OPTIMIZATION OF MULTI PERFORMANCE CHARACTERISTICS IN ELECTRO DISCHARGE MACHINING OF OHNS TOOL STEEL USING GREY RELATIONAL ANALYSIS

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Abstract— Electro-Discharge Machining is one of the non-traditional machining processes used to produce critical shape on hard or brittle conductive materials and it can also be successfully applied on materials that are extremely difficult-to-machine using traditional machining processes. OHNS-O2 tool steel has growing range of applications in industries which offer difficulty in conventional machining in hardened condition. Influence of various process parameters on material removal rate, tool wear rate and surface roughness has been investigated during EDM of OHNS-OS tool steel using graphite electrode. The experimental study evaluates the influence of discharge current, gap voltage, pulse on time and pulse off time on machining of OHNS-O2 tool steel. Discharge current and pulse on time affects the most for machining and the performance characteristics. To optimize process parameters in terms of multi performance characteristics of material removal rate, tool wear rate and surface roughness, the grey relation analysis along with Taguchi approach, which is known as Grey-Taguchi method has been employed. The confirmation experiments have been performed to check the validity of grey-Taguchi method. All this experimental observations and subsequent data analysis study assures that GRA method is a powerful and most versatile tool which can manipulate the input data as per requirement and comes with results that can be used to have best multi performance in respective concerns.

Keywords: Electro-Discharge Machining, OHNS-O2, Taguchi, Grey Relational Analysis

1. INTRODUCTION

In today´s world manufactured product are not only required in time but they are also required with high precision and quality at the same time. There is a growing trend to use light, slim and compact mechanical components in recent years. Recent years have increased interest in development of new generation manufacturing techniques to fit the demands of industries. Advanced materials having high hardness, temperature resistance, and high strength to weight ratio are used in mould and die making industries, aerospace component, medical appliance and automotive industries [1]. There is a heavy demand for new manufacturing technologies to meet with productivity and accuracy requirements with these materials. Unconventional machining process are used when no other traditional machining process can meet the necessary requirements efficiently and economically [4]. The traditional processes are unable to cope up with these challenges.

Electrical discharge machining is one of the most extensively used non-conventional material removal processes [2]. Electrical Discharge Machining has been a mainstay manufacturing process providing unique capabilities to machine “difficult to machine” materials with desired shape, size and required dimensional accuracy. It is the most widely and successfully applied non-traditional machining process for various work piece materials in the said advanced industries. According to the survey of Fallbohmer almost 90% of mould and die makers employed EDM process to finish the products in USA, Germany, and Japan [3].

EDM is a thermal process were material is removed by heat. Heat is allowed to flow between the electrode and work piece in the form of spark. This spark removes the material and increases distance between the work piece and electrode. The area heated by each spark is very small so the dielectric fluid quickly cools the vaporized material and the electrode and work piece surfaces. To maintain sparking gap dielectric fluid is used. Dielectric fluid used is DNR spark SPO-A. For controlling the sparking gap spacing between electrode and work piece, cooling the heated material and removing the EDM chips from the sparking zone dielectric fluid is used [5].

Literature review provides the scope for the present study. Some of the literature review is discussed below as different researchers did various investigations about EDM. The results are summarizes as follows:

Rajesh Khanna et al. [1] studied the response variables material removal rate and tool wear rate correlate the machining parameters such as a pulse on-time, pulse off-time, and water pressure, in the Electro discharge machining of drilling process of Al-7075. Brass rod of 2 mm diameter was selected as a tool electrode. An experimental plan was planned based on Taguchi method. The optimization results showed that the combination of maximum pulse on-time and minimum pulse off-time gives maximum MRR. Tool wear rate was most significantly affected by pulse on-time, pulse off-time. Multi-quality characteristics for the same material considering material removal rate and tool wear rate were given as under by Taguchi grey relational analysis. The predicted value of grey relational grade is 0.685120. The experimental value at the optimal setting was observed to be 0.0359 mm^3/min and 0.252 g/s for MRR and TWR.

