MULTI-OBJECTIVE PROCESS OPTIMIZATION OF WIRE ELECTRICAL DISCHARGE MACHINING BASED ON GREY RELATIONAL ANALYSIS

Kasiviswanadh chevuru, Naga satya kirti chinta,
Mechanical Engineering,
Gayatri vidya parishad college engineering, Madhurawada,
Andhra Pradesh, India.

Abstract-Manufacturing sectors demands the use of optimization techniques to obtain the best manufacturing conditions, which is an essential need for industries towards manufacturing of quality products at lower cost. The present experimental study deals with the optimizing the set of process parameters on wire electrical discharge machining (WEDM) on Inconel 925 super alloy and multiple performance characteristics of Material removal rate, surface roughness and kerf width are identified by using Grey relational analysis (GRA) to show the impact of machining parameters on WEDM for disparate Inconel 925. Initially the metal is machined on WEDM. Machining parameter namely pulse on time, pulse off time, peak current and servo voltage on the material is noticed in Inconel 925. A central composite design (CCD) of Response surface methodology (RSM) has been pre-owned for experimental work. The optimal process parameters are find out by using grey relational analysis (GRA) and confirmation test was conducted. A number of trial runs were carried out for identifying better material removal rate (MRR), kerf width (k) and surface roughness (Ra).

Keywords: WEDM, RSM, MRR, Ra, kw.

1. INTRODUCTION

Wire electrical discharge machining (WEDM) is one of the most widely used unconventional machining process, which are impenetrable to machine complex shapes. WEDM has enhanced a crucial non-traditional machining procedure, widely pre-owned in the aerospace, nuclear & automotive industries. This is thus the WEDM procedure supply & successful solution for machining impenetrable materials (namely Titanium, Nimonics, Inconel etc.,) with intricate design/profiles, which is not feasible by any conventional machining approaches. In WEDM, the erosion apparatus has been explained as evaporation of surface material by heat fabricated in the plasma channel. A flash is fabricated in between wire electrode & work piece through deionized water, (worked as dielectric medium surrounding work piece) & erodes work piece to fabricate complex two & 3-dimensional profiles.

In this study Inconel 925 was adopted for WEDM machining process due to its vast mechanical properties. Inconel 925 is used in various applications requiring a combination of high strength and corrosion resistance. Inconel is a family of austenite nickel-chromium-based super alloys. Inconel alloys are oxidation and corrosion resistant materials well suited for service in extreme environments subjected to pressure and heat. Optimization plays the vital role in the evaluation of performance characteristics and the iterative adjustments of the parameters in orders to find out the optimal solution.

This present study investigates the WEDM machining process of Inconel 925 with multi response optimization. The number of experiments were conducted by using central composite design (CCD) method. For multi response optimization, Grey relational analysis (GRA) was adopted to find out the best results of optimal process parameters for Inconel 925 super alloy. Confirmation test was conducted to achieve the improvement of higher Material removal rate (MRR), lower surface roughness (Ra) and kerf width (k).

2. MATERIAL AND METHOD USED

A. Work material

For this present investigation Inconel 925 super alloy was selected as the work material for multi response optimization of WEDM machining process parameters. The chemical composition of Inconel 925 was shown in table 1.

Table 1 chemical composition of Inconel 925

%	C %	Si %	Mn %	P %	S %	Cr %	Mo %	Ni %	Al %
COMP	0.0140	0.0640	0.4080	0.0020	0.0050	19.5230	3.4100	45.1310	0.1280
REQD	-- 0.0300	-- 0.5000	-- 1.0000	-- --	-- 0.0300	19.5000 23.5000	2.5000 3.5000	38.0000 46.0000	0.1000 0.5000

%	Cn	Cu	Nh %	Ti %	V %	W %	Pb%	Fe %	N%
COMP	0.2240	1.5510	0.3190	2.3620	0.0200	0.3210	--	26.2000	--
REQD	-- --	1.5000 3.0000	-- 0.5000	1.9000 2.4000	-- --	-- --	-- --	-- --	-- --

Fig.2.1. Inconel 925 during WEDM machining

B. Illustrative of machining

Fig.2.2. Electronica Sprintcut Wire EDM machine, Chennai

Electronica Sprintcut Wire EDM machine was used to conduct the experiments. The brass wire with diameter of 0.25 mm was used as the electrode material for machining. A gap of 0.025 mm - 0.05 mm is maintained repeatedly in between wire & work-piece. The material removed by erosion between a series of repetitive flash in between electrodes, i.e. wire and work piece. Deionized water is claimed as the dielectric fluid. A collection tank that is located at bottom to collect the wire & then discard it. The wires once used cannot be reused again because of the variation in dimensional precision.

