International Journal of Engineering Research and Development
e-ISSN: 2278-067X, p-ISSN: 2278-800X, www.ijerd.com
Volume 10, Issue 10 (October 2014), PP.12-21

Modeling and Optimization of Wire EDM Process With Grey-Taguchi Technique for Super Alloy Material Incoloy-800

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Abstract:- The main purpose of this research work is to investigate the effect and optimization of cutting parameters : pulse on time (Ton), pulse off time (Toff), spark gap voltage (SGV), peak current (IP) and wire feed rate (WFR) on the control parameters material removal rate, surface roughness, gap current and kerf width in wire electrical discharge machining (WEDM). The experiment is planed as per Taguchi design methodology.The Incoloy 800 is chosen for design of experiment with L_{27} orthogonal array. A Grey analysis is used for optimal combination of process parameter for rough and finish cutting. These optimal results are comparing with Grey-Taguchi method and find out the best solutions. A regression model validate with regression-ANOVA results.

Keywords:- Wire Electrical Discharge Machining (WEDM), Grey relation analysis, Regression model

I. INTRODUCTION

The manufacturing industries have demands of better finish, low tolerance, higher production rate, etc for newer and harder materials like titanium, hardened steel, high strength temperature super alloys, fiber-reinforced composites and ceramics [1]. Due to difficulties occur with conventional machining operation, Electrical discharge machining (EDM) method is the best option to machine hard and nonconductive composites. Wire electrical discharge machining (WEDM) is a unique form of EDM [2]. Wire electrical discharge machining is a nontraditional widely accepted machining process used in tool & die industry, aerospace, surgical, automotive, nuclear industries due to its ability to cut materials very hard materials, which are difficult to cut by conventional machining process. In WEDM there is no contact between tool and work piece [3]. WEDM is able to machine any material irrespective of its hardness, brittleness or toughness with highest accuracy due to its electro-thermal machining process [4]. The dielectric water has a number of functions including insulation, ionization, cooling, and removal of waste metal particles. While the voltage builds up, the water ionizes and behaves as a conductor. After the spark, which develops great heat, the water flushes away the eroded material [5].

II. EXPERIMENTAL SETUP

2.1 WORK MATERIAL

The Incoloy800 have ultimate chemical properties for high-temperature strength and resistance to oxidation, carburization and other types of high-temperature corrosion. The Chemical Composition of the Work Material are 31.42% of nickel, 20.37 % of chromium,0.86% of magnesium, 0.40% of aluminium, 0.23% of silicon,0.08% of carbon , 0.009 % of sulpher and rest of iron. The Incoloy800 rectangular plate of 100 mm x 85 mm x 26 mm size is used to cut 52 specimens shown in figure 1. The size of specimens is 5 mm x 5 mm x 26 mm.