Jong Hyuk Jung et al. [2] studied optimal machining conditions for drilling of a micro-hole of minimum diameter and maximum aspect ratio. The Taguchi method was employed to determine the relations between the machining parameters and the process characteristics. The electrode wear and the entrance and exit clearances had a significant effect on the diameter when the diameter of the electrode is identical of the micro-hole. Grey relational analysis was used to determine the machining parameters affecting the electrode wear and the entrance and exit clearances. Input voltage and the capacitance were found the most significant controlling parameters. A micro-hole of 40μm average diameter and an aspect ratio of 10 could be machined under these conditions.

Yan-Cherng Lin et al. [3] investigated a novel process of magnetic-force-assisted electrical discharge machining. MRR of the magnetic-assisted EDM were found nearly three times compared to conventional EDM, and the Ra was less than that of conventional EDM. The machined surface was found smoother than conventional EDM and surface crack were reduced in magnetic-force-assisted EDM process. ANOVA results indicated that the peak current, pulse duration, and no load voltage were the significant machining parameters that obviously affected the multiple performance characteristics in the magnetic-force-assisted EDM process.

T. M. Chenthil Jegan et al. [4] used Grey relational analysis to optimize the machining parameters and applied to find Grey grade and it was used to represent the multi objective model. Workpiece was taken as AISI 202 Stainless Steel and copper as electrode. Machining parameters were selected as discharge current, pulse on time, pulse off time to measure the response performance of MRR and Ra. Design of experiment was designed with three level and L27 array was selected. GRA was used to convert multi response optimization model to single response relational grade. Optimal machining parameters were determined by grey relational grade obtained from the grey relational analysis for multi performance characteristics. Optimal machining performance for both surface roughness and material removal rate was obtained for current (Level 3), pulse on time (Level 2), pulse off time (Level 2). Result showed that discharge current was main parameter affecting MRR.

Mohit Tiwari et al. [5] investigated the optimal process parameters for maximum material removal rate and minimum tool wear rate for carbon fiber epoxy composites with copper cadmium tool by using GRA method. Peak current was found to be most significant towards MRR and TWR. Contour plot showed the maximum and minimum value of GRG with dark green and dark blue portion. Optimal combination of process parameters based on grey relational analysis for maximum MRR and minimum TWR were current of 1 amp, gap voltage of 60 volt, pulse-on-time of 150 micro seconds and duty cycle of 0.4.

Subhakanta Nayak et al. [6] discussed the application of the Taguchi method to optimize the process parameters for machining of tungsten carbide in electro-discharge machining for individual responses such as material removal rate, electrode wear rate and surface roughness. A grey relational analysis of the experimental results of MRR, EWR and surface roughness can convert optimization of a single performance characteristic called the grey relational grade. As a result, optimization of the complicated multiple performance characteristics were greatly simplified through this approach. Result showed that the performance characteristics of the EDM process such as MRR, EWR and surface roughness are improved together by using this approach.

Mr. Anand. N. Nikalje et al. [7] investigated the influence of process parameters on the machining of AISI O2 OHNS tool steel. Objective of this work was to find out the effect of process parameters on MRR, EWR, Micro hardness and surface roughness during EDM. Result showed the same optimal combination for the MRR and EWR. Current has the large impact on the material removal rate and electrode wear rate. Micro hardness depends on the duty cycle. To obtain the high value of material removal rate for OHNS tool steel, within the work interval one should use the high value of intensity and duty cycle.

K. Saraswathamma et al. [8] studied the effect of machining parameters on response parameters on machining of OHNS tool steel using a statistical design of experiments. Analysis of variance was used to find out the contribution of each parameter affecting the improvement in material removal rate and tool wear rate. Result showed that with increase in current and pulse on time, MRR and TWR also increase.

S Gopalakannan et al. [9] studied recent advanced material metal matrix composites of aluminium 7075-B4C using RSM methodology. Analysis of variance was used to study the influence of process parameters and their interactions on response parameters. Optimal parameters were found out to be voltage 49.02 volts, pulse current 14 amp, pulse on time 7.77 micro seconds and pulse off time to be 5 micro seconds for maximum MRR and minimum EWR and SR. the higher the pulse off time offers the lowest electrode wear rate.MRR is affected by the pulse current and pulse on time. Ra decreases up to 50 volt and increase with increase in pulse current and pulse on time.

