Multi Objective Optimization of Process Parameters of Electro Discharge Machining On Nimonic 80A Using Grey Relational Analysis

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ABSTRACT

Abrasive powder-mixed electrode coated electrical discharge machining (APMEC-EDM), a hybrid manufacturing process involving the use of a dielectric fluid mixed with abrasive powder and coated electrodes, combines the benefits of mechanical and thermal interactions. The aim of this article is to use a new approach of performance evaluation, gray relational analysis (GRA), to evaluate the effectiveness of optimizing multiple performance characteristics of APMEC-EDM of Nimonic80A Super alloy. The considered process parameter includes the five control factors namely pulse current (A), pulse ON time (Ton), pulse off time (Toff), Inter Electrode gap (mm) Aluminum powder concentration (g/L). The combination of L27 orthogonal array design of experiment with GRA enables to determine the optimal parameters for multiple responses. GRA is used to obtain a single performance index, gray relational grade through gray relational coefficient to optimize the APMEC-EDM process with lower tool wear rate, radial overcut, and higher material removal rate.

Keywords: *Electrical Discharge Machining, Gray Relational Analysis, Pulse on Time, Pulse off Time*

1. INTRODUCTION

Discharge Machining Process, which is also called electro-erosion machining process. When the gap voltage is sufficiently large (i.e. reaches the breakdown voltage of dielectric fluid), high power spark is produced, which increase the temperature about 10,000 degrees Celsius. By this way the metal is removed from the work piece [1].A major advantage of EDM is that the tool and the work piece do not come into contact [2]. In this process material is removed by controlled erosion through a series of electric sparks between the tool (electrode) and the work piece. The thermal energy of the sparks leads to intense heat conditions on the work piece causing melting and vaporizing of work piece 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 work piece 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) and Tool wear ratio (TWR). Electric discharge machining (EDM) is a non- traditional machining operating procedure in the manufacture of complex shaped dies, moulds and scathing parts used in automobile, aerospace, surgical and other industrial applications [3] Electrical-discharge machining (EDM) is extensively used for high strength materials. An analysis on the influence of current, Inter Electrode Gap, Pulse Duration and Different Powder Concentrations over MRR, TWR and ROC was performed. NIMONIC is a family of nickel based high-temperature low creep and high performance super alloys. NIMONIC alloys are primarily composed of nickel and chromium. Additives like aluminum, titanium and carbon are infused into alloy. NIMONIC alloys available commercially are NIMONIC 75, NIMONIC 80A, 81, 86, 252, NIMONIC PE11 and 16.

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The NIMONIC 80A has been used as a work piece material for the present experiment. It is a wrought, age-hardened alloy that is strengthened by additives like titanium, aluminum and carbon. It is manufactured by high-frequency melting and casting in air. It is similar to NIMONIC alloy 75. It has good corrosion and oxidation resistance. Its hardness value is 300HV.

Studies shows that the quality of the machined product depends on the selection of the process parameters and fixing the appropriate range of parameters. Shantisagar Biradar et al. [4] has optimized the process parameters of EDM for High Carbon High Chromium Die steel (HCHCr) using the titanium nitride coated copper electrode as the tool. The experiments were conducted using factorial design, analysis has been carried out using Grey Relational Analysis. Amitesh Goswani et al. [4] studied a multi response optimization method using utility concept for wire electrical discharge machining (WEDM) of Nimonic-80A alloy. The machining characteristics are material removal rate (MRR) and surface roughness (SR). They have done the experimentation using Taguchi's robust design methodology whereas process parameters are peak current, pulse on time and pulse off time. They reported that material removal rate and surface roughness increases with increase in pulse on time and decreases with increase in pulse-off time. The present aim of the Project is to optimize the process parameters of the EDM for machining of NIMONIC 80A using Grey Relational Grade and the percentage contribution of the parameters are found by using Analysis of Variance Method (ANOVA).

2. Experimental Details

2.1. Tool Material

In EDM tool material plays a very significant role in the Machining. In this present study an Copper electrode coated with Silver (3µ) thickness is used. The electrode dimensions are 10mm diameter and 50mm length respectively.

2.2. Work material

In this present study Nimonic 80A is used as the work material. The dimensions of the rectangular workpiece material are 15mm*5mm. The Fig 1 shows the electrode and workpice.