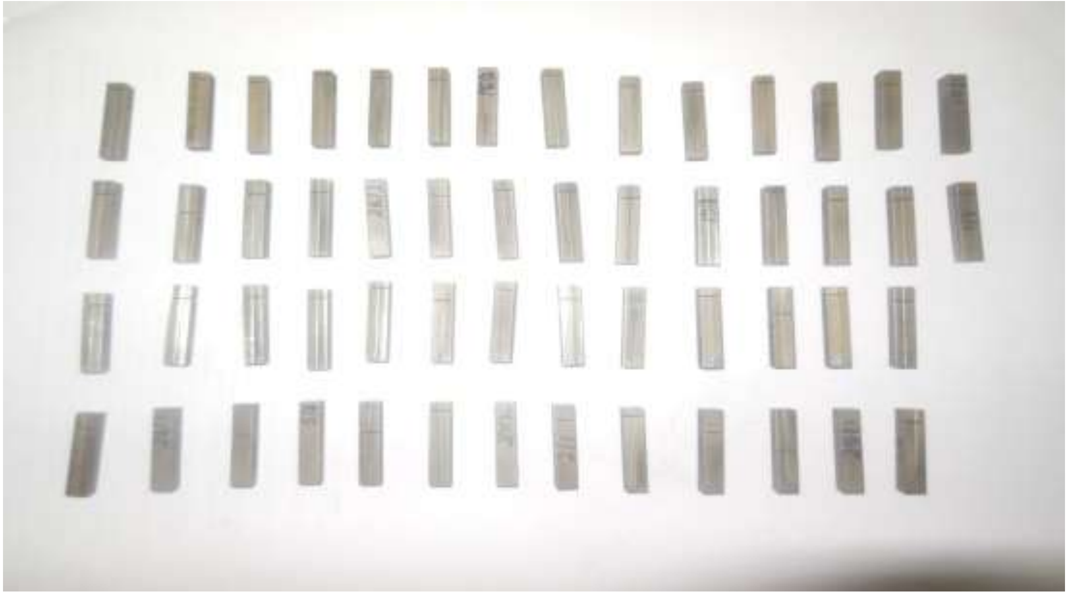

Figure 1: Sample Specimen

2.2 MACHINE SET UP

The experiments are carried out on a wire cut EDM machine (ELEKTRA MAXICUT 734) of Electronica Machine Tool Ltd. Installed at MSME Development Institute, Jaipur (Raj.) India, shown in figure 2. In this experiment the upper and lower de-ionized water pressure are 60 litre/min and 40 litre/min respectively. The conductivity of water is set at 50 mho with a temperature of (26±2) °c. The wire tension is set at 800 kgf.

Figure 2: 'ELEKTRA MAXICUT 734', Electronica Machine Tool Ltd

2.3 DATA COLLECTION

Surface roughness is measured by "MITUTOYO PROJECTOR SURFTEST" in µm with a stylus-type profilometer. Surface roughness measurements are taken on the work pieces shown in figure3.

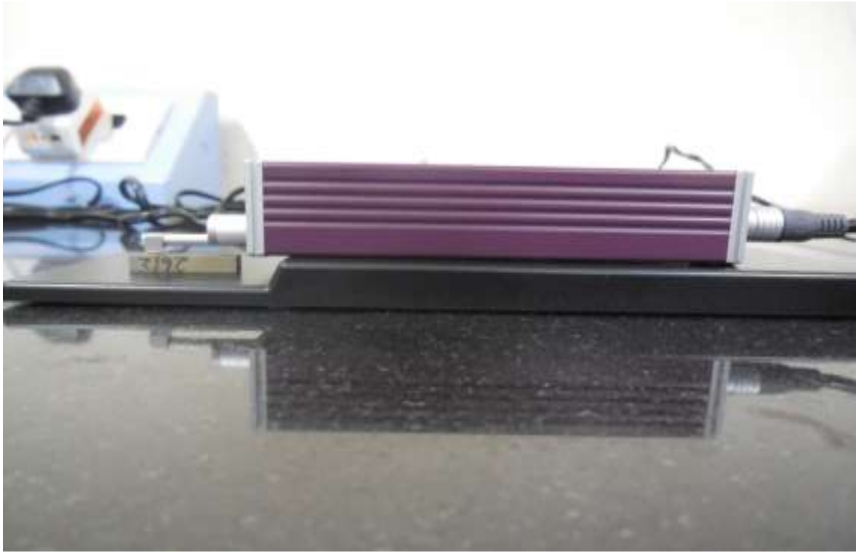

Figure 3: Mitutoyo Projector Surftest

The kerf width of specimen is measured by 'DYNAVERT' PROFILE PROJECTOR shown in figure 4. The least count of this optical profile projector is 0.005mm

Fig 4: 'DYNAVERT' Profile Projector

III. EXPERIMENTAL WORKS

3.1 SELECTION OF ORTHOGONAL ARRAY BY TAGUCHI METHOD

Control factors along with their levels are listed in Table 1. The Taguchi method is used to create the experimental layout, to analyze the effect of each parameter on the machining characteristics. This method predicts the most favorable selection for WEDM process parameter [6]. The purpose of ANOVA experimentation is to decrease and control the deviation of a process. ANOVA is the algebraic method used to read experimental data to make the essential decisions. [7]