R. Rajesh et al. [10] used genetic algorithm to optimize the machining parameters of aluminium alloy with grade HE9 by using the empirical models. Empirical models for material removal rate and surface roughness have been developed by conducting a designed experiment based on the GRA. In this paper a practical method for EDM based on multiple regression models and GA are presented. Optimal conditions obtained by genetic algorithm were current at 3 amp, voltage at 78 V, gap at 0.35, flow rate at 1, pulse on time at 1 and pulse off time at 8 for maximum MRR and minimum SR. Most influencing factor was found to be current for the EDM process.

2. EXPERIMENTAL DETAILS

Experiments were conducted on ENC Electrical Discharge Machine 5030.

2.1 Work piece material

The working material use in this study was OHNS O2, widely used in the tool and die industry. OHNS O2 is an Oil Hardened Non Shrinkage Tool Steel, characterized by its characteristics of offering good durability, excellent wear resistance and its ability to hold a good cutting edge. OHNS also has equivalent names as AISI O2 and DIN 1.2842 [7]. Due to its high strength it cannot be easily machined by conventional machining process. Table 2.1 gives the chemical composition of OHNS O2.

Table 2.1 Chemical composition of OHNS O2 Tool Steel

Element	**C**	**Si**	**Mn**	**P**	**S**	**Cr**	**V**	**Fe**
Composition by weight %	0.87	0.31	1.52	0.024	0.022	0.072	0.08	Balance

For experimentation one piece of 130 × 50 × 10 mm dimensional was used for machining with graphite electrode. Machining was carried out for 3 mm depth for each experiment. Before experimentation, the workpiece top and bottom faces were ground to a good surface finish using a surface grinding machine [11]. Table 2.2 enumerates the properties of workpiece material.

Table 2.2 Properties of OHNS O2 Tool Steel

Property	**Value**	**Unit**
Density	7.85	g/cm^3
Thermal Conductivity	30	w/mk
Electrical Resistivity	0.35	Ω mm^2 / min
Specific Heat Capacity	0.46	J/g K
Elastic Modulus	190-210	Gpa
Tensile Strength	965-1030	Mpa
Compressive Strength	862	Mpa
Hardness, Rockwell C	30	HC