2.3. Powder Material

The powder used in the present study is Aluminum metal powder of 325 mesh is used to mix in the dielectric. Aluminum powder concentration in the dielectric ranges from 3 to 9 g/l.

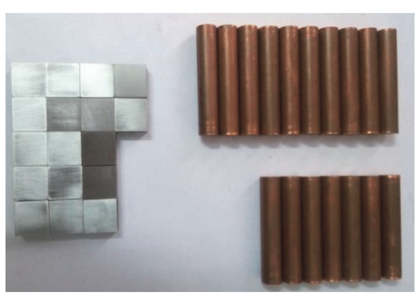

Figure 1: Workpiece and Electrode(Before Coating)

3. 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

3.1. Selection of Process parameters and Response variables

The process parameters chosen and the levels of the variables are tabulated in the table 1. The response variables affected with respect to the process parameters are Material Removal Rate (MRR), Tool Wear rate (TWR) and Radial Over Cut (ROC).

Table 1: Levels of Process Parameters

Process Parameters	Units	Low level (-1)	Medium level (0)	High Level (-1)
Current	A	3	9	15
Pulse on time (ton)	µs	300	600	900
Pulse off time (toff)	µs	30	60	90
Inter electrode gap	mm	1	2	3
Aluminum powder concentration	g/l	3	6	9

3.2. Design of Experiments

The Experiments were Performed randomly according to the L27 Orthogonal array generated using MINITAB. For each experiment different electrode (Silver Coated Copper Electrode) is used. The machining time considered for Nimonic 80A is 5 minutes. The arrangement of the experiments according to the L27 Orthogonal array is tabulated below with the Actual values.

Table 2: Design of Experiments with actual value

DOE	IEG (mm)	Current (A)	Powder Concentration (g/l)	On Time (µs)	Off Time (µs)
1	1	5	3	300	30
2	1	5	3	300	60
3	1	5	3	300	90
4	1	12	6	600	30
5	1	12	6	600	60
6	1	12	6	600	90
7	1	15	9	900	30
8	1	15	9	900	60
9	1	15	9	900	90
10	2	5	6	900	30
11	2	5	6	900	60
12	2	5	6	900	90

13	2	12	9	300	30
14	2	12	9	300	60
15	2	12	9	300	90
16	2	15	3	600	30
17	2	15	3	600	60
18	2	15	3	600	90
19	3	5	9	600	30
20	3	5	9	600	60
21	3	5	9	600	90
22	3	12	3	900	30
23	3	12	3	900	60
24	3	12	3	900	90
25	3	15	6	300	30
26	3	15	6	300	60
27	3	15	6	300	90

4. Experimental Setup

The whole experiments were carried out on an Electro Discharge Machining model ARD ARTM30D (Die-sinking type). White kerosene was used as dielectric fluid. The EDM machine tool is shown in Fig 3. Aluminum powder is added to the dielectric to examine the effect on responses. As concentration of powder is taken as one of the input variables it is difficult to maintain the total tank with 200 liters capacity. To minimize this, separate tray of one liter capacity was prepared and the different concentration levels were examined. The Workpieces are fitted with the help of Glue.

Figure 2: EDM setup

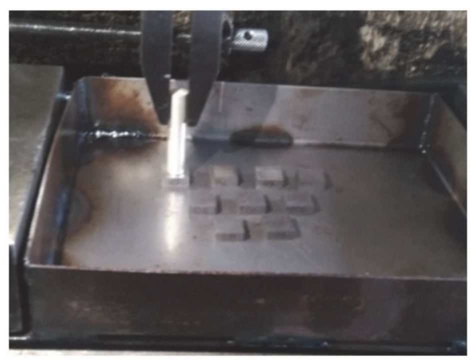

Figure 3: Arrangement of Workpieces in the Tray

5. Calculation of Response Variables

The experiments were conducted on all the 27 specimens with 5 minutes of machining time. The specimens and the electrodes are to be weighed before and after conducting the experiments. The Diameter of the electrode at the tip of the machining and the diameter of the hole produced are to be measured for every specimen using vernier calipers. The weights

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and dia measured before and after the experiments are tabulated. The response variables (MRR, TWR, ROC) are calculated and are tabulated.

Material Removal Rate (MRR):

$$MRR=\frac{W_b - W_a}{t} g/min$$

Tool Wear Rate (TWR):

$$TWR=\frac{w_{tb} - w_{ta}}{t} \ g/min$$

Radial Over Cut (ROC):

$$ROC= \frac{D_h - D_t}{2} \ mm$$

t = time taken for Machining.

