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Multi Objective Optimization of Process Parameters of EDM on EN 31 Alloy Steel by Using Grey-Taguchi Method

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***Abstract:** The use of Taguchi method with grey relational analysis to establish the process parameters in electro-discharge machining of EN-31 alloy steel with selected tool electrode materials brass, aluminium, and graphite. Throughout the study, multiple quality characteristics like tool wear rate (TWR) & metal removal rate (MRR) are focused. The effort has been made to minimize tool wear rate and maximize metal removal rate to produce high-quality finishing of the die. The process parameters, namely Peak Current, Pulse on time, Electrode Material are optimized with respect to tool wear rate and metal removal rate, using the Taguchi quality design concept, an L_9 Orthogonal Array table is chosen for the experiments. From the grey analysis, a grey relational grade is obtained and based on this value; an optimum level of process parameters has been identified. Furthermore, using analysis of variance (ANOVA) method, significant contributions of various process parameters have been determined. The results of the confirmation experiment show that the optimal process parameters may be determined successfully so as to benefit up numerous quality characteristics (TWR & MRR) through this approach.*
***Keywords:** EDM, Electrode, Peak Current, Pulse on Time, MRR, TWR, OA*

I. INTRODUCTION

Electrical discharge machining (EDM) process is one of the most ordinarily used non-traditional precise material removal processes. Electrical discharge machining (EDM) is a process for shaping hard metals and forming deep complex shaped holes by arc erosion in all kinds of electro electrode. This removes the unnecessary material from the parent metal through melting and vaporization in presence of dielectric fluid [1].A major advantage of EDM is that the tool and the workpiece do not come into contact [2]. In Electrical discharge machining material is removed by controlled erosion through a series of electric sparks among the tool (electrode) material and the workpiece material. The thermal energy of the sparks leads to intense heat conditions on the workpiece causing melting and vaporizing of workpiece material. Due to the high temperature of the sparks, not only work material is melted and vaporized, but the electrode material is also melted and vaporized, which is known as electrode wear (EW). The EW process is quite similar to the material removal mechanism as the electrode and the workpiece are considered as a set of electrodes in EDM. Due to this wear, electrodes lose their dimensions resulting in inaccuracy of the cavities formed. During EDM, the main output parameters are the material removal rate (MRR), Tool wear ratio (TWR) and Surface Roughness (SR).Electric discharge machining (EDM) is a non- traditional machining operating procedure in the manufacture of intricate parts, complex shaped dies, moulds and scathing parts used in aerospace, automobile, surgical and other industrial applications. Electrical-discharge machining (EDM) is widely used for high strength materials. An analysis of the influence of peak current, pulse duration and electrode material over MRR and TWR was performed. EDM is now unquestionably recognized as an important precision machine tool forming process for producing internal shapes on the workpiece. This study presents experimental analysis based on three factors and three levels Orthogonal Array L_9 design. The purpose of this research is to optimize the performance of various electrode materials on the EN-31 workpiece with EDM process.

Studies show that selection of process parameters and fixing the appropriate range of parameters to machine every product decides the quality of the product and in turn the processes requirements. N. S. Kundrakpam et al. studied Grey Taguchi approach with L_{27} orthogonal array was considered to investigate and optimize the process parameters of ND-EDM for EN-8 material [3]. B.P. Mishra et al. investigate exploration of electrical discharge machining (EDM) process on EN-24 alloy steel using Taguchi robust design approach and multi-objective grey relational grade with four controllable input parameters such as pulse on time, Pulse off time, peak current and flushing pressure for analysis of material removal rate (MRR) and tool wear rate (TWR) [4]. Kuldip Kumar Shahu et al. Studied the machinability of Al based binary composites reinforced with 5% SiC and Al based Hybrid Composite reinforced with 5% SiC, 1% and 2% graphite powder have been studied by considering the effect of process parameters such as speed, feed, depth of cut and composition of material. The multi-objective optimization has been carried out using grey relational based Taguchi method [5]. Shailesh Dewangan et.al studied the process of EDM with cylindrical shaped graphite tool electrode and AISIP20 work-piece for obtaining favourable preference measures in surface integrity (surface crack density, white layer thickness and surface roughness) using PCA based grey relational analysis has been selected [6].The original Taguchi method was designed to optimize only a single performance characteristic whereas The Grey relational analysis has been proved to effectively resolve the complicated interrelationships among multiple performance characteristics of the EDM process [7].

