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Technical note

Electrical discharge machining of the AISI D6 tool steel: Prediction and modeling of the material removal rate and tool wear ratio

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ABSTRACT

In this investigation, response surface method was used to predict and optimize the material removal rate and tool wear ratio during electrical discharge machining of AISI D6 tool steel. Pulse on time, pulse current, and voltage were considered as input process parameters. Furthermore, the analysis of variance was employed for checking the developed model results. The results revealed that higher values of pulse on time resulted in higher values of material removal rate and lower amounts of tool wear ratio. In addition, increasing the pulse current caused to higher amounts of both material removal rate and tool wear ratio. Moreover, the higher the input voltage, the lower the both material removal rate and tool wear ratio. The optimal condition to obtain a maximum of material removal rate and a minimum of tool wear rate was 40 μs, 14 A and 150 V, respectively for the pulse on time, pulse current and input voltage.

1. Introduction

There is an ever need of advanced technology to manufacture and machining of materials through excessive strength and stability, thus, the modern processes of machining is replacing the traditional process. Electrical discharge machining (EDM) is one of the most crucial and most useful of these processes. In this process, the material removal and a machining can be made by applying a voltage pulse between the tool and the work piece, which produces a dielectric fluid and spark between them per pulse. Because the EDM process does not engage mechanical energy, the material features like hardness, strength, toughness, etc. do not affect the material removal rate. Therefore, materials with poor machinability such as tool steels can also be machined without much difficulty by the EDM [1–3].

The material removal rate and tool wear ratio during EDM play an important role in industrial performances. Furthermore, these features are generally influenced by EDM parameters such as pulse on time, pulse current, voltage and etc., which should be optimized to reach the best conditions [3,4]. One of the methods for optimizing the process parameters is Response Surface Methodology (RSM).

Recently some investigators have tried to model and optimize the EDM process of different metals and alloys [5–15]. For instance, Gopalakannan et al. [5] have studied the EDM process of the Al-SiC metal matrix nanocomposite by developing mathematical models using RSM in conjunction with a centered central composite design. They showed that the main significant factors that influence the material removal rate (MRR) are pulse current, pulse on time, and pulse off time whereas voltage remains insignificant. In addition, the pulse current and pulse on time have statistical significance on both tool wear ratio (TWR) and surface roughness (Ra). Furthermore, Dewangan et al. [4] suggested an optimal setting of EDM process factors with an aim to improve surface integrity aspects after EDM of AISI P20 tool steel using RSM. They have recommended an optimal condition of process factors of pulse current (=1 A), pulse-on time (=10 μs), tool work time (=0.2 s) and tool lift time (=1.5 s). Likewise, Nikalje et al. [9] have studied the effect of the process factors and optimization of MDN 300 steel during EDM by using Taguchi method. They revealed that discharge current, pulse on time, and pulse off time have important role in EDM procedures. Also, they revealed that the discharge current is more significant than pulse on time for MRR and TWR; whereas pulse on time is more significant than discharge current for TWR and Ra. Additionally, Bagherian Azhiri et al. [15] have explored the EDM process of the Al-SiC metal matrix composites by application of Taguchi, ANFIS and gray relational analysis. They found that pulse on time and discharge current are the most significant parameters rather than the others, and wire tension was the most insignificant parameter based on its percentage of contribution. Additionally, they confirmed that the setting of 126 μs pulse on time, 40 μs pulse

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off time, 20 V gap voltage, 230 A discharge current, 12 mm/min wire feed and 4 gr wire tension lead to higher cutting velocity and lower surface roughness.

Even though the prior investigators explored mathematical models in the case of some alloys, a research into the establishing mathematical relationships between the input parameters and output responses during EDM of AISI D6 tool steel is lacking. Therefore, the aim of this study was to apply RSM in conjunction with full factorial design, to establish the functional relationships for EDM of parameters i.e. pulse on time, pulse current and voltage, and responses of AISI D6 tool steel i.e. material removal rate and tool wear ratio.