Table 3: Measured Weights, Diameter of tool and Workpiece along with the measured Response variables.

DOE	Wb (g)	WA (g)	MRR (g/min)	Wtb (g)	Wta (g)	TWR (g/min)	Dt (mm)	Dh (mm)	ROC (mm)
1	11.123	11.087	0.0072	34.689	34.673	0.0032	9.920	9.933	0.0067
2	11.163	11.123	0.008	34.868	34.820	0.0096	9.870	9.917	0.0233
3	11.132	11.096	0.0072	34.826	34.812	0.0028	9.860	9.877	0.0083
4	11.119	10.992	0.0254	34.761	34.743	0.0036	9.870	9.910	0.02
5	11.087	10.942	0.029	34.726	34.697	0.0058	9.930	10.007	0.0383
6	11.047	10.826	0.0442	34.774	34.736	0.0076	9.940	9.980	0.02
7	11.149	11.033	0.0232	34.796	34.727	0.0138	9.950	10.060	0.055
8	11.093	10.914	0.0358	34.829	34.801	0.0056	9.840	9.967	0.0633
9	11.104	10.881	0.0446	34.735	34.718	0.0034	9.930	9.867	-0.0317
10	11.094	11.071	0.0046	34.791	34.773	0.0036	9.950	9.980	0.015
11	11.152	11.131	0.0042	34.759	34.751	0.0016	9.920	10.083	0.0817
12	11.173	11.150	0.0046	34.718	34.704	0.0028	9.940	9.840	-0.05
13	11.156	10.703	0.0906	34.788	34.770	0.0036	9.970	10.120	0.075
14	11.171	10.590	0.1162	34.727	34.719	0.0016	9.920	10.120	0.1
15	11.093	10.570	0.1046	34.798	34.760	0.0076	9.930	10.013	0.0417
16	11.129	10.932	0.0394	34.489	34.461	0.0056	9.830	9.940	0.055
17	11.167	10.759	0.0816	34.776	34.737	0.0078	9.940	10.113	0.0867
18	11.089	10.585	0.1008	34.673	34.641	0.0064	9.960	10.123	0.0817
19	11.106	11.076	0.006	34.820	34.789	0.0062	9.850	9.767	-0.0417
20	11.122	11.096	0.0052	34.812	34.784	0.0056	9.910	9.880	-0.015
21	11.156	11.128	0.0056	34.743	34.713	0.006	9.910	9.553	-0.1783
22	11.100	10.936	0.0328	34.697	34.668	0.0058	9.950	10.000	0.025
23	11.153	10.974	0.0358	34.736	34.707	0.0058	9.900	10.057	0.0783
24	11.078	10.904	0.0348	34.727	34.698	0.0058	9.930	10.090	0.08
25	11.121	10.618	0.1006	34.801	34.771	0.006	9.900	10.157	0.1283
26	11.091	10.341	0.15	34.718	34.687	0.0062	9.940	10.133	0.0967
27	11.087	10.246	0.1682	34.773	34.742	0.0062	9.950	10.130	0.09

Where

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W_b & W_a = Weight of the workpiece Before and After Machining.

W_{tb} & W_{ta} = Weight of Tool Before and After Machining.

D_t & D_h = Diameter of Tool and Hole respectively.

6. Optimization of Response Variables

It is important for any process to follow optimal combination of process parameters to achieve desired output response by utilizing minimum possible resources. The Optimization of the Response Variables and the Effect of the Process paremeters on the Response Variables are calculated by using Analysis of Variance (ANOVA) method.

A CALCULATION OF S/N RATIO FOR MRR, TWR & ROC

A. Calculation of S/N Ratio For MRR: Taguchi's signal to noise ratio is the logarithmic function of desired output. S/N ratio is the ratio of the mean to standard deviation. Here mean refers to signal and standard deviation refers to noise. The ratio depends on the quality characteristic of the product/process to be optimized. A high value of S/N implies that signal is much higher than the random effects of noise factors. Process operation consistent with highest S/N always yields optimum quality with minimum variation.