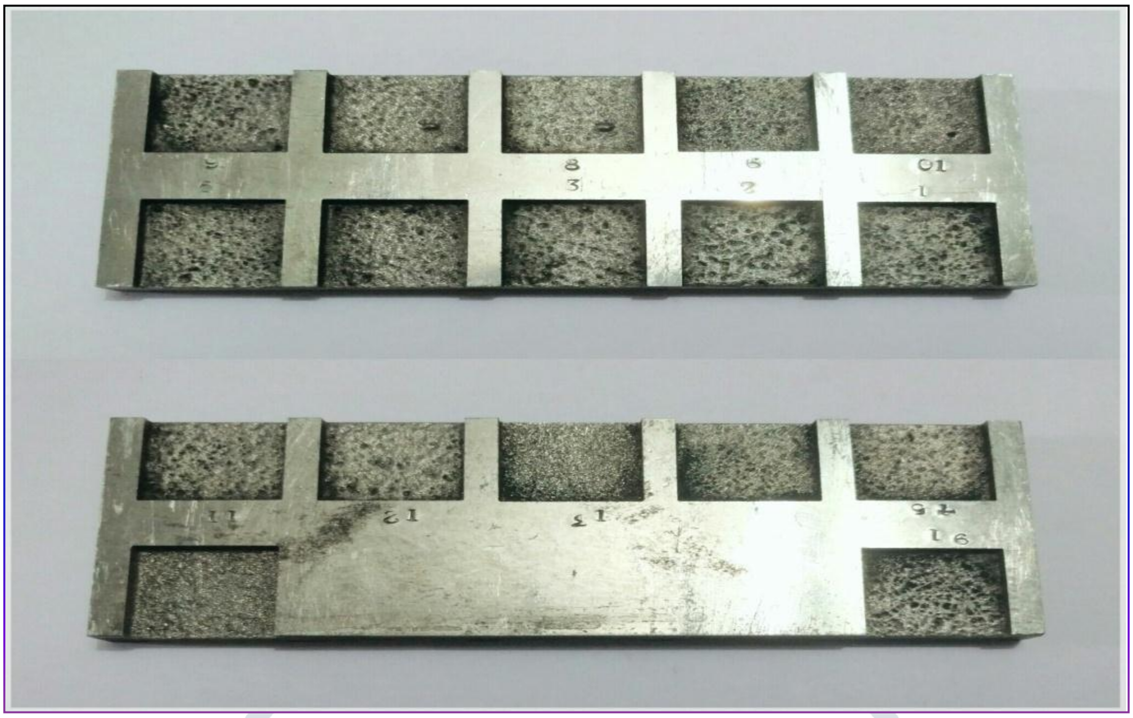

Figure 2.1 Photographic view of workpiece after machining

2.2 Electrode material

Graphite electrode is 90% used in all sinkers EDM application. Graphite is made from carbon derived from petroleum. Graphite has lower mechanical strength then the other metallic electrode materials. It also has a high melting point. Due to significant difference between metallic electrodes and graphite, there are certain properties unique to graphite. Smaller the particles size better is the resulting surface finish. Higher density material is used as it is a porous material. Smallest particle size highest is the flexural strength. Graphite is faster than copper in both roughing and finishing [12]. This electrode is recommended for application which requires taper cavities, blind cavities requiring sharp corners, engraving, moulds and dies, small hole drilling, machining of carbides and aerospace applications. This electrode was selected for its speed; wear and surface finish [13]. Figure 2.2 shows photograph of graphite electrode.

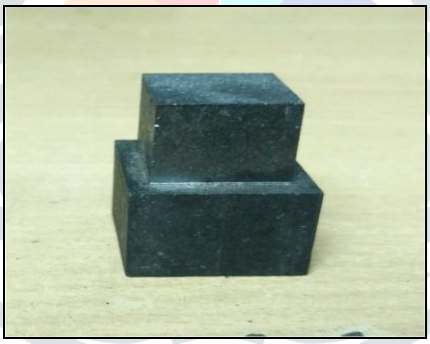

Figure 2.2 Photographic view of Graphite electrode

It is a square section having electrode face size of 20 × 20 mm in dimensions which is used for experimentation. Electrode was prepared by keeping minus 0.05 microns to actual required size. Properties of graphite electrode are tabulated in Table 2.3

Table 2.3 Properties of Graphite electrode

Properties	Value	Unit
Density	1.811	g/cm^3
Melting Point	3350	Degree Celcius
Average Particle Size	5	µm
Electric Resistivity	14	µΩcm
Thermal Conductivity	160	W/mk
Hardness	10	HB
Flexural Strength	76	Mpa
Specific Heat	0.17-0.2	cal/g°C

2.3 Process parameters and range

Process parameters for this work are selected as discharge current, gap voltage, pulse on time and pulse off time. Many researchers have considered these parameters for analysis and optimization in spark erosion machining method along with other parameters. The levels for the process parameters were selected based on the literature review. Four levels of each process parameters were selected as the non-linear behavior of a process parameter can be studied if more than two levels are used. Ranges of the process parameters were decided as per the literature review, practical manual, experienced person from industry and set up range available on machine and its capability. All the parameters were varied for the four levels each. The levels and ranges of the parameters along with the units are shown in Table 2.4

Table 2.4 Machining parameters and their level

Sr.No	Parameter	Unit	Level 1	Level 2	Level 3	Level 4
A	Discharge Current	A	4	6	8	10
B	Gap Voltage	V	20	30	40	50
C	Pulse ON Time	μs	8	11	17	29
D	Pulse OFF Time	μs	3	5	7	9

2.4 Characterization of machining performance

The machining performance of the electric discharge machining process was characterized with the following performance parameters.