C. Experimental Design and process parameters

In this study, process parameters such as pulse on time, pulse off time, servo voltage and peak current were considered as input process parameters which are shown in table 2. To determine the optimum settings for the WEDM process of each factor is investigated at five levels. Selection of levels and parameters was taken with the help of review of literature, importance and their compatibility as per the few investigations.

Table 2 Control factors and their levels

Symbol	Control Factors	Units	Level 1	Level 2	Level 3	Level 4	Level 5
A	Pulse-on Time(T_{on})	µs	108	111	114	117	120
B	Pulse-off Time (T_{off})	µs	25	30	35	40	45
C	Peak Current (I_p)	A	110	120	130	140	150
D	Servo Voltage (S_v)	Volts	45	48	51	54	57

Based on central composite design (CCD) of response surface methodology the thirty experimental runs with the allocated levels of process parameters were selected are shown in table 3.

Table 3 Central composite design (CCD) and Experimental results

Run	Inputs				Outputs		
	PULSE ON (micro seconds)	PULSE OFF (micro seconds)	PEAK (Ampere)	SERVO (Volts)	KERF WIDTH (mm)	MATERIAL REMOVAL RATE (mm^3/min)	SURFACE ROUGHNESS (µm)
1	114	25	130	51	0.273	2.425	2.28
2	111	40	140	54	0.243	4.706	2.472
3	111	30	120	54	0.279	2.24	2.437
4	117	40	140	54	0.277	4.026	2.732
5	117	40	120	54	0.264	3.495	2.812
6	114	35	130	45	0.275	3.105	2.357
7	108	35	130	51	0.274	1.986	1.937
8	117	30	120	48	0.267	5.41	3.12
9	117	30	140	54	0.259	5.043	3.16
10	114	35	130	51	0.263	3.453	2.927
11	114	35	130	51	0.282	3.664	2.525

12	114	35	130	51	0.296	4.086	2.717
13	117	30	120	54	0.296	4.211	3.112
14	117	30	140	48	0.301	5.209	3.215
15	111	40	140	48	0.288	6.612	2.265
16	114	35	110	51	0.306	4.418	2.545
17	114	45	130	51	0.301	7.111	2.965
18	111	40	120	48	0.288	5.859	2.282
19	114	35	130	51	0.3	4.032	2.675
20	114	35	130	51	0.295	4.129	2.667
21	120	35	130	51	0.3	4.403	3.02
22	117	40	120	48	0.296	3.064	2.84
23	111	30	140	48	0.291	2.518	2.467
24	114	35	130	57	0.282	4.083	2.642
25	111	30	120	48	0.327	3.022	2.44
26	111	40	120	54	0.29	5.402	2.45
27	111	30	140	54	0.298	2.888	2.68
28	114	35	150	51	0.293	3.794	2.77
29	114	35	130	51	0.293	4.212	2.647
30	117	40	140	48	0.292	4.946	3.157

In this case the important output responses such as Material removal rate (MRR), surface roughness (Ra) and kerf width (k) were chosen for optimizing process parameters of WEDM. Mitutoyo Surf test SJ 201P surface roughness tester is used to measure the surface roughness (R_a). The kerf width of the machined surface was measured by using Video measuring system (VMS). The Material removal rate (MRR) can be calculated as

$$MRR = k\,L\,T/T_m$$

Here, k is the kerf width (mm), L is the length of cut (mm), T is the thickness of work piece (mm) and T_m is the machining time (min)