The goal of the present study was to determine the optimal machining parameters for maximum MRR and minimum TWR under given machining conditions. The Taguchi method was employed to explain the effect of the machining parameters on the characteristics of the EDM process. Additionally, Grey relational analysis was used to find the optimal machining parameters satisfying the multiple characteristics of the EDM process.

II. EXPERIMENTAL DETAILS

A. Tool Material

In EDM electrode material plays an important role. During study, the electrode material is considered as a variable. In the present study, three different electrodes are used as tool material for machining. The electrode materials used are brass, aluminum, and graphite.

B. Work Material

The chemical composition of the work material EN-31 is shown in Table 1 and whose hardness is 263 BHN. Fig. 1. Shows that workpiece before and after the machining.

TABLE I
COMPOSITION OF EN-31*

Composition	Percentage (Wt. %)
Carbon	1.04
Manganese	0.35
Silicon	0.190
Phosphorus	0.024
Sulphur	0.017
Chromium	1.56
Molybdenum	0.025

*Percentage of composition based on Spectroscopy test.

Fig. 1 Work piece before and after machining

III.RESEARCH METHODOLOGY

The selection of optimum machining parameters in EDM is an important step. Taguchi Optimization technique is single parameter optimization based on the signal to noise ratio [8]. Grey relational analysis is applied to optimize the parameters having multi-responses through grey relational grade. Furthermore, a statistical analysis of variance (ANOVA) is performed to see which process parameters are statistically significant. The steps involved are:

A. Selection Of Process Parameters and Response

From literature review it has been exposed that, the material removal rate, tool wear rate; plays important role in any EDM work piece. Therefore the choice of optimized cutting parameters is very necessary for controlling the required surface quality. Hence the design optimization of the machining parameters that is peak current, type of electrode material and pulse on time based on the Grey Taguchi technique is adopted for higher MRR and less TWR in an EDM operation. The process parameters and levels chosen for the experiments are shown in Table 2.

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TABLE II
LEVEL VALUES OF INPUT FACTORS

Control Factors, Units	I Level	II Level	III Level
Peak Current (I_p) Amp	5	10	15
Pulse on Time (T_{on}) µsec.	500	1000	1500
Electrode Material	Brass	Aluminium	Graphite

B. Design of experiment

Experiments are performed, randomly, according to the L_9 OA created by Minitab-17 software on EN-31. For each experiment, a separate electrode is selected as per the L_9 OA. The machining time is 10 minutes for every experiment. The machining time is noted from the timer of the machine. The electrode wear rate is calculated by weight difference between the electrodes using an automatic weighing machine with 300g capacity with a precision of 10mg. The observations along with the details of the values of various parameters for evaluating TWR, MRR based on the L_9 OA are shown in Table 3.

TABLE III
DESIGN OF EXPERIMENT

S.No.	Peak Current	Pulse on Time	Electrode Material
1	5	500	Brass
2	10	1000	Graphite
3	15	1500	Aluminium
4	5	1000	Aluminium
5	10	1500	Brass
6	15	500	Graphite
7	5	1500	Graphite
8	10	500	Aluminium
9	15	1000	Brass

IV. RESULT AND DISCUSSION

A. Observation and Calculation for MRR and TWR

Experimental results are represented by Table IV. After the experimental procedure, different response factors like MRR, TWR calculated from the observed data. Calculated data is represented by table V. The MRR is defined as the ratio of the difference in weight of the work piece before and after machining to the machining time. MRR is given by equation-1.