2.4.1 Material removal rate

Material removal rate is a performance measure for the erosion rate of the work piece and is typically used to quantify the speed at which machining is carried out. It is expressed as the volumetric amount of work piece material removed per unit time.

$$MRR = \frac{(W_i - W_f) \times 1000}{(\rho \times t)} mm^3/min$$

Where,
W_i – Initial weight of work piece (gm)
W_f – Final weight of work piece (gm)
t – Period of trial (min)
ρ – Density of work piece material (gm/cm^3)

2.4.2 Tool wear rate

Tool wear rate is a performance measure for the erosion rate of the tool electrode and is a factor commonly taken into account when considering the geometrical accuracy of the machined feature. It is expressed as the volumetric amount of tool electrode material removed per unit time.

$$TWR = \frac{(W_i - W_f) \times 1000}{(\rho \times t)} mm^3/min$$

Where,
W_i – Initial weight of tool (gm)
W_f – Final weight of tool (gm)
t – Period of trial (min)
ρ – Density of tool material (gm/cm^3)

2.4.3 Surface roughness

Surface roughness is an important output performance in EDM which is influences the product quality and cost. Ra is a classification of surface parameter used to describe an amplitude feature, which translates to roughness of the surface finish. Of the many parameters available to quantify Ra, the most commonly used in EDM are arithmetical mean surface roughness (*Ra*). Surface roughness is measured by surface roughness tester.

3. DESIGN OF EXPERIMENT

Design of experiment is done with Taguchi method as it is powerful technique for the design of a high quality system. To optimize designs for performance and quality, Taguchi is best possible tool to use for design as it reduces the experiments as well as it is efficient and a systematic approach. The objective of the method is to produce better quality product at minimum cost to the manufacturer. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varied; it allows for the collection of the necessary data to determine which factors most affect product quality with a minimum amount of experimentation, thus saving time and resources [14]. Orthogonal arrays are widely used in design of experiments. Orthogonal array provide a set of well-balanced objective functions for optimization, it helps in data analysis and predication of optimum results [15]. In this method responses are represented by S/N ratio. These are logarithmic function of desired output and served as objective function in the optimization process. There are three types of S/N ratio lower the better, higher the better and normal the better.

The S/N ratio η is expressed in logarithmic decibel scales as;

$$S/N = -10log\frac{1}{n}\sum_{i=1}^{n} y_i^2 \quad \text{– for lower the better characteristics}$$

$$S/N = -10log\frac{1}{n}\sum_{i=1}^{n} \frac{1}{y_i^2} \quad \text{– for higher the better characteristics}$$

$$S/N = -10log\frac{1}{ns}\sum_{i=1}^{n} y_i^2 \quad \text{– for normal the better characteristics}$$

Based on the number of control factors and levels of variation for each parameter, L16 orthogonal array is selected to design the experiments as shown in Table 5. Some parameters were kept constant. Bi pulse current at 2 ampere, sparking time as 2, lift time of quill while sparking as 0.2, sensitivity at 40 and flushing pressure 5 kg/cm^2 were kept constant throughout the experimental plan. The operation was stopped and the workpiece and electrode was removed from the machine. Machining time was noted using a digital stopwatch to evaluate MRR and TWR. At the end of each experiment, the workpiece and electrode were removed and weighed using the electronic weighing machine.

Table 3.1 Experimentation results after machining

Expt. No	I_P (A)	V_g (V)	T_{ON} (µs)	T_{OFF} (µs)	MRR (mm^3/min)	TWR (mm^3/min)	Ra (µm)
1	4	20	8	3	5.52803	0.23860	8.068
2	4	30	11	5	5.42611	1.50277	7.537
3	4	40	17	7	7.16433	1.10436	8.154
4	4	50	29	9	8.57598	0.54232	8.151
5	6	20	11	7	10.31177	1.45311	6.106
6	6	30	8	9	8.20203	1.16249	7.054
7	6	40	29	3	12.65823	0.90865	9.126
8	6	50	17	5	8.28026	1.60635	7.948
9	8	20	17	9	35.31737	0.76163	8.476
10	8	30	29	7	31.33758	2.20872	9.106
11	8	40	8	5	8.10654	1.90754	7.422
12	8	50	11	3	6.52636	1.80059	6.999
13	10	20	29	5	55.85987	0.55218	11.204
14	10	30	17	3	30.87299	0.64963	9.821
15	10	40	11	9	18.58508	1.18325	8.162
16	10	50	8	7	9.52814	1.57766	7.467

4. METHODOLOGY

Grey relational grade is employ to convert multi objective problem into a single objective. The scope of this study is to identify the optimal combination of process parameters that concurrently minimize the surface roughness, tool wear rate and maximize the material removal rate. In grey relational analysis, the first step is data pre-processing. This avoids the problem of different scales, units and targets. The following steps are in GRA:

Step 1. Normalization

Experimental data will be converted to S/N ratio then it was normalized in the range between zero and one.

