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Optimization of EDM Process with Coated Electrode using GRA

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Abstract

The correct selection of manufacturing conditions and technique is one of the most important aspects to take into consideration in the majority of manufacturing processes and, particularly, in processes related to Electrical Discharge Machining (EDM). Optimization is one of the techniques used in manufacturing sectors to arrive for the best manufacturing conditions, which is an essential need for industries towards manufacturing of quality products at lower cost. This paper aims to investigate the optimal set of process parameters such as current, voltage and pulse on time in EDM process to identify the variations in performance characteristics such as material removal rate and electrode wear rate for machining High Carbon High Chromium Die steel (HCHCr) using the titanium nitride coated copper electrode. Based on the experiments conducted using factorial design, analysis has been carried out using Grey Relational Analysis. The confirmation experiments were carried out to validate the optimal results. Thus, the machining parameters for EDM were optimized for achieving the combined objectives of higher material removal rate and lower electrode wear rate. Grey relational Analysis is being effective technique to deal with multi objective optimization problem.

Keywords: *EDM, Factorial design, Tin coated electrode, GRA.*

1. Introduction

With the industrial and technological growth, development of harder and difficult to machine materials, which find wide application in aerospace, nuclear engineering and other industries owing to their high strength to weight ratio, hardness and heat resistance qualities has been witnessed. New developments in the field of material science have led to new engineering metallic materials, composite materials and high tech ceramics having good mechanical properties and thermal characteristics as well as sufficient electrical conductivity so that they can readily be machined by non-conventional machining process like spark erosion. The Electrical Discharge Machining process is employed widely for making tools, dies and other precision parts. The EDM has many advantages, such as non-contact with the workpiece during the machining process and ability to machine any conductive material, regardless of its hardness. Hence, it does not create any vibration during machining as compared to other conventional machining [1]. The quality of a product is the main factor for growth of a company. The quality of the product mainly depends upon the material and process parameters. Optimization of process parameter plays a vital role to increase the quality of the product [2]. Hence, many authors have presented their works on the optimization of process parameters for various machining processes. S. Dhanabalan and K Sivakumar have done EDM process optimization with multiple performance characteristics based on orthogonal array with grey relational analysis for Titanium grades with brass electrode [3]. Saha and Choudhury studied the process of dry EDM with tubular copper tool electrode and mild steel work-piece [4]. Grey relational analysis (GRA) has been used by many researchers for machining processes which include electric discharge machining [5], chemical mechanical polishing [6], determining condition of tool in turning [7], side milling [8], and flank milling [9] to analyse the performance of diamond tool carbide inserts in dry turning [10], and optimization of parameters in drilling [11]. The objective of this paper is to determine the optimal levels of the process parameters for Electric-Discharge Machining process using Taguchi approaches. This work was done with Mild Steel IS 2026 grade as work piece material and copper as tool electrode. Signal-to-Noise ratio analysis and Grey relational analysis were applied to obtain the optimum values of the process parameters for the formation of a blind hole of 10 mm diameter and 3 mm depth. The process parameters such as peak current, pulse on time and pulse off time were optimized with the considerations of multiple performance characteristics such as material removal rate, tool wear rate and surface roughness value on the work material.

2. Experimentation

During this study, series of experiments on the HCHCr were conducted by EDM process (shown in Fig 1) to examine the effect of input machining parameters, such as current, voltage and pulse on time on material removal rate and electrode wear rate.

Fig. 1: EDM machine

In this experimental work the titanium nitride coated copper electrode was used as tool material. MRR and EWR was measured with digital weighing machine. On the basis of preliminary experiments conducted by using one variable at a time approach the range of input parameters were selected. The table 1 shows the Machining parameters and their level chosen for this study.

Table 1. Machining Parameters and their levels

Values/ Variables	Coded values	Current (Amp)	Voltage (Volt)	Pulse ON time (μs)
Minimum	-1	6	45	50
Maximum	+1	10	55	200
Average	0	8	50	100

Design of experiment is an effective tool to design and conduct the experiments with minimum resources. In this work, factorial design is used to set the control parameters to evaluate the process performance. A well designed factorial experiment 2^3+3=11 experiments for three inputs variables at three levels were conducted as shown in table 2.