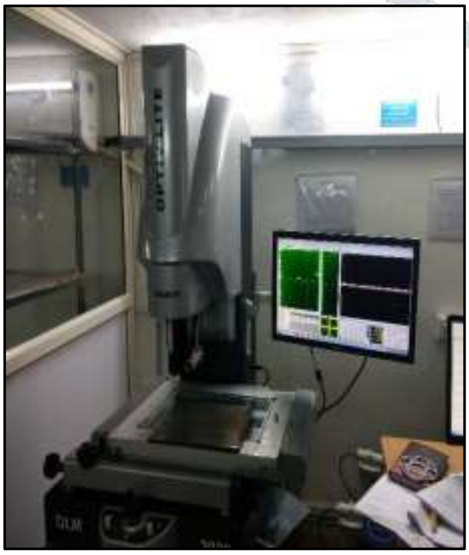

Fig.2.3. Video measuring system (VMS)

Fig.2.4. Mitutoyo Surf test SJ 201P

3. OPTIMIZATION OF WEDM PARAMERTERS USING GREY RELATIONAL ANALYSIS (GRA)

Step 1: In this step, at first initial response values are converted into the s/n ratio values. These s/n values are carried out for the further analysis. For Material removal rate (MRR) the higher-the-better performance characteristics is applicable and it can be expressed as

$$\text{S/N ratio} = -10\log_{10}\left(\frac{1}{n}\right)\sum_{i=1}^{n}\frac{1}{y_{ij}^{2}} \quad \text{(higher-the-better)}$$

Where, n = number of replications, y_{ij} = observed response value, i = 1, 2....n and j = 1, 2...k. For surface roughness and kerf width the lower-the-better performance characteristics is applicable and it can be expressed as

$$\text{S/N ratio} = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} y_{ij}^{2}\right) \quad \text{(lower-the-better)}$$

The experimental results of s/n ratio values were calculated was submitted in the table 4.

Table 4 S/N ratio values

Exp. No	Output responses			S/N ratio values		
	Material Removal Rate (mm3/min)	Surface Roughness (µm)	Kerf Width (mm)	Material Removal Rate (Db)	Surface Roughness (Db)	Kerf Width (Db)
1	2.425	2.28	0.273	7.694	-7.158	11.276
2	4.706	2.472	0.243	13.453	-7.862	12.287
3	2.24	2.437	0.279	7.004	-7.236	11.087
4	4.026	2.732	0.277	12.097	-8.040	11.150
5	3.495	2.812	0.264	10.868	-8.564	11.567
6	3.105	2.357	0.275	9.841	-7.449	11.213
7	1.986	1.937	0.274	5.959	-4.889	11.244
8	5.41	3.12	0.267	14.663	-8.899	11.469
9	5.043	3.16	0.259	14.053	-8.796	11.734
10	3.453	2.927	0.263	10.763	-7.889	11.600
11	3.664	2.525	0.282	11.279	-7.668	10.995
12	4.086	2.717	0.296	12.225	-7.704	10.574
13	4.211	3.112	0.296	12.487	-8.608	10.574
14	5.209	3.215	0.301	14.335	-9.229	10.428
15	6.612	2.265	6.612	2.265	6.612	2.265
16	4.418	2.545	4.418	2.545	4.418	2.545
17	7.111	2.965	7.111	2.965	7.111	2.965
18	5.859	2.282	5.859	2.282	5.859	2.282
19	4.032	2.675	4.032	2.675	4.032	2.675
20	4.129	2.667	4.129	2.667	4.129	2.667
21	4.403	3.02	4.403	3.02	4.403	3.02
22	3.064	2.84	3.064	2.84	3.064	2.84
23	2.518	2.467	2.518	2.467	2.518	2.467

24	4.083	2.642	4.083	2.642	4.083	2.642
25	3.022	2.44	3.022	2.44	3.022	2.44
26	5.402	2.45	5.402	2.45	5.402	2.45
27	2.888	2.68	2.888	2.68	2.888	2.68
28	3.794	2.77	3.794	2.77	3.794	2.77
29	6.612	2.265	6.612	2.265	6.612	2.265
30	4.418	2.545	4.418	2.545	4.418	2.545

