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A GRA Approach Towards Optimization of Multiple Responses in Electrical DischargeMachining of AISI ۲۳۱۲ steel

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A GRA Approach Towards Optimization of Multiple Responses in Electrical Discharge Machining of AISI 2312 steel

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Abstract

In any manufacturing process, optimization of process parameters is the key step in producing high quality parts without cost inflation. Multi-criteria optimization of processes parameters could be used to simultaneously achieve several conflicting goals such as increasing product quality and reducing production time. In this paper grey relational analysis (GRA) and Taguchi method have been employed to optimize Electrical Discharge Machining (EDM) process parameters for AISI 2312 (40CrMnMoS86) hot worked steel alloy. The experimental data are gathered based on Taguchi L_{36} design matrix. The tests are conducted under varying peak current (I), voltage (V), pulse on time (T_{on}), pulse off time (T_{off}) and duty factor (η). The process output characteristics include surface roughness (SR), tool wear rate (TWR) and material removal rate (MRR). The objective is to find a combination of process parameters to minimize TWR and SR and maximize MRR. The three performance characteristics are combined into a single objective using grey relational analysis. The GRA was followed by the signal to noise ratio to specify the optimal levels of process parameters. The significance of the process parameters on the overall quality characteristics of the EDM process was also evaluated quantitatively using the analysis of variance (ANOVA) method. Optimal results were verified through additional experiments.

Keywords: "Electrical Discharge Machining (EDM), Grey Relational Analysis (GRA), Multi objective optimization, Taguchi method, Analysis of Variance (ANOVA)".

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Introduction

With the increasing demand for new, hard, high strength, hardness, toughness, and temperature resistant material in engineering, the development and application of EDM has become increasingly important. EDM has been used effectively in machining of hard, high strength, and temperature resistance materials. Material is removed by means of rapid and repetitive spark discharges across the gap between electrode and work piece. Therefore, the merits of the EDM technique become most apparent when machining AISI2312 hot worked steel which has the highest hardness in reinforcement. In addition, mechanical and physical properties of AISI2312 hot worked steel such as hardness, toughness, high wear resistance has made it an important material for engineering components particularly in making moulds and dies [1, 2].

In recent years, Design of Experiments (DOE) approaches have increasingly been employed to establish the relationships between various process parameters and the process outputs in variety of manufacturing industries. Taguchi method uses a design of experiments to study the entire parameters space with small number of experiments [3].

To the best of our knowledge, there is less published work to statistically study the effect of machining parameters on AISI2312 hot worked steel. As mentioned earlier, Surface Roughness (SR), Tool Wear Rate (TWR) and Material Removal Rate (MRR) are the most important performances characteristic in EDM. Therefore in turn, they are determined by the process parameters settings, such as peak current (I), voltage (V), pulse on time (T_{on}), pulse off time (T_{off}) and duty factor (η). Moreover, the main objectives of the present study are: 1. to establish the relationship between these parameters and out put values, and 2. to derive the optimal parameter levels for maximum material removal rate, minimum tool wear rate and surface roughness, using statistical analysis of the experimental data. Finally, the article concludes with the verification of the proposed approach and a summary of the major findings.

The Grey theory can provide a solution of a system in which the model is unsure or the information is incomplete. It also provides an efficient solution to the uncertainty, multi-input and discrete data problem. The relation between machining parameters and performance can be found out with the Grey relational analysis[4].

Experimental condition

Many factors affect the MRR, TWR and SR in EDM process. In this study the important machining parameters include peak current (I), voltage (V), pulse on time (T_{on}), pulse off time (T_{off}) and duty factor (η) have been selected as machining variables. "Table 1" lists the ranges of machining parameters and "Figure 1" shows Die-sinking EDM machine used. The 36 sets of data used for modeling, are obtained using L_{36} matrix in Taguchi Design of Experiments ("Table 2"). The tests were performed under the following conditions:

In this study, an Azerakhsh-304H EDM machine has been used to perform the experiments ("Figure 1"). Also, 20 mm diameter cylindrical shape pure copper (99% purity and 8.98 g/cm^3 density) electrodes were selected as the EDM tool. The pure kerosene was used as the dielectric fluid in all experiments. Furthermore Surface finish was measured with using an automatic digital Surtronic (3+) SR tester.

The test specimens were of AISI 2312 hot worked steel with dimensions of 60 mm×20 mm×10 mm. A total of 4 tests were performed on each samples (two tests on each side).