As the material removal rate is the response which is to be maximum, so the larger is better will be considered in calculating the S/N ratios. The Higher the material removal rate indicates that the performance of the machining will be maximum. The calculated values of "Larger the Better S/N ratios" for MRR are in negative sign are tabulated.

$$\left(\frac{S}{N}\right)_{HB} = -10log_{10}(MSD_{HB})dB$$

$$MSD_{HB} = \frac{1}{n}\sum_{i=1}^{n}\frac{1}{Y_i^2}$$

B. Calculation of S/N Ratios for TWR: Low tool rate will permit the increase in the life of the tool, which means that the tool can be used for longer period of time without getting a change in the accuracy while machining. The sound to noise ratios for the tool wear rate are calculated using the formulae smaller the better. The sound to noise ratios for the Tool wear rate are calculated and tabulated.

$$\left(\frac{S}{N}\right)_{LB} = -10log_{10}(MSD_{LB})dB$$

$$MSD_{LB} = \frac{1}{n}\sum_{i=1}^{n}(Y_i^2)$$

C. Calculation of S/N ratios for ROC: Radial overcut is an error which is generated during the machining. It shouldn't be large as it may result in the improper contours. Hence smaller the better formulae was used to calculate the S/N Ratio's for the Radial Overcut and are tabulated.

$$\left(\frac{S}{N}\right)_{LB} = -10log_{10}(MSD_{LB})dB$$

$$MSD_{LB} = \frac{1}{n}\sum_{i=1}^{n}(Y_i^2)$$

Where

MSD = Mean Square Data

Yi = Response value of i^{th} experiment

n = Number of Replicants

Table 4: S/N Ratios of MRR, TWR & ROC

DOE	Powder Concen-tration (g/l)	IEG (mm)	Current (A)	Ton (µs)	Toff (µs)	MRR S/N Ratio	TWR S/N Ratio	ROC S/N Ratio
1	3	1	6	300	30	-42.853	49.8970	43.52183
2	3	1	6	300	60	-41.938	40.3545	32.64046
3	3	1	6	300	90	-42.853	51.0568	41.58362
4	3	2	12	600	30	-31.903	48.8739	33.9794
5	3	2	12	600	60	-30.752	44.7314	28.32847
6	3	2	12	600	90	-27.092	42.3837	33.9794
7	3	3	15	900	30	-32.69	37.2024	25.19275
8	3	3	15	900	60	-28.922	45.0362	23.96735
9	3	3	15	900	90	-27.013	49.3704	55.56303
10	6	2	6	900	30	-46.745	48.8739	36.47817
11	6	2	6	900	60	-47.535	55.9176	21.7591
12	6	2	6	900	90	-46.745	51.0568	43.52183
13	6	3	12	300	30	-20.857	48.8739	22.49877
14	6	3	12	300	60	-18.696	55.9176	20
15	6	3	12	300	90	-19.609	42.3837	27.60422
16	6	1	15	600	30	-28.09	45.0362	25.19275
17	6	1	15	600	60	-21.766	42.1581	21.24296
18	6	1	15	600	90	-19.931	43.8764	21.7591
19	9	3	6	600	30	-44.437	44.1521	41.58362
20	9	3	6	600	60	-45.68	45.0362	34.73517
21	9	3	6	600	90	-45.036	44.4369	55.56303
22	9	1	12	900	30	-29.683	44.7314	32.0412
23	9	1	12	900	60	-28.922	44.7314	22.12107
24	9	1	12	900	90	-29.168	44.7314	21.9382
25	9	2	15	300	30	-19.948	44.4369	17.83321
26	9	2	15	300	60	-16.478	44.1521	20.29447
27	9	2	15	300	90	-15.484	44.1521	20.91515

B) EFFECT OF PROCESS PARAMETERS ON RESPONSE VARIABLES:

The extent upto which the input variables effects the responses are to be identified. This is done by generating the response table using Minitab 18 Statistical Software.

Effect of Process Parameters on MRR: The Main effects plot is generated by taking the input variables with 3 levels in the Abcissa and Response variable (MRR) on the ordinate.