Step 2: Normalizing, the preprocessing of the data is first performed for convenient to normalize the raw data for analysis. Normalization is the process of transforming the single data input to acceptable range of data which is distributed uniformly in a scale for further analysis. In this case, a linear normalization is performed in between the range of zero and unity. The normalized Material removal rate (MRR) is the higher-the-better performance characteristics is appropriate and it can be expressed as

$$z_{ij} = \frac{y_{ij} - \min(y_{ij,} i = 1,2,...n)}{\max(y_{ij,} i = 1,2,...n) - \min(y_{ij,} i = 1,2,...n)} \quad \text{(higher-the-better)}$$

For surface roughness and kerf width lower-the-better performance characteristics is appropriate and it can be expressed as

$$z_{ij} = \frac{\max(y_{ij,} i = 1,2,...n) - y_{ij}}{\max(y_{ij,} i = 1,2,...n) - \min(y_{ij,} i = 1,2,...n)} \quad \text{(lower-the-better)}$$

The values of normalized responses are shown in the table 5.

Table 5 Normalized s/n values

Exp. No	S/N ratio values			Normalized S/N ratio		
	Material Removal Rate (Db)	Surface Roughness (Db)	Kerf Width (Db)	Material Removal Rate (Db)	Surface Roughness (Db)	Kerf Width (Db)
1	7.694	-7.158	11.276	0.1565	0.4910	0.3920
2	13.453	-7.862	12.287	0.6763	0.6433	0
3	7.004	-7.236	11.087	0.0943	0.5078	0.4653
4	12.097	-8.040	11.150	0.5540	0.6818	0.4410
5	10.868	-8.564	11.567	0.4431	0.7951	0.2791
6	9.841	-7.449	11.213	0.3503	0.5538	0.4166
7	5.959	-4.889	11.244	0	0	0.4044
8	14.663	-8.899	11.469	0.7856	0.8676	0.3172
9	14.053	-8.796	11.734	0.7305	0.8452	0.2147
10	10.763	-7.889	11.600	0.4336	0.6492	0.2663
11	11.279	-7.668	10.995	0.4801	0.6012	0.5013
12	12.225	-7.704	10.574	0.5656	0.6092	0.6645
13	12.487	-8.608	10.574	0.5892	0.8047	0.6645
14	14.335	-9.229	10.428	0.7559	0.9389	0.7209
15	16.406	-6.496	10.812	0.9429	0.3478	0.5722
16	12.904	-8.113	10.285	0.6268	0.6976	0.7764
17	17.038	-8.098	10.428	1	0.6943	0.7209

18	15.356	-6.937	10.812	0.8481	0.4432	0.5722
19	12.110	-7.290	10.457	0.5551	0.5194	0.7097
20	12.316	-7.564	10.603	0.5738	0.5787	0.6531
21	12.874	-9.511	10.457	0.6241	1	0.7097
22	9.725	-8.311	10.574	0.3399	0.7403	0.6645
23	8.021	-6.090	10.722	0.1860	0.2599	0.6071
24	12.219	-8.246	10.995	0.5650	0.7264	0.5013
25	9.605	-6.522	9.709	0.3291	0.3533	1
26	14.651	-7.001	10.752	0.7845	0.4569	0.5955
27	9.211	-8.465	10.515	0.2935	0.7737	0.6872
28	11.581	-8.208	10.662	0.5074	0.7182	0.6302
29	12.489	-8.133	10.662	0.5894	0.7018	0.6302
30	13.885	-8.741	10.692	0.7153	0.8334	0.6187

Step 3: Grey relational coefficient, the relationship between the ideal (best) and actual normalized experimental results can be expressed. Before that, deviation sequence is performed for the reference and comparability sequence can be found out.

Deviation sequence can be expressed as follows

$$\Delta_{0,i}(k) = \left| y_0(k) - y_i(k) \right|$$

Where, y_0 (k) is the reference sequence and y_i (k) is the specific comparability sequence.

Grey relational coefficient can be expressed as fallows

$$\xi_{0,i}(k) = \frac{\Delta\min + \zeta\Delta\max}{\Delta_{0,i}(k) + \zeta\Delta\max}$$

Where, $\Delta_{0,i}$ (k) is the deviation sequence. ζ is known as the distinguishing or identified coefficient, range is defined as $0 \le \zeta \le 1$. The ζ value is the smaller and the distinguished ability is larger. ζ = 0.5 is generally used.