The design matrix with results and S/N ratio of output parameters is shown in table 3 and table 4 respectively. MRR and EWR are calculated by weight difference method.

Table 2. Design matrix with coded values

Experimental runs	Current (I)	Voltage (V)	Pulse ON time (Ton)
01	-1	-1	-1
02	-1	-1	+1
03	-1	+1	-1
04	-1	+1	+1
05	+1	-1	-1
06	+1	-1	+1
07	+1	+1	-1
08	+1	+1	+1
09	0	0	0
10	0	0	0
11	0	0	0

Table 3. Design matrix with actual values and experimental results

Expt. runs	Current (I)	Voltage (V)	Pulse ON Time (Ton)	MRR g/min	EWR g/min
01	6	45	50	0.0861	0.005
02	6	45	200	0.0762	0.01
03	6	55	50	0.0679	0.008
04	6	55	200	0.0617	0.017
05	10	45	50	0.159	0.016
06	10	45	200	0.162	0.021
07	10	55	50	0.1432	0.019
08	10	55	200	0.132	0.022
09	8	50	100	0.121	0.015
10	8	50	100	0.116	0.015
11	8	50	100	0.12	0.017

Table 4. S/N ratio of output parameter

Expt. runs	Current (I)	Voltage (V)	Pulse ON Time (Ton)	MRR g/min	EWR g/min
01	6	45	50	-21.29	46.02
02	6	45	200	-22.36	40.00
03	6	55	50	-23.36	41.93
04	6	55	200	-24.19	35.39
05	10	45	50	-15.97	35.91
06	10	45	200	-15.80	33.55
07	10	55	50	-16.88	34.42
08	10	55	200	-17.58	33.15
09	8	50	100	-18.34	36.47
10	8	50	100	-18.71	36.47
11	8	50	100	-18.41	35.39

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3. Grey relational analysis

The grey relational analysis is a widely used analyzing system even when a model is uncertain or the information is incomplete. It provides an efficient solution to complicated interrelationships among multiple performance characteristics. Steps of grey relational analysis are given as follow:

3.1 Normalization

There are three different types of data normalization according to whether we require the LB (lower-the-better), the HB (higher-the-better) and NB (nominal-the-best). The normalization is taken by the following equations.

(a) HB (higher-the-better)

$$x_i(k) = \frac{y_i - min\ y_i\ (k)}{\max y_i(k) - min\ y_i\ (k)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

(b) LB (lower-the-better)

$$x_i(k) = \frac{\max y_i(k) - y_i\ (k)}{\max y_i(k) - min\ y_i\ (k)} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

(c) NB (nominal-the-best)

$$X_i^*\ (k) = \frac{y_i\ (k) - y_i}{\max y_i(k) - y_i\ (k)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where x_i (k) is the value after the grey relational generation, min y_i (k) is the smallest value of y_i (k) for the k^{th} response, and max y_i (k) is the largest value of y_i (k) for the k^{th} response. An ideal sequence is x_0 (k) for the responses. The purpose of grey relational grade is to reveal the degrees of relation between the sequences say, [x_0 (k) and x_i (k) , i = 1, 2,3.......,9].

Table 5. Normalization

Sr. No	ACTUAL			Normalization	
	I	V	Ton	MRR	EWR
1	6	45	50	0.3452	0.0000
2	6	45	200	0.2187	0.4678
3	6	55	50	0.0992	0.3172
4	6	55	200	0.0000	0.8260
5	10	45	50	0.9806	0.7851
6	10	45	200	1.0000	0.9686
7	10	55	50	0.8722	0.9011
8	10	55	200	0.7878	1.0000
9	8	50	100	0.6977	0.7415
10	8	50	100	0.6540	0.7415
11	8	50	100	0.6891	0.8260

3.2 Deviation sequence

The deviation sequence Δ_{0i} is the absolute the reference sequence x0 (k) and the comparability sequence xi (k) after normalization. It is determined using

$$\Delta_{0i} = |x0\ (k) - xi\ (k)| \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Table 6. Deviation sequence

