versus the predicted values; and (c) the residuals versus case number

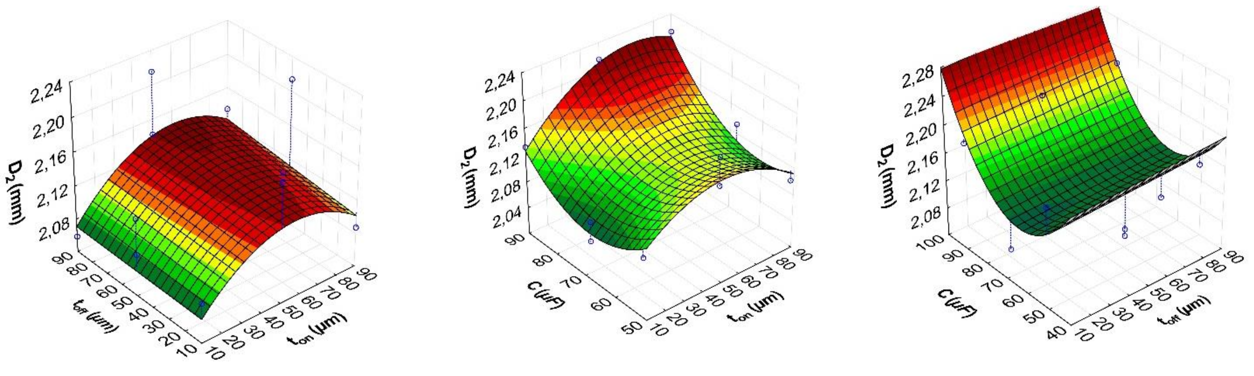
To better understand the influence of the EDM parameters on the entrance diameter D_1, exit diameter D_2, roundness deviation R_{d1}, and R_{d2} the response surface plots were developed. The influence of the pulse time t_{on}, pulse interval t_{off}, and capacitor capacity C on the D_1, D_2, R_{d1}, R_{d2} is shown in (**Figures 4-7**), respectively. The conducted experimental studies indicated that the main parameters that influenced entrance diameter D_1 and exit diameter D_2 were pulse time and capacitor capacity (**Figures 4-5**). Hole diameters D_1 and D_2 increase with the growth of the pulse time and capacitor capacity. With the increase of the t_{on} and C, the discharge energy grows to cause melting and evaporation of a higher volume of material. This led to obtaining a higher value of the diameter hole. Furthermore, analyses of differences in the size of entrance diameter D_1 and exit diameter D_2 indicate that the exit diameter is smaller than the entry diameter. This is directly due to the conical wear of the working electrode. The presented dependence also has effects on the roundness deviation. The increased pulse time and capacitor capacity corresponded to an increase in the amount of eroded material and wear of electrodes. Nonetheless in this case the value of roundness deviation in the exit of hole R_{d2} is bigger than in the entry to hole R_{d1}. Shape errors of manufacturing holes are caused by physical phenomena occurring during electrical discharge machining. Electrical discharge case local melting and evaporation of small pieces of material and electrode. Debris is removed from the gap by flushing the dielectric. Furthermore, uneven distribution of treatment products in the gap leads to uneven wear of electrodes and in the end leads to shape errors. Uneven wear of the working electrode along its diameter and length causes the end part of the electrode may move out of the axis, causing an increase in roundness deviation.

The result of experimental studies shows that time interval in the investigated range do not have a significant influence on the entry and exit diameter of hole and roundness deviation (**Figures 4-7)**.