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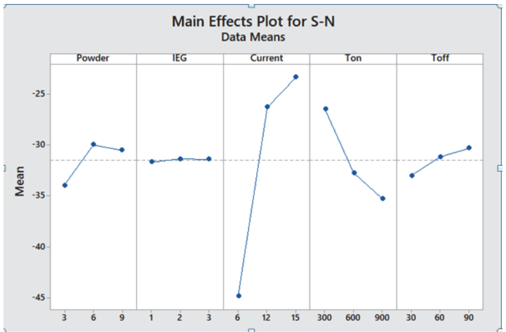

Figure 4: Main effects plot for MRR

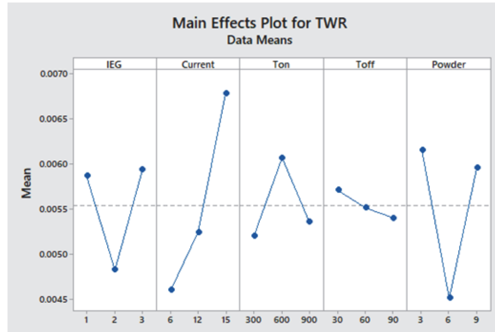

Figure 5: Main effects plot for TWR

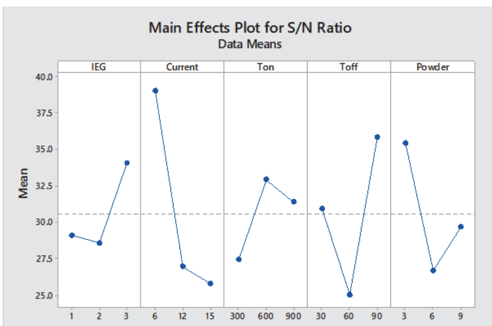

Figure 6: Main effects plot for roc

Response Table for MRR

The process parameters thus selected should be in such a way that MRR should be maximum. The levels at which the process parameters gives maximum MRR are generated by using Taguchi's technique. The so obtained values are tabulated in response Tables.

Table 5: Response table for MRR

Response Table for Signal to Noise Ratios					
Level	P C (g/l)	IEG (mm)	Current (A)	T_{on} (µs)	T_{off} (µs)
1	-34	-31.69	-44.87	-26.52	-33.02
2	-30	-31.41	-26.3	-32.74	-31.19
3	-30.54	-31.44	-23.37	-35.27	-30.33
Delta	4	0.28	21.5	8.75	2.7
Rank	3	5	1	2	4

The rank is generated for the different process parameters at different levels. The maximum values of the levels are considered as the MRR follows the Larger the better concept. The obtained Optimized values for MRR are Current (l3), Pulse on Time (l1), Powder Concentration (l2), Pulse off Time (l3) and IEG(l2).

The optimized parameters for MRR are

Current = 15 A

T_{on} = 300 µs
Powder concentration= 6 g/l
T_{off} = 90 µs
IEG = 2 mm

Response Table for TWR

Response Table for Signal to Noise Ratios					
Level	IEG (mm)	T_{on} (µs)	Current (A)	T_{off} (µs)	P C (g/l)
1	-33.08	-33.36	-33.56	-33.18	-33.1
2	-33.44	-32.96	-33.29	-33.29	-33.62
3	-33.17	-33.36	-32.84	-33.22	-32.97
Delta	0.37	0.4	0.73	0.1	0.65
Rank	4	3	1	5	2

The optimized parameters for TWR are

Current = 12 A
Powder concentration= 3 g/l
T_{on} = 300 µs
IEG = 1 mm
T_{off} = 30 µs

Response Table for ROC

Response Table for Signal to Noise Ratios					
Level	IEG (mm)	Current (A)	T_{on} (µs)	T_{off} (µs)	P C (g/l)
1	29.12	39.04	27.43	30.92	35.42
2	28.57	26.94	32.93	25.01	26.67
3	34.08	25.77	31.4	35.83	29.67
Delta	5.51	13.27	5.5	10.82	8.74
Rank	4	1	5	2	3

The rank is generated for the different process parameters at different levels. The minimum values of the levels are considered as the TWR follows the smaller the better concept. The obtained Optimized values for TWR are Current (l1), Powder concentration (l1), Pulse on Time(l3), Pulse off Time(l2)and IEG (l3).

The optimized parameters for ROC are

Current = 6 A
Powder Concentration = 3 g/l
T_{off} = 90 µs
T_{on} = 600 µs
IEG = 3 mm

ANOVA for Reponse Variables

ANOVA, a statistical tool, is used to identify any differences in the average performance of the set of items under test. The significant effect of process variables on the response parameters can be specified using ANOVA at a 95% confidence interval. ANOVA is calculated for all the response variables in order to know the effect of each process parameter on the response variable, and also to find out the contribution level of process parameters on the responses.