Table 6 values of deviation sequence and grey relational coefficient.

Exp. No	Deviation Sequence			Grey Relational Coefficient		
	Material Removal Rate (Db)	Surface Roughness (Db)	Kerf Width (Db)	Material Removal Rate (Db)	Surface Roughness (Db)	Kerf Width (Db)
1	0.8434	0.5090	0.6079	0.3722	0.4955	0.4513
2	0.3236	0.3567	1.0000	0.6071	0.5837	0.3333
3	0.9056	0.4922	0.5347	0.3557	0.5039	0.4832
4	0.4460	0.3181	0.5589	0.5285	0.6112	0.4722
5	0.5569	0.2049	0.7208	0.4731	0.7093	0.4096
6	0.6496	0.4462	0.5833	0.4349	0.5284	0.4615
7	1.0000	1.0000	0.5956	0.3333	0.3333	0.4564
8	0.2143	0.1323	0.6828	0.6999	0.7907	0.4227
9	0.2694	0.1547	0.7852	0.6498	0.7637	0.3890
10	0.5664	0.3508	0.7336	0.4689	0.5877	0.4053
11	0.5199	0.3987	0.4987	0.4903	0.5563	0.5007
12	0.4344	0.3908	0.3355	0.5351	0.5613	0.5985

13	0.4108	0.1953	0.3355	0.5490	0.7192	0.5985
14	0.2440	0.0610	0.2791	0.6720	0.8912	0.6418
15	0.0570	0.6522	0.4278	0.8976	0.4340	0.5389
16	0.3731	0.3024	0.2236	0.5726	0.6232	0.6910
17	0.0000	0.3057	0.2791	1.0000	0.6206	0.6418
18	0.1518	0.5568	0.4278	0.7671	0.4731	0.5389
19	0.4448	0.4806	0.2903	0.5292	0.5099	0.6327
20	0.4262	0.4212	0.3469	0.5398	0.5428	0.5904
21	0.3758	0.0000	0.2903	0.5709	1.0000	0.6327
22	0.6601	0.2596	0.3355	0.4310	0.6582	0.5985
23	0.8139	0.7400	0.3929	0.3805	0.4032	0.5600
24	0.4350	0.2736	0.4987	0.5348	0.6463	0.5007
25	0.6709	0.6466	0.0000	0.4270	0.4361	1.0000
26	0.2155	0.5431	0.4044	0.6988	0.4793	0.5528
27	0.7064	0.2262	0.3128	0.4144	0.6885	0.6152
28	0.4925	0.2818	0.3698	0.5038	0.6396	0.5749
29	0.4106	0.2981	0.3698	0.5491	0.6265	0.5749
30	0.2846	0.1665	0.3813	0.6372	0.7501	0.5673

Step 4: Grey relational grade, by averaging the grey relational coefficient corresponding to each individual performance characteristics is defined as grey relational grade. The multiple response process of its overall performance characteristic is mainly depends on the obtained grey relational grade. Table 7 shows the grey relational grade values. The grey relational grade can be expressed as

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

Where, γ_i - grey relational grade for the j^{th} experiment and k - number of performance characteristics.

Table 7 grey relational grade values

Exp . No	Control Factors				Grey Relational Coefficient			Grey relational grade	Rank
	A Pulse ON (µs)	B Pulse OFF (µs)	C Peak Current (Ampere)	D Servo Voltage (Volts)	Material Removal Rate (Db)	Surface Roughness (Db)	Kerf Width (Db)		
1	3	1	3	3	0.3722	0.4955	0.4513	0.4396	29
2	2	4	4	4	0.6071	0.5837	0.3333	0.5080	24
3	2	2	2	4	0.3557	0.5039	0.4832	0.4476	28
4	4	4	4	4	0.5285	0.6112	0.4722	0.5372	21
5	4	4	2	4	0.4731	0.7093	0.4096	0.5306	22
6	3	3	3	1	0.4349	0.5284	0.4615	0.4749	26
7	1	3	3	3	0.3333	0.3333	0.4564	0.3743	30
8	4	2	2	2	0.6999	0.7907	0.4227	0.6378	5
9	4	2	4	4	0.6498	0.7637	0.3890	0.6008	10
10	3	3	3	3	0.4689	0.5877	0.4053	0.4872	25
11	3	3	3	3	0.4903	0.5563	0.5007	0.5157	23
12	3	3	3	3	0.5351	0.5613	0.5985	0.5649	16
13	4	2	2	4	0.5490	0.7192	0.5985	0.6222	8
14	4	2	4	2	0.6720	0.8912	0.6418	0.7350	2

