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"Mathematical modeling of EDM hole drilling using response surface methodology"

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Abstract

This paper reports an experimental investigation of EDM drilling of Ø2 mm holes on Inconel 718 using brass electrode. The effect of process parameters (discharge current, pulse on and off times, and capacitance) on process outputs (material removal rate and electrode wear rate) was determined based on minimum number of experiments. The mathematical modeling of process has been done using response surface methodology. The results show that the developed model can achieve reliable prediction of experimental results within acceptable accuracy.

Key words: Electrical discharge machining, IN718, response surface methodology

Introduction

Various aerospace components made of special super alloys are working under hostile service conditions. These components have small-size cooling holes produced by EDM process [1]. In this process, a small gap is maintained between a work piece and an electrode while the machining takes place due to high-voltage sparks causing the removal of small particles away from the work piece. Special tubular electrodes are used through which dielectric fluid is continuously flowing [2]. Certain parameters in EDM process directly influence the process outputs. Setting appropriate values for such parameters requires the implementation of many drilling trials. This leads to time consuming and expensive experimental work. Response Surface Methodology (RSM) has been used for modeling EDM drilling of various size holes on many materials using different electrodes [1, 3-6]. RSM is employed to represent relationships between inputs and pertinent outputs based on minimum number of experiments. This paper presents a mathematical modeling of EDM drilling of Ø2 mm holes on Inconel 718 using RSM approach.

Table 1. Chemical composition of IN718 (wt. %).

Ni	50-55	C	0.08	Cr	17-21	Al	0.2-0.8
Mo	2.8-3.3	Si	0.35	Co	1	Mn	0.35
Ti	0.65-1.15	Cu	0.30	Nb(+Ta)	4.75-5.5	B	0.06

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Experimental Setup

The experiments were performed on IN718 test pieces (6 mm x 11 mm x 35 mm) using JS-EDM AD-20 hole drilling EDM machine. Table 2 presents the machining conditions for drilling Ø2 mm holes with a depth of 11 mm.

Table 2. Machining conditions.

Discharge current (**I**)	10-30 A
Pulse-on time ($\mathbf{t_{on}}$)	8-44 µs
Pulse-off time ($\mathbf{t_{off}}$)	5-26 µs
Capacitance (**C**)	104-474 µF
Dielectric	deionized water
Dielectric flushing pressure	75 bar
Electrode rotation	200 rpm
Polarity of tool electrode	negative

Measurement Procedure

The drilling time was recorded using an electronic timer. The test piece was weighed before and after drilling operation using a digital precision scale. Material Removal Rate (MRR) for each experiment was calculated by the following formula:

$$\text{(mg/min)} = \frac{\text{initial weight} - \text{final weight}}{\text{machining time}} \quad (1)$$

Electrode Wear Rate (EWR) was determined according to the depth of drilled hole and the amount of electrode consumption (i.e. the variation in electrode length):

$$\text{EWR (\%)} = \frac{\text{consumed electrode in length}}{\text{machined hole depth}} * 100 \quad (2)$$

Design of Experiments

Design of Experiments (DOE) is a method to obtain useful information about a process by conducting only minimum number of experiments [7]. Each controllable variable (I, ton, t, off, C) can be set on EDM machine at five consecutive levels from 1 to 5, and hence the design consisting of 31 experiments based on Central Composite Design (CCD) was generated at these levels using Minitab® statistical software. Other factors given in Table 2 were kept constant. Table 3 shows the design matrix with experimental and predicted results. MRR and EWR values can be predicted within error range of ± 16% (except experiment no. 29) and ± 19%, respectively.

Table 3. Experimental plan with experimental and predicted results.