Table 1- Machining parameters and their levels

Parameters	unit	levels		
		1	2	3
Current (I)	A	2.5	5	7.5
Pulse-on time (T_{on})	μs	25	100	200
Gap voltage (V)	V	50	55	60
Time on work (η)	s	0.4	1.0	1.6
Plus-off time (T_{off})	μs	10	75	-

Figure (1) Die-sinking EDM machine used

Taguchi method and grey relational analisis

Signal to Noise Ratio (S/N)

Taguchi uses S/N ratio rather than mean value of data. The term 'signal' represents the mean value and the term 'noise' represents the undesirable value for the output characteristic [5]. There are several S/N calculation method available depending on type of characteristic; lower is better (LB), nominal is best (NB), or higher is better (HB) [6]. The smaller is better quality characteristics can be explained as

$$\textbf{LB}:\ S/N(\eta) = -10\ \log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^{\,2}\right) \tag{1}$$

$$\textbf{HB}:\ S/N(\phi) = -10\ \log\left(\frac{1}{n}\sum_{i=1}^{n} \frac{1}{y_i^{\,2}}\right) \tag{2}$$

Where n is number of iteration in a trial, in this case, n =1 and y_j is the jth measured value in a run. S/N ratio values are calculated for observed SR and TWR results by taking into consideration Eq. 1. Also the larger is better is explained as Eq. 2. S/N ratio values are calculated for observed MRR results using Eq. 2.

Grey Relational Generations

The grey theory first proposed by 'Deng' [7], in order to avoid the inherent defects of conventional, statistical methods and only requires a limited set of data to estimate the behavior of an unknown system. During the past two decades, with hard work by scholars, the grey theory has been successfully applied to research in industry, social systems, ecological systems etc [7]. In GRA of a process following steps are performed [8]:

a) Data normalizing of each response to avoid the effect of adopting different units and reduce the variability:

$$Z_i = \frac{S/N(\eta)_i - \min(S/N(\eta)_i)}{\max(S/N(\eta)_i) - \min(S/N(\eta)_i)} \tag{3}$$

$$Z_i = \frac{\max(S/N(\phi)_i) - S/N(\phi)_i}{\max(S/N(\phi)_i) - \min(S/N(\phi)_i)} \tag{4}$$

Where i=Number of experiments, in this case, n = 36, max $(S/N)_i$ and $\min(S/N)_i$ respectively are the larger and the smaller value of S/N for observed responses. Thus, using Eq. 4 normalized values of S/N ratio of observed MRR, TWR and SR can be computed.

a) Calculating the Grey Coefficients via following equation:

$$\gamma(z_i, z_0) = \frac{\Delta_{\min} + \Omega\Delta_{\max}}{\Delta_{0,j} + \Omega\Delta_{\max}} \tag{5}$$

In this expression, Z_o is the reference sequence (in this study Z_o=1), Z_i is normalized response (Z_i usually named as comparability sequence) , $\Delta_{o,j}$ is the absolute value of the difference between Z_o and Z_i ($\Delta_{o,j}$ = | Z_i - Z_o), Δ_{max} = max{ | Z_i - Z_o | }), Δ_{min} and Δ_{max} respectively are the smallest and the largest value of difference between Z_o and Z_i (Δ_{min} = min { | Z_i - Z_o | } and also Ω is the distinguishing coefficient ($0 \leq \Omega \leq 1$).

b) Averaging weighted value of GRCs for three observed responses (p=3), namely Grey Relational Grade (GRG: ($\gamma(Z_i, Z_o)$))for every tests :

$$\gamma(z_i, z_0) = \sum_{k=1}^{p}\{\beta_k \times \gamma(z_i, z_0)\} \tag{6}$$

Where β_k is weighting factor of each response ($\sum\beta_k$=1).This factor depends on the relative importance of responses. When weighting coefficients of each response are equal (in this work β_k=1/3), the value of Ω is set to 0.5 [9]. Keep on this regard grey grade is performed and results are shown in "Table 2". In this table, last row is due to obtained grey relational grades and 3 other columns respectively are due to grey relational coefficient for each response of S/N ratio.

The machining time for each test was 20 minutes and all experiments were repeated twice with the average being taken as the results. Some of the 36 experimental design matrix and the average values of duplicated runs for MRR and SR are listed in ""Table 2" ".

Table 2- Experimental design and results

No.	parameters					GRC TWR	GRC SR	GRC MRR	GRG
	T_{off} (µs)	T_{on} (µs)	I (A)	η (Sec.)	V_{gap} (V)				
1	1	1	1	1	1	0.40256	0.7862	0.3376	0.5087
2	1	2	2	2	2	0.51314	0.4771	0.5814	0.5239
3	1	3	3	3	3	0.70992	0.3336	0.7895	0.6116
4	1	1	1	1	1	0.41655	1	0.3333	0.5833
5	1	2	2	2	2	0.49057	0.4861	0.5157	0.4975
6	1	3	3	3	3	0.77181	0.3453	0.7974	0.6382
7	1	1	1	2	3	0.43713	0.8084	0.3547	0.5335
8	1	2	2	3	1	0.51008	0.4296	0.7261	0.5553
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
29	2	2	1	3	3	0.57403	0.6671	0.3862	0.5424
30	2	3	2	1	1	0.73517	0.3609	0.5029	0.5329
31	2	1	3	3	3	0.33797	0.6305	0.4762	0.5329
32	2	2	1	1	1	0.52761	0.5177	0.3533	0.4662
33	2	3	2	2	2	0.68108	0.4182	0.6553	0.5848
34	2	1	3	1	2	0.33333	0.6305	0.4076	0.4572
35	2	2	1	2	3	0.56858	0.5731	0.3821	0.5079
36	2	3	2	3	1	1	0.3938	0.7045	0.6994