15	2	4	4	2	0.8976	0.4340	0.5389	0.6235	7
16	3	3	1	3	0.5726	0.6232	0.6910	0.6289	6
17	**3**	**5**	**3**	**3**	**1.0000**	**0.6206**	**0.6418**	**0.7541**	**1**
18	2	4	2	2	0.7671	0.4731	0.5389	0.5930	11
19	3	3	3	3	0.5292	0.5099	0.6327	0.5572	20
20	3	3	3	3	0.5398	0.5428	0.5904	0.5576	19
21	5	3	3	3	0.5709	1.0000	0.6327	0.7345	3
22	4	4	2	2	0.4310	0.6582	0.5985	0.5625	17
23	2	2	4	2	0.3805	0.4032	0.5600	0.4479	27
24	3	3	3	5	0.5348	0.6463	0.5007	0.5605	18
25	2	2	2	2	0.4270	0.4361	1.0000	0.6210	9
26	2	4	2	4	0.6988	0.4793	0.5528	0.5769	13
27	2	2	4	4	0.4144	0.6885	0.6152	0.57270	15
28	3	3	5	3	0.5038	0.6396	0.5749	0.57272	14
29	3	3	3	3	0.5491	0.6265	0.5749	0.5834	12
30	4	4	4	2	0.6372	0.7501	0.5673	0.6515	4

Step 5: Determination of the optimal and its level combination, Fig.3.1 shows the graph for the grey relational grade which is the mean of each individual grey relational coefficient performance characteristic. The higher grey relational grade value represents the better performance characteristic. The maximum MRR, minimum R_a and k of grey relational grades are plotted in fig.3.1. The experimental design which is central composite design (CCD) helps to notice the independent effect of each machining parameter on the grey relational grade at different levels.