Sr. No	ACTUAL			Deviation sequence	
	I	V	Ton	MRR	EWR
1	6	45	50	0.6548	1.0000
2	6	45	200	0.7813	0.5322
3	6	55	50	0.9008	0.6828
4	6	55	200	1.0000	0.1740
5	10	45	50	0.0194	0.2149
6	10	45	200	0.0000	0.0314
7	10	55	50	0.1278	0.0989
8	10	55	200	0.2122	0.0000
9	8	50	100	0.3023	0.2585
10	8	50	100	0.3460	0.2585
11	8	50	100	0.3109	0.1740

3.3 Grey relational coefficient

GRC for all the sequences expresses the relationship between the ideal (best) and actual normalized S/N ratio. If the two sequences agree at all points, then their grey relational coefficient is 1.

$$\xi_i(k) = \frac{\Delta_{min} + \theta\ \Delta_{max}}{\Delta_{0i}(k) + \theta\ \Delta_{max}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Where, $\Delta_{0i} = \|x_o(k) - x_i(k)\| =$ difference of the absolute value $x_o(k)\ and\ x_i(k)$; θ is the distinguishing coefficient $0 \le \theta \le$ 1; $\Delta_{min} = \forall j^{min} \in i \forall k^{min} \|x_o(k) - x_j(k)\|$ = the smallest value of Δ_{0i} ; and Δ_{max} = $\forall j^{max} \in i \forall k^{max} \|x_o(k) - x_j(k)\|$ = largest value of Δ_{0i}. Comparability sequence and ζ is the distinguishing coefficient. The value of θ can be adjusted with the systematic actual need and defined in the range between 0 and 1, $\theta \in [0, 1]$. It will be 0.5 generally.

Table 7. Grey relational coefficient

Sr. No	ACTUAL			GRC	
	I	V	Ton	MRR	EWR
1	6	45	50	0.4330	0.3333
2	6	45	200	0.3902	0.4844
3	6	55	50	0.3569	0.4227
4	6	55	200	0.3333	0.7418
5	10	45	50	0.9627	0.6994
6	10	45	200	1.0000	0.9409
7	10	55	50	0.7964	0.8348
8	10	55	200	0.7021	1.0000
9	8	50	100	0.6232	0.6592
10	8	50	100	0.5910	0.6592
11	8	50	100	0.6166	0.7418

3.3 Grey relational grade

The overall evaluation of the multiple performance characteristics is based on the grey relational grade. After averaging the grey relational coefficients, the grey relational grade γ_i can be computed as:

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n}\xi_i(k) \qquad \text{(6)}$$

Where, n = number of process responses.
In this experiment, the normalized MRR corresponds to "higher-the-better" and TWR values corresponds to "smaller-the-better" (SB) criterion that can be calculated Using equation 1 and 2 respectively. The overall performance characteristic of the multiple response process depends on the calculated grey relational grade.

Table 8. Grey relational grade

Sr. No	ACTUAL			GRG
	I	V	Ton	
1	6	45	50	0.383154
2	6	45	200	0.437318
3	6	55	50	0.389836
4	6	55	200	0.537575
5	10	45	50	0.831039
6	10	45	200	0.970457
7	10	55	50	0.815622
8	10	55	200	0.851048
9	8	50	100	0.641206
10	8	50	100	0.625104
11	8	50	100	0.679213

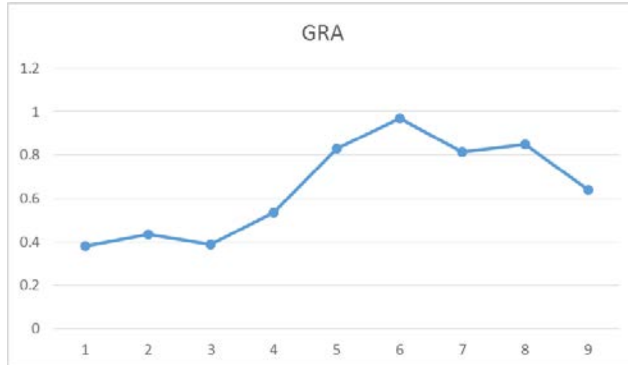

Fig. 2: GRA at different combinations

4. Result and discussion

According to Table 9, the factor A, the current is the most significant controlled parameter for the EDM operation followed by Ton and voltage for maximization of MRR and minimization of EWR. The A2-B1-C2 is an optimal parameter combination of the EDM process with the titanium nitride coated copper electrode.