Higher-the-better quality characteristics is used for material removal rate to normalize the original sequence by using the following equation,

$$X_i^*(k) = \frac{Y_i(k) - \min Y_i(k)}{\max Y_i(k) - \min Y_i(k)}$$

Lower-the-better quality characteristics is used for tool wear rate and surface roughness to normalize the original sequence by using the following equation,

$$X_i^*(k) = \frac{\max Y_i(k) - Y_i(k)}{\max Y_i(k) - \min Y_i(k)}$$

Here, min $Y_i(k)$ is smallest value of $Y_i(k)$ and, max $Y_i(k)$ is largest value of $Y_i(k)$ for k^{th} response. $X_i^*(k)$ is a normalized comparability sequence.

Step 2. Determination of deviation sequence

The deviation sequence $\Delta_{0i}(k)$ is the absolute difference between the reference sequence $X_0^*(k)$ and the comparability sequence $X_i^*(k)$ after normalization. The value $X_0^*(k)$ was considered as 1.

$$\Delta_{0i}(k) = ||x_0^*(k) - x_i^*(k)||$$

Normalized value and deviation sequence is calculated and tabulated in Table 4.1

Table 4.1 Normalized value and deviation sequence

Expt. No	Normalized Value of S/N Ratio			Deviation Sequence		
	MRR	TWR	Ra	MRR	TWR	Ra
1	0.00798	**0.00000**	0.45903	0.99202	**1.00000**	0.54097
2	**0.00000**	0.82695	0.34688	**1.00000**	0.17305	0.65312
3	0.11918	0.68853	0.47650	0.88082	0.31147	0.52350

4	0.19632	0.36896	0.47589	0.80368	0.63104	0.52411
5	0.27537	0.81185	**0.00000**	0.72463	0.18815	**1.00000**
6	0.17720	0.71158	0.23777	0.82280	0.28842	0.76223
7	0.36330	0.60088	0.66203	0.63670	0.39912	0.33797
8	0.18127	0.85690	0.43436	0.81873	0.14310	0.56564
9	0.80337	0.52156	0.54030	0.19663	0.47844	0.45970
10	0.75209	**1.00000**	0.65843	0.24791	**0.00000**	0.34157
11	0.17217	0.93412	0.32154	0.82783	0.06588	0.67846
12	0.07918	0.90820	0.22487	0.92082	0.09180	0.77513
13	**1.00000**	0.37706	**1.00000**	**0.00000**	0.62294	**0.00000**
14	0.74569	0.45009	0.78295	0.25431	0.54991	0.21705
15	0.52802	0.71953	0.47811	0.47198	0.28047	0.52189
16	0.24148	0.84880	0.33150	0.75852	0.15120	0.66850

Step 3. Determination of grey relational coefficient

The grey relational coefficient $\xi_i(k)$ for the k^{th} response characteristics in the i^{th} experiment can be expressed as;

$$\xi_i(k) = \frac{\Delta_{min} + \mu\,\Delta_{max}}{\Delta_{0i}(k) + \mu\,\Delta_{max}}$$

Where,

Δ_{min} is the smallest value of $\Delta_{0i}(k)$ and Δ_{max} is the largest value of $\Delta_{0i}(k)$.

$$\Delta_{0i}(k) = \Delta_{min} = \min||x_0^*(k) - x_i^*(k)|| = ||1-1|| = 0$$

$$\Delta_{0i}(k) = \Delta_{max} = \max||x_0^*(k) - x_i^*(k)|| = ||1-0|| = 1$$

Here, μ is the identification coefficient of $0 \leq \mu \leq 1$ and its value is taken as 0.5

$$\xi_i(k) = \frac{\Delta_{min} + \mu\,\Delta_{max}}{\Delta_{0i}(k) + \mu\,\Delta_{max}}$$

Step 4. Determination of grey relational grade

The overall evaluation of the multi-performance characteristics is based on the grey relational grade and it is defined as an average sum of the grey relational coefficients which is defined as follows;

$$Y_i = \frac{1}{n}\sum_{k=1}^{n} \xi_i(k)$$

Where γ_i is grey relational grade; n is the number of performance characteristics. The GRC and corresponding GRG for each experiment for EDM operation are calculated. The value of GRG is near to the product quality for optimum process parameters.