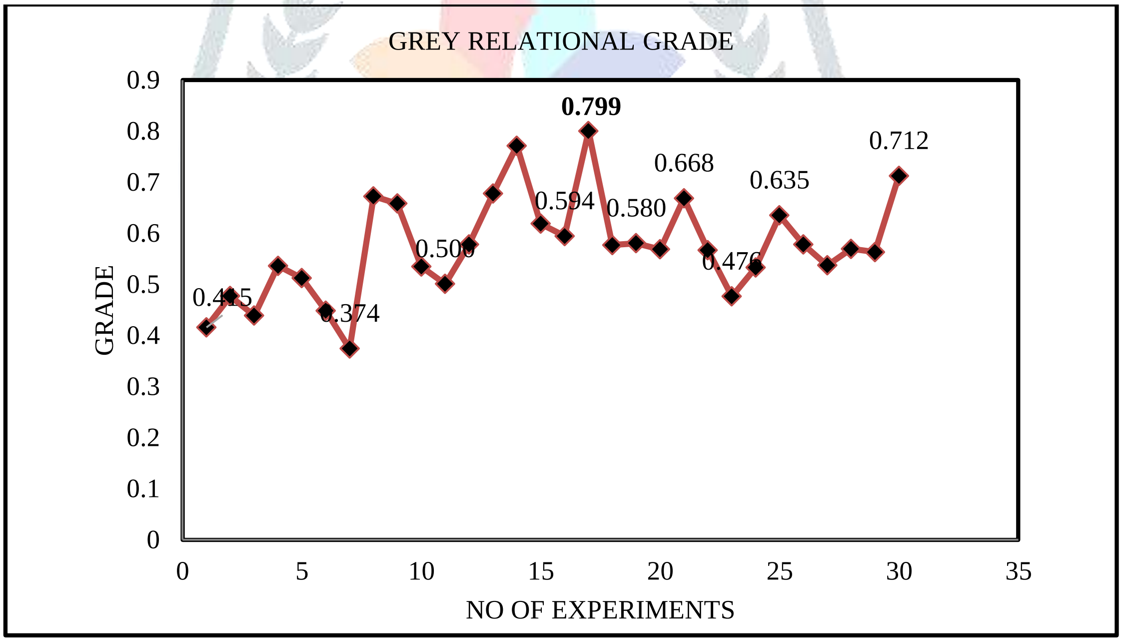

Fig.3.1 Grey relational grade graph

For suppose, the mean of grey relational grade for the pulse on time (A) at level 2 can be calculated by averaging the grey relational grade for the experiments 2 to 3, 15, 18, 23 and 25 to 27 respectively. Table 8 shows the mean of grey relational grade at each level of machining parameters. The higher mean of grey relational grade of each machining parameter to their corresponding levels are considered as the optimum levels. From the table 8 and fig.3.2 the combination of optimal parameter was considered as A5 (pulse on time, 120 µs), B5 (pulse off time, 45 µs), C1 (peak current, 110A), D2 (servo voltage, 48V).

Table 8 Main effects of the factors on grey relational grade

Run	Parameters	Level 1	Level 2	Level 3	Level 4	Level 5	Max-Min	Rank
A	Pulse on time	0.3743	0.5488	0.5656	0.6097	**0.7345***	0.3601	1
B	Pulse off time	0.4396	0.5856	0.5510	0.5729	**0.7541***	0.3144	2
C	Peak current	**0.6289***	0.5672	0.5503	0.5951	0.5727	0.0448	4
D	servo voltage	0.4749	**0.6090***	0.5491	0.5773	0.5605	0.1340	3