Results and disccussion

Optimum set of Multi criterion

Mean effect analysis of variables in Grey Analysis is very simple [10]. To determine the effect of any parameter it's enough to compute average result of GRG for each test containing this parameter in desired level. For example mean effect of T_{off} in level 1 obtains from averaging test runs number 1, 2 up to 18. By taken this in regard mean effect of other variables in each level can be computed, so mean effect of parameters is computed and listed in "Table 3". Large value of mean GRG is favorable so due to datas in "Table 2" optimum set of parameters in multi criterion respectively are: T_{off} in first level, T_{on} in third level, I in second level, η in third level and V in the first level (A_1 B_3 C_2 D_3 E_1).

Table 3- Response (mean) of overall GRGs

	Level 1	Level 2	Level 3
T_{off}	0.5332*	0.5086	-
T_{on}	0.4946	0.4993	0.5688*
I	0.5156	0.5245*	0.5226
η	0.4925	0.5255	0.5447*
V	0.5434*	0.5024	0.5168

*Significant

Effect estimation – ANOVA

Analysis of variance (ANOVA) is a mathematical way to determine precision statistical analysis. It shows how well the proposed model fits the experimental data and, therefore, represents the actual process under study [9]. The results of ANOVA have been presented in "Table 4".

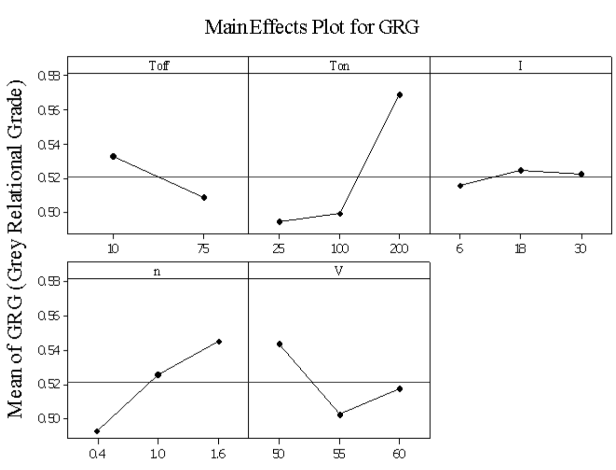

Figure (2) Plot of factor effects on GRG

"Figure 2" schematically shows the effect of machining parameters on the GRG. The same trend as discussed above may be seen in this figure.

Verification Test at Optimal set

The complementation step is the verification test. Since the optimum condition of parameter levels was not included in the main experiment, an indirect method was chosen to predict the single and multiple characteristics. The predicted optimum value of each response (η_{opt}) at optimum set (A_1 B_3 C_2 D_3 E_1) is determined as [11]:

$$\eta_{opt} = \eta_m + \sum_{i=1}^{\alpha} (\eta_i - \eta_m) \qquad (7)$$

Where η_m is total average of any response, η_i is predicted mean response at optimum level i of parameter j and α is the number of main design parameters that affect the performance. The predicted responses for GRA, MRR, SR and TWR for the optimum parameter levels (A_1 B_3 C_2 D_3 E_1) are listed in "Table 5".

Table 4- Result of ANOVA

Cleaning parameters	Degree of freedom (Dof)	Sum of square (SS_j)	Variance (F_j)	F-Value
A	1	0.0054	4.909	2.76
B	2	0.0414	0.8106	3.73*
C	2	0.0005	2.4306	10.51*
D	2	0.0167	0.5962	4.32*
E	2	0.0104	0.3215	2.64
Error	26	0.0512	0.0456	-
Total	35		-	-

*Significant
$F_{0.05,1,26} = 4.23$ & $F_{0.05,2,26} = 3.37$

Table 5-Result of verification test

	Optimal Parameter Set		
	l set	Prediction	Experiment
Setting Level	A2B3C2D3E1	A1B3C2D3E 1	A1B3C2D3E 1
Material Removal Rate	0.114	0.165	0.175
Surface Roughness	9.8	6.5	6.8
Tool Wear Rate	0.001	0.0018	0.002
Grade	0.6994	0.7235	0.7452
Improvement of GRG = 0.0458			

Conclusion

Multi objective EDM process evaluation and optimization based on Taguchi method grey analysis is successfully implemented. Material removal rate, surface roughness and tool wear rate are combined in a multi criterion model using Grey Relational Grades. From ANOVA results, peak current, duty factor and pulse on time respectively are the most effective parameters in developed multi objective model. Selecting peak current in 5 A, duty factor in 1.6 S and pulse on time in 200μs concludes optimum machining condition. Also by this approach effect of every machining parameter on each quality performance were evaluated. This paper shows that multiple performance characteristics such as material removal rate and surface roughness can be improved by using this approach. Also ANOVA due to adaptability and ease of use is a powerful tool for effect analysis. From the analysis obtained From ANOVA concluded that peak current is having highest influence on process performance.

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