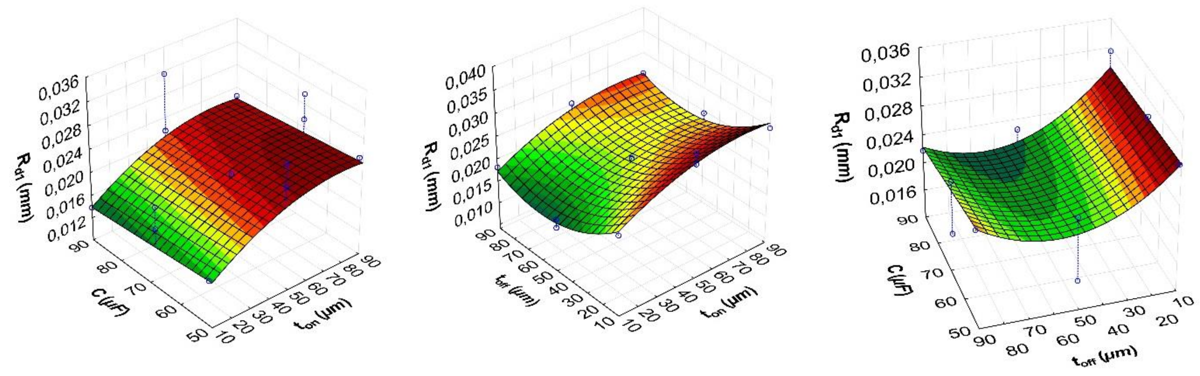
(a) (b) (c)

Figure 4 Estimated response surface plot for the entrance diameter D_1: (a) constant C = 50 μF; (b) constant t_{off} = 50 μs and (c) constant t_{on} = 50 μs



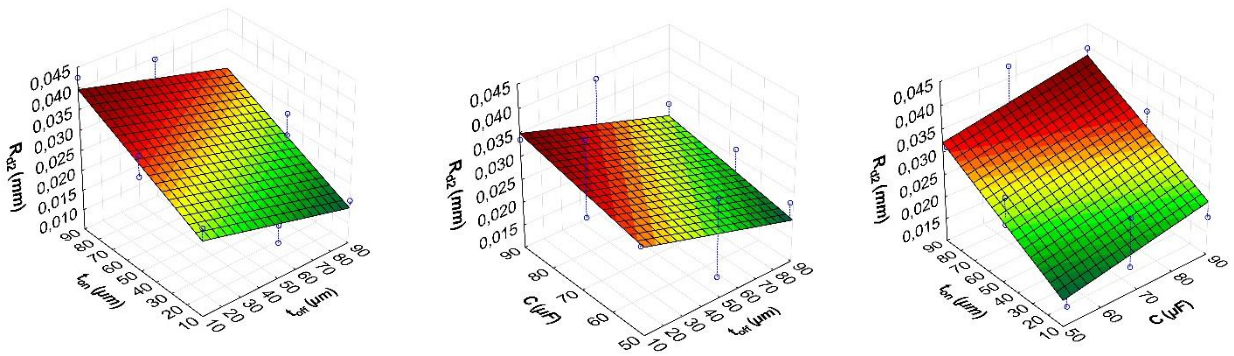
(a) (b) (c)

Figure 5 Estimated response surface plot for exit diameter D_2: (a) constant C = 50 μF; (b) constant t_{off} = 50 μs and (c) constant t_{on} = 50 μs



(a) (b) (c)

Figure 6 Estimated response surface plot for the roundness deviation R_{d1}: (a) constant C = 50 μF; (b) constant t_{off} = 50 μs and (c) constant t_{on} = 50 μs



(a) (b) (c)

Figure 7 Estimated response surface plot for roundness deviation R_{d2}: (a) constant C = 50 μF; (b) constant t_{off} = 50 μs and (c) constant t_{on} = 50 μs

4. CONCLUSION

The experimental studies were focused on the analyses of the influence of EDM parameters on the diameter and roundness deviation of holes during machining of Inconel 718. Summarizing the results of the experimental investigation can be concluded:

- The main process parameter influencing the diameter and roundness deviation of holes after EDM machining is discharge energy which dispenses pulse time and capacitor capacity. The source of roundness deviation is the uneven wear of the tool electrode and its non-axial move that is reflected in the workpiece.
- Time intervals in the investigated range do not have a significant influence on the entry and exit diameter of hole and roundness deviation.
- The developed regression equations could be used in electrical discharge machining holes in Inconel 718 as a guideline for the suitable EDM parameters.

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