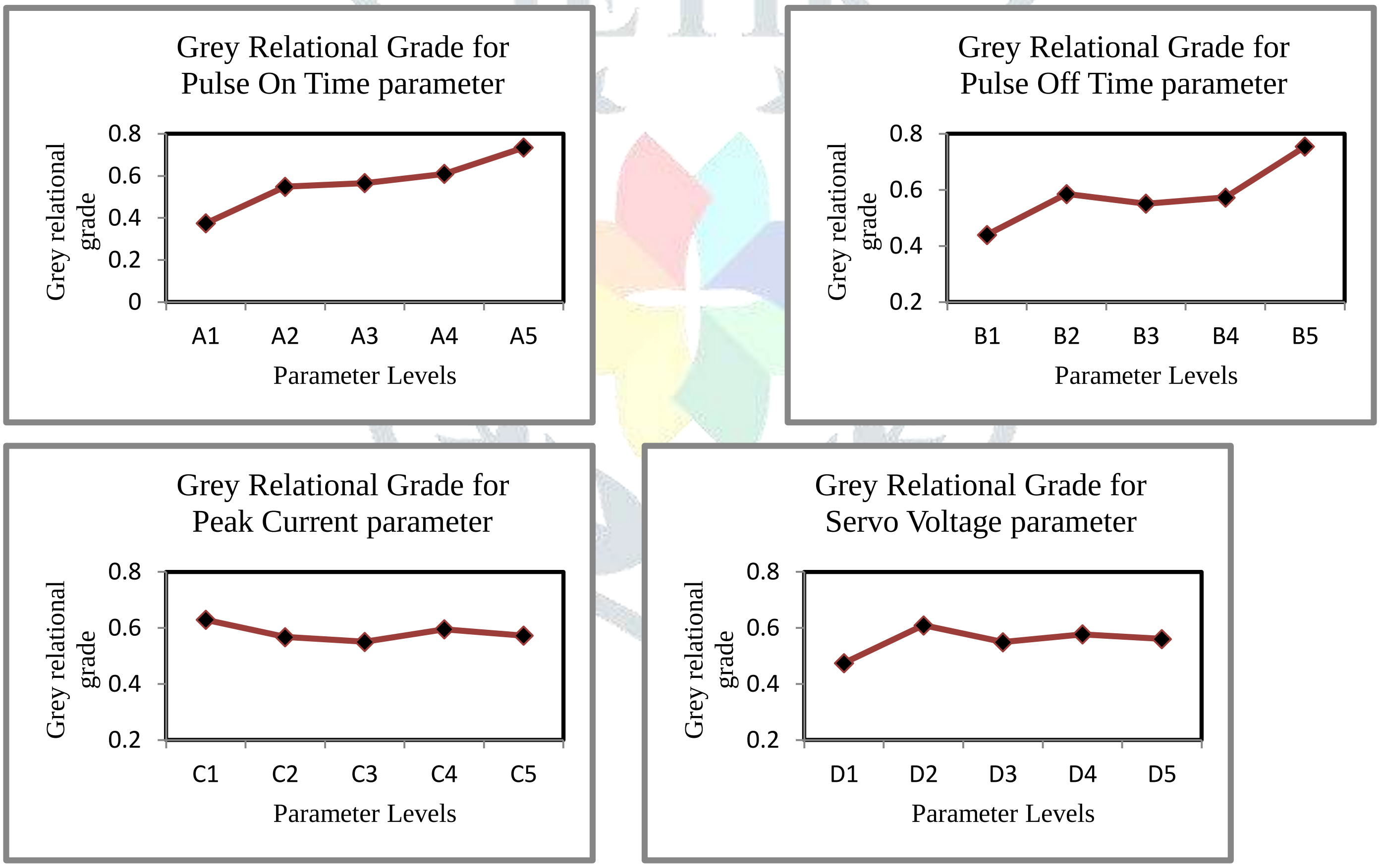

Fig.3.2. Grey relational grade graph for individual parameter

4. CONFIRMATION EXPERIMENT

The confirmation test was conducted for the optimal process parameters with its selected levels to determine the quality characteristic of WEDM for Inconel 925 super alloy. From table 7 highest grey relational grade is obtained at the experiment 17 which shows the optimal process parameter set of $A_3B_5C_3D_3$ has the finest multiple performance characteristics considering the thirty experiments. For validation purpose initial parameters ($A_3B_5C_3D_3$) was compared with optimal parameters ($A_5B_5C_1D_2$).

Table 9 Results of confirmation experiment

Level	Optimal process parameters		% of Improvement
	CCD	GRA	
	A3B5C3D3	A5B5C1D2	
Material Removal Rate (mm^3/min)	7.111	7.686	7.48%
Kerf Width (mm)	0.301	0.275	8.63%
Surface Roughness (µm)	2.965	2.945	6.74%

From table 9, the initial process parameters $A_3B_5C_3D_3$ was compared with the optimal process parameters $A_5B_5C_1D2$ of WEDM on Inconel 925 super alloy. Using confirmation experimental results the obtained response values are Material removal rate (MRR) = 7.686 mm^3/min, kerf width (k) = 0.275 mm and surface roughness (R_a) = 2.945 µm. The confirmation experiment results clearly shows that the increased in Material removal rate value from 7.111 mm^3/min to 7.686 mm^3/min, reduced the value of kerf width from 0.301 mm to 0.275 mm and also surface roughness from 2.965 mm to 2.945mm respectively. The identical improvement in Material removal rate (MRR), Kerf width (k) and surface roughness (R_a) were 7.48%, 8.63% and 6.74%.

5. CONCLUSIONS

In this investigation, Grey relational analysis method was adopted to improve the multiple response characteristic which are namely material removal rate (MRR), surface roughness (R_a) and kerf width (k) on Inconel 925 super alloy during wire-cut EDM (Electrical discharge machining). The complex multi response optimization can be significantly made easy, thus it can be utilized in any manufacturing industries to improve their quality performance characteristic.

i. The optimal process parameters which are identified by using Grey relational analysis method for Inconel 925 were considered are 120 µs pulse-on time, 45 µs pulse-off time, 110A peak current and 48V servo voltage.

ii. The improvement of multiple response characteristic such as Material removal rate (MRR), Kerf width (k) and surface roughness (R_a) were 7.48%, 8.63% and 6.74%. Thus, it shows that the Grey relational analysis method is best suitable and convenient for the parametric optimization of Wire-cut EDM machining process.

iii. Grey relational analysis method shows the beneficial results for multiple response parametric optimization which are the positive signs for the efficiency in the machining process.

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