$$MRR = \frac{W_{jb}-W_{ja}}{t} \text{ -- } (1)$$

TWR is expressed as the ratio of the difference of weight of the tool before and after machining to the machining time. TWR is given by equation-2

$$TWR = \frac{W_{tb}-W_{ta}}{t} \text{ -- } (2)$$

TABLE IV
EXPERIMENTAL RESULT OF EDM

S.NO.	Peak Current	Pulse on Time	TOOL MATERIAL	W_{jb}	W_{ja}	W_{tb}	W_{ta}
1	5	500	Brass	290.25	289.5	40.04	39.52
2	10	1000	Graphite	267.00	264.13	10.92	10.74
3	15	1500	Aluminium	263.24	263.14	22.56	22.53
4	5	1000	Aluminium	289.50	288.41	22.66	22.56
5	10	1500	Brass	264.13	263.24	39.52	38.00
6	15	500	Graphite	263.14	259.47	10.69	10.61
7	5	1500	Graphite	288.41	284.23	10.74	10.69
8	10	500	Aluminium	282.51	281.40	22.53	22.35
9	15	1000	Brass	284.23	282.51	38.00	36.14

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TABLE V
CALCULATED MRR AND TWR

Experiment Number	MRR (g/min)	TWR (g/min)
1	0.0750	0.0520
2	0.2870	0.0180
3	0.0100	0.0030
4	0.1090	0.0100
5	0.0890	0.1520
6	0.3670	0.0080
7	0.4180	0.0050
8	0.1110	0.0180
9	0.1720	0.1660

B. Calculation of the Normalized value of S/N ratio

In this step of the grey relational analysis, pre-processing of the data was first performed for normalizing the raw data for analysis. This is shown in Table-VI, Y_i, X_i is normalized by the following formula to avoid the effect of adopting different units and to reduce the variability. The normalized output parameter (MRR) corresponding to the larger-the-better criterion can be expressed by equation-3.

$$X_i(k) = \frac{x_i(k) - \min x_i(k)}{\max x_i(k) - \min x_i(k)} \text{ -- (3)}$$

Then for the output parameters (TWR), which follow the lower-the-better criterion can be expressed by equation-4.

$$Y_i(k) = \frac{\max y_i(k) - y_i(k)}{\max y_i(k) - \min y_i(k)} \text{ -- (4)}$$

Where

$x_i(k)$, $X_i(k)$ & $y_i(k)$, $Y_i(k)$ are the sequence after the data preprocessing and comparability sequence respectively, k=1;i=1, 2, 3…, 9 for experiment numbers 1 to 9.

TABLE VI
NORMALIZED VALUE FOR MRR AND TWR

Expt. No.	Normalized MRR (X_i)	Normalized TWR (Y_i)
Reference Sequence	1.0000	1.0000
1	0.1593	0.6994
2	0.6789	0.9080
3	0.0000	1.0000
4	0.2426	0.9571
5	0.1936	0.0859
6	0.8750	0.9693
7	1.0000	0.9877
8	0.2475	0.9080
9	0.3971	0.0000

C. Calculation Of Deviation Sequence

The grey relational coefficient is calculated to express the relationship between the ideal (best) and actual normalized experimental results. Before that the deviation sequence for the reference and comparability sequence were found out. These are given in Table VI and the grey relational coefficient is given in Table VII the deviation sequence can be expressed by equation-5.

$$\Delta_{oi} = |x_o^*(k) - x_i^*(k)| \text{ -- (5)}$$

Where Δ_{oi} is the deviation sequence of the reference sequence $x_o^*(k)$ and the comparability sequence $x_i^*(k)$ and comparability value is taken as 1 for all the experiments