Table 4.2 Grey relational coefficient and grey relational grade

Expt. No	**Grey Relational Coefficient**			**Grey Relational Grade**	**Rank Order**
	MRR	**TWR**	**Ra**		
1	0.33512	0.33333	0.48032	0.3829	16
2	0.33333	0.74289	0.43361	0.5033	11
3	0.36210	0.61616	0.48852	0.4889	13
4	0.38353	0.44207	0.48823	0.4379	15
5	0.40829	0.72658	0.33333	0.4894	12
6	0.37798	0.63418	0.39612	0.4694	14
7	0.43987	0.55610	0.59668	0.5309	9
8	0.37915	0.77748	0.46920	0.5419	7

9	0.71774	0.51102	0.52100	0.5833	4
10	0.66853	1.00000	0.59413	0.7542	2
11	0.37656	0.88358	0.42428	0.5615	5
12	0.35191	0.84487	0.39212	0.5296	10
13	1.00000	0.44526	1.00000	**0.8151**	**1**
14	0.66285	0.47623	0.69730	0.6121	3
15	0.51441	0.64064	0.48929	0.5481	6
16	0.39729	0.76782	0.42790	0.5310	8

5. RESULT AND DISCUSSION

The grey relational grade calculated for each sequence (as shown in Table 4.2) is taken as a response for the further analysis. The larger-the better quality characteristic was used for analyzing the GRG, since a larger value indicates the better performance of the process. The Figure 5.1 shows the main effect plot for grey relational grade.

Optimal condition is predicted from the below graphs of each parameters highest level. Initial condition was A4B1C4D2 for the highest grade i.e, level 4 for discharge current (10 A), level 1 for gap voltage (20 V), level 4 for pulse on time (29 μs) and level 2 for pulse off time (5 μs).

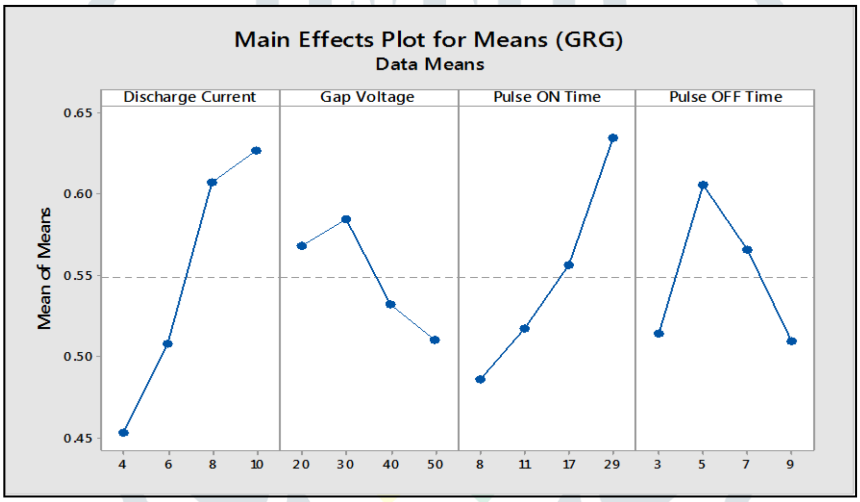

Figure 5.1 Main effects plot for means for GRG

Response table for means of grey relational grade is shown below. ANOVA is used to investigate the parameters that significantly affect the characteristics. An ANOVA Table 5.2 shows the contribution of process parameters that influence the grey relational grade.