Table 9: Response table for the Grey Relational Grade

parameters	Grey Relational Grade			Main effect	Rank
	Level-1	Level-2	average		
A) current	0.4369	0.8670	0.6485	0.2185	1
B) voltage	0.6554	0.6485	0.6485	0.0070	3
c) Ton	0.6049	0.6991	0.6485	0.0942	2

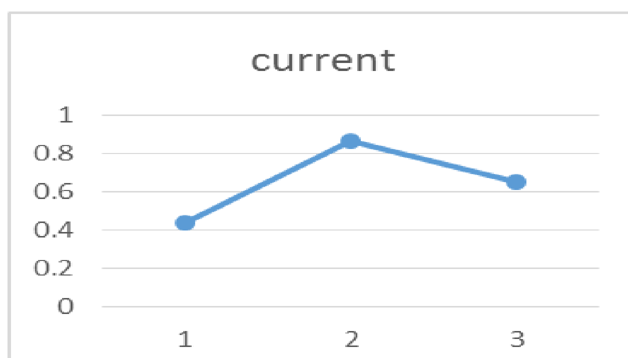

Fig. 3: Effect of current on GRG

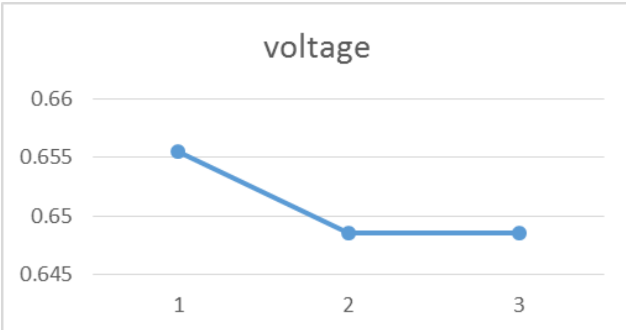

Fig. 4: Effect of voltage on GRG

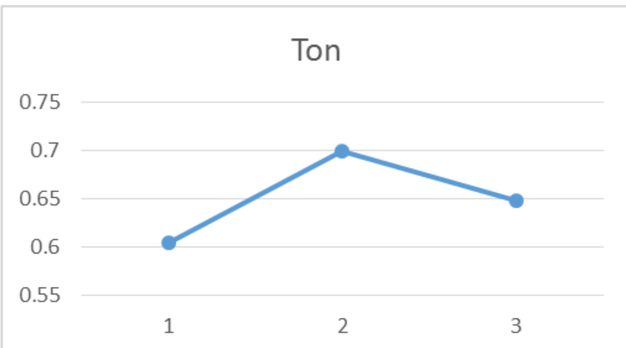

Fig. 5: Effect of Ton on GRG

The optimal combinations of the machining parameter levels is determined from Table 9, as A2 (current 10 Amp), B1 (voltage 45 volt) and C2 (Ton 200 µs). Regression models were prepared and used for prediction of responses.

MRR = 0.0649 + 0.0190 I - 0.00196 V - 0.000049 Ton … (7)

EWR = - 0.0256 + 0.00237 I + 0.000350 V + 0.000035 Ton … (8)

The % errors between experimental and predicted values were found within a range of ±0.20. Confirmatory experiments were performed using the optimum values and it was found that experimental response values were close enough to predicted values. If the optimum setting with current of 10 Amp, voltage of 45 volt and Ton of 200 µs is used, it gives MRR of 0.1568 g/min and EWR of 0.02088 g/min.

4. Conclusions

Based on the experimental and predicted results, following conclusions are drawn:

1. The Optimal combination of process parameters for obtaining maximum MRR and minimum EWR are current of 10 Amp, voltage of 45 volt and Ton of 200 µs.

2. If the optimum setting is used, it gives MRR of 0.1568 g/min and EWR of 0.02088 g/min.

3. It was found that current is the most dominant parameter for the titanium nitride coated copper electrode that has high influence on both MRR and EWR followed by Ton.

4. Regression models prepared were used for prediction of responses. The % errors between experimental and predicted values were within a range of ± 0.20.

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