TABLE VII
DEVIATION SEQUENCE FOR MRR AND TWR

DEVIATION SEQUENCES	Δ_{0i}(MRR)	Δ_{0i}(TWR)
Exp. No. 1	0.8407	0.3006
Exp. No. 2	0.3211	0.0920
Exp. No. 3	1.0000	0.0000
Exp. No. 4	0.7574	0.0429
Exp. No. 5	0.8064	0.9141
Exp. No. 6	0.1250	0.0307
Exp. No. 7	0.0000	0.0123
Exp. No. 8	0.7525	0.0920
Exp. No. 9	0.6029	1.0000

D. Calculation Of Grey Relational Coefficient And Grade

After data pre-processing is carried out, a grey relational coefficient can be calculated with the pre-processed sequence. It expresses the relationship between the ideal and actual normalized experimental results. The grey relational coefficient is defined as follows by equation-6.

$$\xi_i(k) = \frac{\Delta\min - \xi\Delta\max}{\Delta_{0i}(k) - \xi\Delta\max} \text{ -- (6)}$$

Where Δ_{oi} (k) is the deviation sequence of the reference sequence x*(k) and the comparability sequence is xi*(k), ξ distinguishing or identification coefficient. If all the parameters are given equal preference & taken as 0.5 [9].The grey relational coefficient for each experiment of the L_9 OA can be calculated using equation and same is expressed in Table VII. After obtaining the grey relational coefficient, the grey relational grade is computed by averaging the grey relational coefficient corresponding to each performance Characteristic. The overall evaluation of the multiple performance characteristics is based on the grey relational grade that is given by equation-7 [10].

$$\gamma_i = \frac{1}{n}(\xi_{i\,MRR} + \xi_{i\,TWR}) \text{ -- (7)}$$

Where i_{th} the grey relational grade for the i_{th} experiment and n is the number of performance characteristics which is taken as 2 for MRR and TWR, Table VIII shows the grey relational grade for each experiment using L_9 OA. The higher grey relational grade represents that the corresponding experimental results are closer to the ideally normalized value. Experiment 1 has been multiple performance characteristics among nine experiments because it has the highest grey relational grade. It can be seen that in the present study, the optimization of the complicated multiple performance characteristics of EDM of EN-31 has-been converted into optimization of a grey relational grade.

E. Calculation of Main effect and ANOVA

Since the experimental design is orthogonal, it is then possible to separate out the effect of each machining parameter on the grey relational grade at different levels 1, 2 and 3 can be calculated by averaging the grey relational grade for the experiment 1 to 3, 4to 6 and 7 to 9 as respectively as shown in Table 9.

TABLE VIII
GREY RELATIONAL COEFFICIENT AND GRADE

Expt. No.	Grey Relational Coefficient		Grey Relational Grade $\gamma_i = \frac{1}{n}(\xi_{i\,MRR} + \xi_{i\,TWR})$	Rank
	$\xi_{i\,TWR}$	$\xi_{i\,TWR}$		
1	0.3729	0.6245	0.4987	7
2	0.6090	0.8446	0.7268	3
3	0.3333	1.0000	0.6667	4
4	0.3977	0.9209	0.6593	5
5	0.3827	0.3536	0.3682	9
6	0.8000	0.9422	0.8711	2
7	1.0000	0.9760	0.9880	1
8	0.3992	0.8446	0.6219	6
9	0.4533	0.3333	0.3933	8

TABLE IX
Response Table For Grey Relational Grade

SYMBOL	MACHINING PARAMETERS	GREY RELATIONAL GRADE			MAIN EFFECT (MAX-MIN)	RANK
		LEVEL 1	LEVEL 2	LEVEL 3		
A	Current	-3.255*	-5.192	-4.275	1.9370	2
B	T-On	-3.789*	-4.832	-4.102	1.043	3
C	Material	-3.755	-7.609	-1.358*	6.251	1
TOTAL MEAN VALUE OF THE GREY RELATIONAL GRADE γ_m=-4.2407 * Levels of optimum grey relational grade						

The mean of the grey relational grade for each level of the other machining parameters namely Peak current, pulse on time and electrode material can be computed in the same manner. The mean of the grey relational grade for each level of the machining parameters is summarized and shown in Table IX. In addition, the total mean of the grey relational grade for the nine experiments is also calculated and presented in Table IX.