ANOVA for MRR, TWR & ROC

A Two way ANOVA was used for generation of the mean square value and sum of squares. F and P values are thus generated. The contribution table is also generated using ANOVA in Minitab.

Table 6: ANOVA for MRR

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Powder concentration (g/l)	2	0.797	0.15%	0.797	0.398	1.42	0.27
IEG (mm)	2	3.037	0.58%	3.037	1.518	5.42	0.016
Current (A)	2	480.535	91.06%	480.535	240.267	857.12	0
Pulse on Time (µs)	2	36.89	6.99%	36.89	18.445	65.8	0
Pulse off Time (µs)	2	1.941	0.37%	1.941	0.97	3.46	0.056
Error	16	4.485	0.85%	4.485	0.28		
Total	26	527.684	100.00%				

Table 7: ANOVA for TWR

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Powder concentration (g/l)	2	8.9767	24.16%	8.9767	4.4884	1.89	0.0183
IEG (mm)	2	0.2485	3.92%	0.24857	0.1242	0.52	0.602
Current (A)	2	10.9385	34.81%	10.9385	5.4692	1.98	0.0171
Pulse on Time (µs)	2	6.423	16.67%	6.423	3.2115	0.89	0.043
Pulse off Time (µs)	2	0.0286	0.45%	0.02867	0.0143	0.06	0.0942
Error	16	3.8011	19.98%	3.8011	0.2375		
Total	26	6.3376	100.00%				

Table 8: ANOVA for ROC

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
IEG (mm)	2	0.000978	2.74%	0.000978	0.000489	1.08	0.364
Current (A)	2	0.013553	37.94%	0.013553	0.006777	14.94	0
Pulse on Time (µs)	2	0.003339	9.35%	0.003339	0.00167	3.68	0.048
Pulse off Time (µs)	2	0.003984	11.15%	0.003984	0.001992	4.39	0.03
Powder concentration (g/l)	2	0.006608	18.50%	0.006608	0.003304	7.29	0.006
Error	16	0.007257	20.32%	0.007257	0.000454		
Total	26	0.035719	100.00%				

If the P-value is lower than 0.05, they are considered to have a significant effect on the response variable. Thus the Percentage contribution of the process parameters on the response variables are found.

7. MULTI OBJECTIVE OPTIMIZATION

It is important for any process to follow optimal combination of process parameters to achieve desired output response by utilizing minimum possible resources. The optimal parameter setting for a single response may be detrimental for other responses at the same time. So a compromise has to be made and a multi-objective optimization has to be performed to arrive at an optimal parameter setting. Many optimization techniques have evolved over the years to optimize the parameters by solving multiple objective functions. One such technique is Grey Relational Analysis.

Grey Relational Analysis

In Grey Relational Analysis the multiple performance characteristics have been investigated with Grey Relational approach.In this approach the multiple performance characteristics can be converted into single grey relational grade. In the grey relational analysis, the grey relational grade is used to show the relationship among the sequences. If the two sequences are identical, then the value of grey relational grade is equal to 1. The grey relational grade also indicates the degree of influence that the comparability sequence could exert over the reference sequence. Therefore, if a particular comparability sequence is more important than the other comparability sequences to the reference, then the grey relational grade for that comparability sequence and reference sequence will be higher than other grey relational grades.

The steps involved in the Optimization of the process parameters using Grey Relational analysis are shown below:

- Step-1: Transformation of S/N ratio values from the original response values
- Step-2: Preprocessing of data to be performed for normalizing the raw data for analysis
- Step-3: Calculation of Grey Relational co-efficient to express the relationship between the ideal and actual normalized experimental results
- Step-4: Determination of Grey Relational grade by averaging the Grey Relational co-efficient corresponding toeach performance characteristics
- Step-5: Determination of the optimal factor and its level combination

STEP-1 Transformation of S/N ratio values from the original response values:

The S/N ratios for the response variables are already calculated and are tabulated in the table:

STEP-2: Normalizing the Raw Data

The S/N values are normalized and the values are tabulated

For Higher the better

$$z_{ij} = \frac{y_{ij} - \min(y_{ij}, i = 1, 2, \ldots, n)}{\max(y_{ij}, i = 1, 2, \ldots, n) - \min(y_{ij}, i = 1, 2, \ldots, n)}$$

For Smaller the better

$$z_{ij} = \frac{\max(y_{ij}, i = 1, 2, \ldots, n) - y_{ij}}{\max(y_{ij}, i = 1, 2, \ldots, n) - \min(y_{ij}, i = 1, 2, \ldots, n)}$$

The maximum and minimum values for MRR, TWR & ROC are taken respectively in the formulae 5.3 and 5.4 for normalization. The normalized values are tabulated in Table 5.2. The normalized S/N values ranges from 0 to 1.