Table 5.1 Response table for means of grey relational grade

Level	Discharge Current	Gap Voltage	Pulse ON Time	Pulse OFF Time
1	0.4533	0.5677	0.4862	0.5139
2	0.5079	**0.5848**	0.5176	**0.6054**
3	0.6071	0.5324	0.5566	0.5659
4	**0.6266**	0.5101	**0.6345**	0.5097
Delta	0.1733	0.0746	0.1483	0.0958
Rank	**1**	**4**	**2**	**3**

Discharge current contributes highest then the others with 46.34 % followed by pulse on time with 28.15 %, pulse off time with 14.30 % and gap voltage with 7.82 %. Discharge current and pulse on time is significant parameters, where as gap voltage and pulse off time are insignificant parameters. However the average GRG indicates stronger relationship between them. It indicates the optimal level of process parameters. Optimal condition for the predicted is A4B2C4D2 i.e, level 4 for discharge current (10 A), level 2 for gap voltage (30 V), level 4 for pulse on time (29 μs) and level 2 for pulse off time (5 μs).

Table 5.2 Analysis of variance for grey relational grade

Source	DOF	Adj. SS	Adj. MS	F-Value	P-Value	P %
Discharge Current	3	0.081009	0.027003	13.65	0.030	46.34
Gap Voltage	3	0.013660	0.004553	2.30	0.256	7.82
Pulse ON Time	3	0.049205	0.016402	8.29	0.043	28.15
Pulse OFF Time	3	0.024997	0.008332	4.21	0.134	14.30
Error	3	0.005934	0.001978			3.39
Total	15	0.1748050				100

6. CONFIRMATION TEST

Once the optimum level of machining parameters is selected then the final step is to predict and verify the improvement of the performance characteristics using the optimum level of the machining parameters. The estimated or predicted GRG ($Y_{Predicted}$) at the optimum level of the machining parameter can be calculated by following equation.

$$Y_{Predicted} = Y_m + \sum_{i=1}^{n} (Y_i - Y_m)$$

$$Y_m = \frac{8.7796}{16}$$

$= 0.5487$

Where Y_m is total mean of the grey relational grade, Y_i is the mean of GRG at the optimum level of i^{th} parameter, and n is the number of machining parameters that significantly affect GRG.

$$Y_{Predicted} = 0.5487 + [(0.6266 - 0.5487) + (0.6345 - 0.5487)]$$

$$Y_{Predicted} = 0.7124$$

Table 6.1 Results of confirmation experiment for GRG

	Initial Condition	Optimal Process Parameters	
		Prediction	Experiment
Level	A4B1C4D2	A4B2C4D2	A4B2C4D2
MRR (mm^3/min)	55.85987		60.56340
TWR (mm^3/min)	0.55218		0.62340
Ra (µm)	11.204		11.761
Grey Relational Grade	0.8151	0.7124	0.8227

Improvement of grey relational grade = 0.0076

Percentage Error = [(Predicted GRG / Experimental GRG) × 100] - 100
= [(0.7124/0.8227) × 100] – 100
= 13.40 %

Confirmation was carried out after identifying the optimal combination of process parameters for graphite electrode. Confirmation experiment showed that there is increase in material removal rate, tool wear rate and surface roughness too, wear ratio also increases. For optimal test material removal rate was obtained as 60.56340 mm^3/min, tool wear rate as 0.623409 mm^3/min and surface roughness of 11.761 µm. Grey relational grade is improved by 0.0076 and percentage of error is 13.40 %.

7. CONCLUSION

1. ANOVA for GRG of graphite electrode shows discharge current and pulse on time are most significant parameters and contributes with 46.34 and 28.15 % respectively. Gap voltage and pulse off time are insignificant parameters and contributes 7.82 and 14.30 % respectively.
2. Highest GRG was obtained as 0.8151 at experiment number 13, were material removal rate was 55.85987 mm^3/min, tool wear rate was 0.55218 mm^3/min and Ra value of surface roughness as 11.204 µm respectively.
3. Taguchi method with grey relational analysis was employed to optimize the multi response characteristics of EDM using graphite electrode. The optimal setting combination is found to be A4B2C4D2. The predicted value of GRG is 0.7124. The experimental value at optimal setting is observed as 60.56340 mm^3/min for material removal rate, 0.62340 mm^3/min for tool wear rate and Ra of 11.761 µm for surface roughness respectively. Experimental value of GRG is 0.8227 and improvement in grade is 0.0076. The percentage error between predicted and experimental is 13.40 %, which represents good agreement results.

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