Fig.2. shows the grey relational grade obtained for different process parameters. The mean of the grey relational grade for each parameter is shown by a horizontal line. Basically, the larger the grey relation grade is, the closer will be the product quality to the ideal value. Thus, the larger grey relational grade is desired for optimum performance. Therefore, the optimal parameters setting for better MRR and lesser TWR are (A1B1C3) as presented in Table IX. The optimal level of the process parameters is the level with the highest grey relational grade.

Furthermore, ANOVA has been performed on grey relational grade to obtain contribution of each process parameter affecting the two process characteristics jointly and is discussed in the forthcoming section ANOVA for a grey relational grade is presented in Table X. Percentage contributions for each term affecting grey relational grade are shown in Fig.3. Fig.3 clearly shows that electrode material is the dominant parameter that affects grey relational grade and hence contributes in improving MRR and reducing TWR It can be seen from Figures 2 and 3 that electrode material is the most significant factor that affects the grey relational grade.

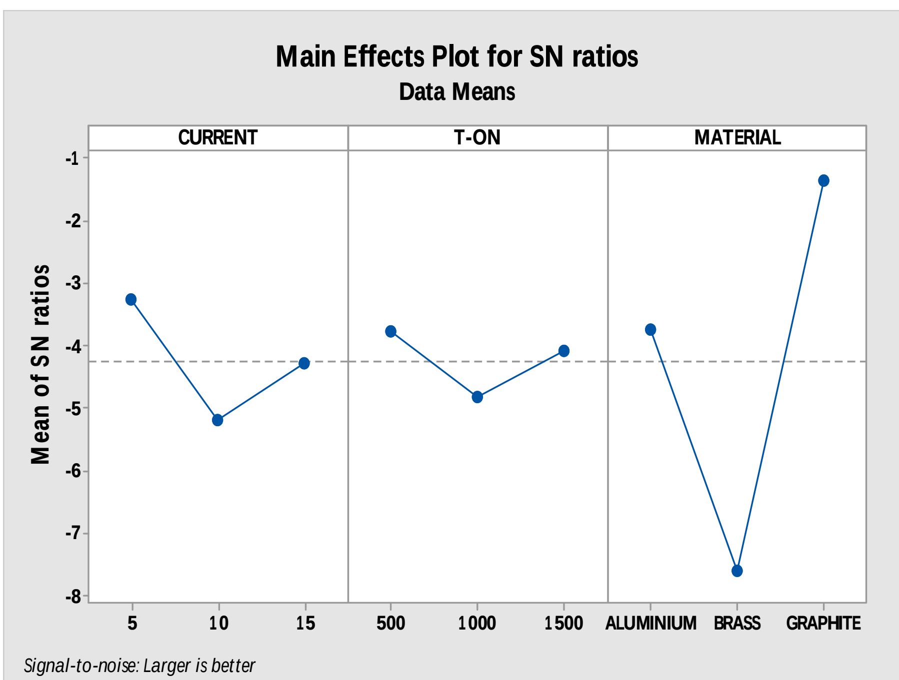

Fig. 2 Main effect plot

TABLE X
ANALYSIS OF VARIANCE FOR GREY RELATIONAL GRADE

Parameter	DOF	Sum of Squares	Adj SS	Mean Squares	F ratio	P	PERCENTAGE CONTRIBUTION
Current	2	5.6321	5.6321	2.816	18.83	0.05	8.37%
T-on	2	1.7177	1.7177	0.8588	5.74	0.148	2.55%
material	2	59.6744	59.6744	29.8372	199.56	0.005	88.64%
residual error	2	0.299	0.299	0.1495			0.44%
Total	8	67.3232					100.00%