DOE	**Normalizing the S/N values**

	MRR	TWR	ROC
1	0.1461	0.3217	0.3191
2	0.1746	0.8316	0.6075
3	0.1461	0.2597	0.3705
4	0.4877	0.3764	0.5721
5	0.5236	0.5977	0.7218
6	0.6378	0.7231	0.5721
7	0.4632	1	0.8049
8	0.5807	0.5814	0.8374
9	0.6403	0.3498	0
10	0.0247	0.3764	0.5058
11	0	0	0.8959
12	0.0247	0.2597	0.3191
13	0.8323	0.3764	0.8763
14	0.8998	0	0.9426
15	0.8713	0.7231	0.741
16	0.6067	0.5814	0.8049
17	0.804	0.7352	0.9096
18	0.8612	0.6434	0.8959
19	0.0967	0.6287	0.3705
20	0.0579	0.5814	0.552
21	0.078	0.6134	0
22	0.557	0.5977	0.6234
23	0.5807	0.5977	0.8864
24	0.573	0.5977	0.8912
25	0.8607	0.6134	1
26	0.969	0.6287	0.9348
27	1	0.6287	0.9183

Step-4: Calculation of Grey Relational Grade

$$y_i = -> \xi_i(k)$$

Where γi is the gray relational grade for the jth experiment and k is the number of performance characteristics.

The Grey Relational Grade is found out by taking the average of Response variables for the particular experiment. Average of three response variables were calculated and are shown in the Table

Table 9: Grey Relational coefficient for the Design of Experiments

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DOE	Powder concentration (g/l)	IEG (mm)	Current (A)	T_{on} (µs)	T_{off} (µs)	MRR	TWR	ROC	GRG
1	3	1	6	300	30	0.3693	0.4243	0.4234	0.4057
2	3	1	6	300	60	0.3773	0.7480	0.5603	0.5618
3	3	1	6	300	90	0.3693	0.4031	0.4427	0.4050
4	3	2	12	600	30	0.4939	0.4450	0.5388	0.4926
5	3	2	12	600	60	0.5121	0.5541	0.6425	0.5696
6	3	2	12	600	90	0.5799	0.6436	0.5388	0.5875
7	3	3	15	900	30	0.4822	1	0.7194	0.7339
8	3	3	15	900	60	0.5439	0.5443	0.7546	0.6143
9	3	3	15	900	90	0.5816	0.4347	0.3333	0.4499
10	6	2	6	900	30	0.3389	0.4450	0.5029	0.4289
11	6	2	6	900	60	0.3333	0.3333	0.8277	0.4981
12	6	2	6	900	90	0.3389	0.4031	0.4234	0.3885
13	6	3	12	300	30	0.7489	0.4450	0.8017	0.6652
14	6	3	12	300	60	0.8330	0.3333	0.8970	0.6878
15	6	3	12	300	90	0.7953	0.6436	0.6588	0.6992
16	6	1	15	600	30	0.5597	0.5443	0.7194	0.6078
17	6	1	15	600	60	0.7184	0.6538	0.8469	0.7397
18	6	1	15	600	90	0.7828	0.5837	0.8277	0.7314
19	9	3	6	600	30	0.3563	0.5738	0.4427	0.4576
20	9	3	6	600	60	0.3467	0.5443	0.5274	0.4728
21	9	3	6	600	90	0.3516	0.5640	0.3333	0.4163
22	9	1	12	900	30	0.5302	0.5541	0.5704	0.5516
23	9	1	12	900	60	0.5439	0.5541	0.8148	0.6376
24	9	1	12	900	90	0.5394	0.5541	0.8213	0.6383
25	9	2	15	300	30	0.7821	0.5640	1	0.7820
26	9	2	15	300	60	0.9416	0.5738	0.8846	0.8000
27	9	2	15	300	90	1	0.5738	0.8596	0.8111

5.1.5: Step-5: Determination of Optimum Parameters

The process parameters are now optimized using the grey relational grade. i.e. the grey relational grade is now assigned with the ranking system. The highest will be assigned as 1 and the rest follows. The Grey Relational grades are ranked as per their value and are tabulated in Table 9.