2. Theory of RSM and full factorial design

2.1. Steps of RSM

RSM was invented by Box and Wilson in 1951, and it has been used to model and optimize the various processes [16]. The RSM has two main aims. The first one is optimizing the responses which are a function of various input parameters. The second one is predicting the mathematical relationships between the process parameters and the measured responses [17]. The RSM would include following steps for EDM process: Identifying the EDM effective parameters; Considering a reasonable limits of the identified parameters; Developing a desired experimental design; Performing the tests according to the developed experimental design; Measuring the responses; Establishing the mathematical models; Controlling the model adequacy using analysis of variance (ANOVA), and exploring the influence of the parameters on responses and optimizing them. In Sections 2.2 and 2.3, the choosing of effective parameters and their limitations, and developing experimental designs and mathematical models will be discussed in details. The ANOVA, effect of parameters and optimizing will be explained in their related sections.

Table 1
Coded and actual values of EDM parameters.

Parameters	Symbol	Unit	Levels			
			1	2	3	4
Pulse on time	*A*	μs	10	20	30	40
Pulse current	*B*	A	8	10	12	14
Input voltage	*C*	V	150	250	–	–

2.2. Choosing parameters and their limitations

Various parameters could affect the considered responses, and it is almost difficult to recognize and control the small contributions from each one. Consequently, it is essential to choice those parameters with major effects and their limitations. For this purpose, one can act in two different ways. In first way, screening designs could be carried out to determine which of the numerous experimental parameters and their interactions present more significant effects. In this regard, full or fractional two-level factorial designs may be used mainly because they are well organized [18,19]. In this way, a very large number of the experiments should be done which may be very time consuming and expensive. In second way, one can use the literature in the related field of study and use the obtained results to identify the effective parameters and their limitations.

Table 2
Design layout including experimental and predicted values.

No.	Run	Coded values of parameters			Responses			
					MRR (mm^3/min)		TWR (%)	
		(*A*)	(*B*)	(*C*)	Experimental	Predicted	Experimental	Predicted
1	16	10	8	150	6.044916	5.482303	20.49627	19.54081
2	23	20	8	150	8.696461	9.14349	12.22179	11.33076
3	24	30	8	150	17.05669	16.18345	1.71064	2.06891
4	8	40	8	150	17.77503	18.08385	0.805808	0.66908
5	15	10	10	150	7.911647	7.353789	14.96039	16.0065
6	18	20	10	150	11.34492	12.94661	12.98909	10.58851
7	20	30	10	150	22.64498	21.05618	2.215157	3.24059
8	6	40	10	150	24.34266	25.12277	1.295127	0.98047
9	31	10	12	150	11.10142	10.71295	17.90438	18.3588
10	7	20	12	150	16.91268	18.61025	16.25867	15.55784
11	17	30	12	150	30.0778	28.88321	3.753688	4.34659
12	32	40	12	150	32.78977	33.28974	2.435521	2.10934
13	10	10	14	150	13.11667	13.21345	17.32431	18.07385
14	26	20	14	150	23.10135	24.22426	16.0907	15.09925
15	22	30	14	150	35.64444	35.13187	5.199727	6.77201
16	27	40	14	150	44.64781	43.89593	4.264923	4.21877
17	29	10	8	250	6.712741	7.053654	14.24801	13.55991
18	25	20	8	250	11.02284	11.73944	6.914154	6.87793
19	9	30	8	250	15.80746	15.47627	1.411702	1.98571
20	13	40	8	250	16.53784	16.26753	0.775119	0.54813
21	30	10	10	250	7.576641	7.996519	9.954947	10.31685
22	11	20	10	250	14.66197	14.71329	4.279131	5.16263
23	2	30	10	250	19.60727	19.42621	1.484691	1.81238
24	5	40	10	250	21.47027	21.80084	0.779914	0.45266
25	21	10	12	250	9.611261	9.740073	12.07977	11.58621
26	12	20	12	250	19.1213	18.61017	6.939682	6.23762
27	4	30	12	250	26.23166	24.99409	2.29648	2.37309
28	3	40	12	250	29.1648	28.89020	1.554845	1.04123
29	28	10	14	250	12.20727	11.98709	12.04723	11.91908
30	19	20	14	250	21.89337	21.71730	7.520434	7.34001
31	1	30	14	250	29.43662	29.47398	2.790472	3.24317
32	14	40	14	250	32.86609	34.00657	2.047492	2.47659