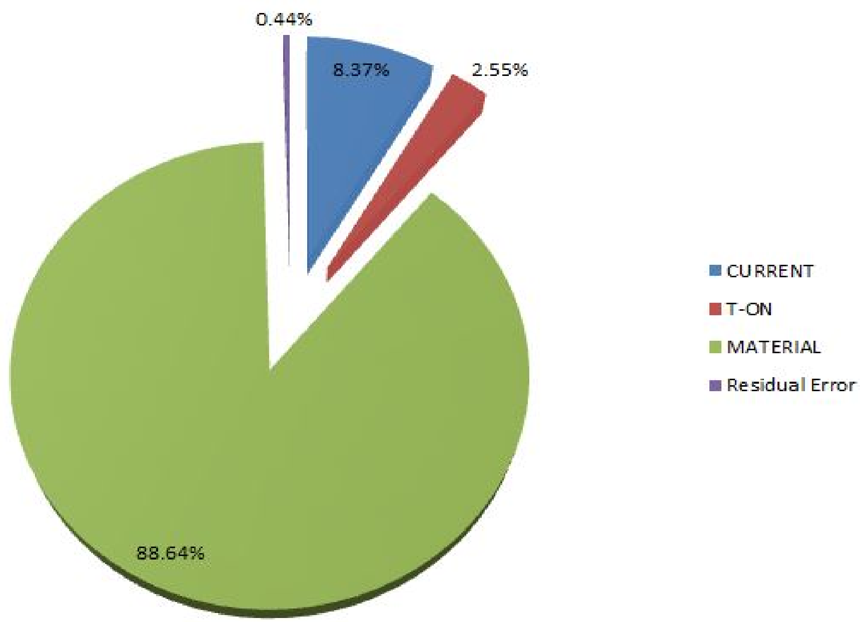

Fig. 3 Percentage contribution of parameters

V. CONFIRMATION TEST

Confirmation test has been carried out to verify the improvement of performance characteristics (MRR & TWR) in EN-31 using EDM the optimum parameters are selected for confirmation test as represented in Table XI

TABLE XI
Theoretical And Grey Optimal Level

CONDITION DESCRIPTION	OPTIMAL MACHINING PARAMETERS	
	MACHINING PARAMETERS IN THE SEVENTH TRIAL OF OA	GREY THEORY PREDICTION DESIGN
LEVEL	A1B3C3	A1B1C3
MRR (g/min)	0.4180	0.4863
TWR (g/min)	0.0050	0.0023

Table XI which shows the comparison of the experimental results using the initial (OA, A1B3C3) and optimal (grey theory prediction design, A1B1C3) machining parameters.

Based on Table, MRR is accelerated from 0.4180 to 0.4863g/min; the TWR is decreased from 0.0050 to 0.0023 g/min. The corresponding improvements in MRR and TWR are 14.04% and 54% respectively. It is clearly shown that the multiple performance characteristics in the EDM process are greatly enhanced through this study.

VI. CONCLUSION

The GRA based on the Taguchi method's response table has-been proposed as a way of studying the optimization of EDM process parameters for EN-31. The optimal machining parameters have been determined by the grey relational grade for Multiperformance characteristics that are MRR and TWR. Nine experimental runs based on OA's have been performed. The following conclusions can be drawn from this study.

A. The work has successfully evaluated the feasibility of EDM of EN-31.

B. From the response table of the average (variance) grey relational grade, it is found that the largest value of grey relational grade for discharge current and pulse on time are 5A, 500µs and tool material for this experiment is graphite, respectively. These are the recommended levels of controllable process factors when better MRR and lesser TWR are simultaneously obtained.

C. The ANOVA of the grey relational grade for multi-performance characteristics reveals that the electrode material and current are the most significant parameter.

D. Based on the confirmation test, the improvements in MRR and TWR are 14.04% and 54% respectively.

It is shown that the performance characteristics of the EDM process such as MRR and TWR are improved together by using the method proposed by this study. The effectiveness of this approach has been successfully established by validation experiment.

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