					MRR (mg/min)			EWR (%)		
No.	I	t_{on}	t_{off}	C	Expt.	Pred.	% Error	Expt.	Pred.	% Error
1	2	2	2	2	61,869	64,120	-3,64	0,384	0,433	-15,81
2	3	3	1	3	92,841	95,104	-2,44	0,866	1,019	-4,11
3	4	4	4	4	128,193	124,714	2,71	1,825	1,731	5,05
4	4	2	4	4	107,012	108,230	-1,14	1,655	1,582	5,03
5	3	3	3	3	80,847	82,133	-1,59	0,814	0,729	13,86
6	3	3	3	3	80,200	82,133	-2,41	0,722	0,729	4,55
7	3	3	3	3	78,600	82,133	-4,49	0,702	0,729	1,83
8	3	3	3	5	103,575	120,090	-15,94	1,341	1,875	-10,35
9	4	4	2	4	136,235	134,549	1,24	2,118	1,989	2,55
10	2	4	2	4	118,510	109,838	7,32	1,612	1,385	2,27
11	2	2	4	2	69,042	64,958	5,91	0,701	0,668	5,19
12	3	3	3	3	88,828	82,133	7,54	0,814	0,729	2,66
13	2	4	4	4	117,843	107,990	8,36	1,498	1,279	-0,37
14	4	2	4	2	83,322	90,766	-8,93	0,779	0,961	-7,33
15	4	4	2	2	102,023	109,930	-7,75	0,827	0,985	-4,29
16	5	3	3	3	147,381	133,852	9,18	1,962	1,839	-8,43
17	2	4	2	2	89,486	82,499	7,81	0,742	0,653	2,93
18	2	2	2	4	93,032	83,651	10,08	1,194	0,978	4,66
19	3	3	5	3	81,371	86,106	-5,82	0,941	0,995	0,19
20	3	5	3	3	102,987	110,162	-6,97	0,930	1,065	-0,28
21	4	2	2	2	93,832	97,916	-4,35	0,822	0,879	9,11
22	3	3	3	3	88,068	82,133	6,74	0,736	0,729	-6,35
23	3	3	3	3	84,444	82,133	2,74	0,736	0,729	-4,10
24	3	1	3	3	75,478	75,300	0,24	0,623	0,695	-4,24
25	2	4	4	2	82,187	79,998	2,66	0,675	0,745	-10,36
26	4	4	4	2	95,83	99,441	-3,77	0,87	0,924	4,08
27	2	2	4	4	94,277	85,142	9,69	1,219	1,016	-1,00
28	4	2	2	4	113,766	114,727	-0,84	1,812	1,697	3,89
29	1	3	3	3	62,807	83,333	-32,68	0,611	0,941	5,23
30	3	3	3	1	84,804	75,287	11,22	0,85	0,523	6,80
31	3	3	3	3	73,941	82,133	-11,08	0,576	0,729	-18,41

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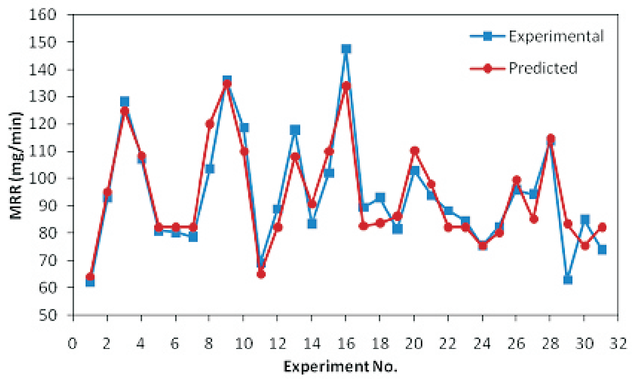
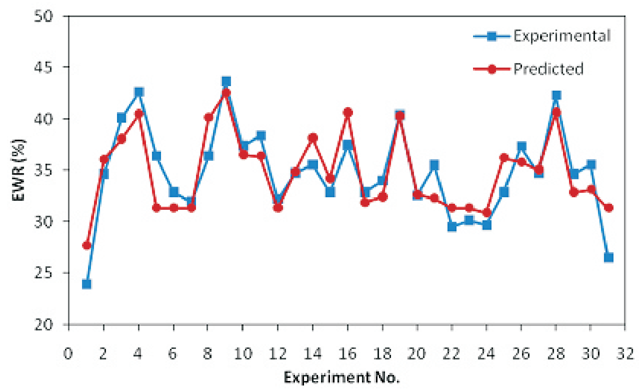
Experimental and predicted results for MRR and EWR are compared in Figure 1. The adequacy of generated model is measured based on Analysis of Variance(ANOVA). The determination coefficient (R2) defines a measure of the degree of fit between actual and predicted data. Higher value of R2 exhibits better fit. The model has produced R2 values of 85.5% and 72.7% for MRR and EWR, respectively.





Comparison of experimental and predicted values for MRR and EWR.

Reproducibility Analysis

Reproducibility is a measure of efficiency of experiments performed at identical machining conditions. In order to check reproducibility, seven replicated experiments were performed as given in Table 4. The results reveal that MRR and EWR can be reproduced within the range of ±10% and ±16%, respectively.

Table 4. Reproducibility errors for MRR and EWR.

Exp.					MRR (mg/min)		EWR (%)	
No.	I	t_{on}	t_{off}	C	Expt.	% Error	Expt.	% Error
5	3	3	3	3	80,847	1,56	36,364	-16,09
6	3	3	3	3	80,200	2,35	32,818	-4,77
7	3	3	3	3	78,600	4,30	31,909	-1,87
12	3	3	3	3	88,828	-8,15	32,182	-2,74
22	3	3	3	3	88,068	-7,23	29,455	5,97
23	3	3	3	3	84,444	-2,81	30,091	3,94
31	3	3	3	3	73,941	9,97	26,455	15,55

CONCLUSIONS

The following conclusions can be derived based on the obtained results:

1. Experimental values of MRR and EWR can satisfactorily be predicted using the developed model by performing minimum number of experiments.
2. Reproducibility analysis and R2 values prove that consistent and reliable results can be achieved within acceptable error ranges.
3. Mathematical modeling of EDM hole drilling process using RSM technique can enable the prediction of MRR and EWR values without performing unnecessary experiments. This leads to

considerable savings on time, material and effort which results in efficient, sustainable and economical production.

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