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Table 10: Ranking of Grey Relational Grade

DOE	Powder Concentration (g/l)	IEG (mm)	Current (A)	T_{on} (µs)	T_{off} (µs)	GRG	Rank
1	3	1	6	300	30	0.4056	25
2	3	1	6	300	60	0.5618	16
3	3	1	6	300	90	0.4050	26
4	3	2	12	600	30	0.4925	19
5	3	2	12	600	60	0.5695	15
6	3	2	12	600	90	0.5874	14
7	3	3	15	900	30	0.7338	5
8	3	3	15	900	60	0.6148	12
9	3	3	15	900	90	0.4498	22
10	6	2	6	900	30	0.4289	23
11	6	2	6	900	60	0.4981	18
12	6	2	6	900	90	0.3884	27
13	6	3	12	300	30	0.6651	9
14	6	3	12	300	60	0.6877	8
15	6	3	12	300	90	0.6992	7
16	6	1	15	600	30	0.6077	13
17	6	1	15	600	60	0.7396	4
18	6	1	15	600	90	0.7314	6
19	9	3	6	600	30	0.4575	21
20	9	3	6	600	60	0.4728	20
21	9	3	6	600	90	0.4163	24
22	9	1	12	900	30	0.5515	17
23	9	1	12	900	60	0.6376	11
24	9	1	12	900	90	0.6382	10
25	9	2	15	300	30	0.7820	3
26	9	2	15	300	60	0.7999	2
27	9	2	15	300	90	0.8111	1

Step-3: Calculation of Grey Relational Coefficient

$$\xi_i(k) = \frac{\Delta_{min} + \zeta\Delta_{max}}{\Delta_{0i}(k) + \zeta\Delta_{max}} \tag{5.5}$$

Where Δ is the Deviation sequence, Where Δ0i(k) is the deviation sequence of the reference sequence and compatibility sequence. ζ is distinguishing or identified coefficients. The value of ζ is the smaller and distinguished ability is the larger. ζ =0.5 is generally used.

The rank 1 represents the optimal solution for obtaining the Maximum MRR, Minimum TWR and ROC. The optimized properties thus obtained are Current at 15A, Inter Electrode Gap at 2mm, Powder concentration in dielectric at 9g/l, Pulse on time at 300µs &Pulse off time at 90µs.

8. Conclusions

In this research , effect of machining response are Material Removal Rate, Tool Wear Rate and Radial Overcut of NIMONIC 80A with silver coated copper electrode have been investigated using EDM process by varying IEG, Powder concentration in di-electric, Current, Pulse On time and Pulse OFF time. Grey relational analysis is used in order to optimize the process parameters for the combined effects of MRR, TWR & ROC. Based on the experimental study, the following conclusions were made:

- Current is most significant parameter on Material Removal Rate (0.168 g), Tool Wear Rate (0.013 g) and Radial Over Cut (0.128 mm).
- For MRR the best process parameters are Current at 15 A, Ton at 300 µs, Powder concentration in dielectric at 6 g/l, Toff at 90 µs and IEG at 2 mm.
- The best process parameters to obtain the minimum tool wear rate are Current at 15 A, Powder concentration in dielectric at 9 g/l, Ton at 600 µs, IEG at 1 mm and Toff at 30 µs.
- The best process parameters to obtain the minimum radial overcut Current at 6 A, Powder concentration in dielectric at 3 g/l, Toff at 90 µs, Ton at 600 µs and IEG at 3 mm.
- The multi objective optimization is done using Grey Relational analysis and the obtained optimum values are Current at 15A, Inter Electrode Gap at 2mm, and Powder concentration in dielectric at 9g/l, Ton at 300µs and Toff at 90µs.

9. FUTURE SCOPE

Although the EDM machining has been thoroughly investigated for NIMONIC 80A work material, still there is a scope for future investigation. The following suggestions may prove useful for future work:

- The effect of machining parameters on recast layer thickness should be investigated.
- Study of effect of the process parameters flushing pressure and polarity etc. may also be investigated.
- Mathematical equations can be calculated in order to determine the change in MRR, TWR & ROC with respect to the change in the process parameters.

Finite element analysis can be done in order to calculate the Heat Affected zones of the required specimen with respect to the change in the parameters.

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