TABLE 1: PROCESS PARAMETER AND THEIR LEVELS

Factors	Process parameters	Units	Levels Selected		
			Level 1	Level 2	Level 3
A	Pulse on time (Ton)	µs	3	4	5
B	Pulse off time (Toff)	µs	2	3	4
C	Peak current (IP)	A	2	3	4
D	Spark gap voltage (SGV)	V	55	60	65
E	Wire feed rate (WFR)	m/min	5	6	7

3.2 GREY RELATIONAL

3.2.1 Grey Relational Analysis (GRA)

In grey relational study, at first experimental data are normalized ranging from zero to one. After that, based on normalized experimental data, grey relational coefficient is calculated to signify the relationship between the desired and actual experimental data. The overall grey relational grade is determined as a result of averaging the grey relational coefficient related to responses parameter. The overall performance characteristics of response process are controlled by the calculated grey relational grade [9]. The weighting factors (w) are selected as their sum is equal to one. A higher weighting factor for an objective indicates more accurate on it [8].The process parameter and mean response parameter are shown in table 2.

TABLE 2: PROCESS PARAMETER AND MEAN RESPONSE PARAMETER

Exp. No.	Ton	Toff	PI	SGV	WFR	MEAN KERF	MEAN SR	MEAN MRR	MEAN GI
1	3	2	2	55	5	0.317	3.99	2.627	4.8
2	3	2	2	55	6	0.31	4.016	2.695	3.8
3	3	2	2	55	7	0.292	3.871	2.251	2.8
4	3	3	3	60	5	0.475	3.467	1.58	2.4
5	3	3	3	60	6	0.38	4.134	1.874	2.7
6	3	3	3	60	7	0.34	3.544	1.584	3.2
7	3	4	4	65	5	0.42	3.128	1.608	3.3
8	3	4	4	65	6	0.387	3.666	1.44	2.5
9	3	4	4	65	7	0.367	3.613	1.135	3.2
10	4	2	3	65	5	0.4	4.235	3.299	6.7
11	4	2	3	65	6	0.472	4.608	3.993	5.6
12	4	2	3	65	7	0.432	5.103	2.987	5.7
13	4	3	4	55	5	0.43	5.243	4.073	5.4
14	4	3	4	55	6	0.432	4.12	4.15	4.7
15	4	3	4	55	7	0.387	4.29	3.765	4.4
16	4	4	2	60	5	0.412	3.175	2.389	3.4
17	4	4	2	60	6	0.407	3.764	2.461	4.4
18	4	4	2	60	7	0.385	3.956	2.108	3.4
19	5	2	4	60	5	0.53	5.014	5.106	6.9
20	5	2	4	60	6	0.447	5.204	3.478	5.6
21	5	2	4	60	7	0.48	5.241	4.356	7
22	5	3	2	65	5	0.412	3.803	2.768	5.1
23	5	3	2	65	6	0.45	4.177	3.527	6.8
24	5	3	2	65	7	0.435	4.004	3.309	6.5
25	5	4	3	55	5	0.425	4.42	3.403	6.2
26	5	4	3	55	6	0.42	4.879	3.432	5.8
27	5	4	3	55	7	0.405	4.454	2.063	3.4

Grey theory has been used for analysis, and it has the potential to solve the set of optimal machining parameters connected with multiple response parameters [10]. The grey theory is based on the random uncertainty of small samples. It developed into an evaluation technique to solve problems that are difficult and having incomplete information [11]. The calculated data pre processing and its deviations are shown in table 3.

TABLE 3: CALCULATED DATA PRE PROCESSING AND ITS DEVIATIONS								
Sr. No.	**Data Pre Processing**				**Deviation**			
	X KERF	**X SR**	**X MRR**	**X GI**	**Δ KERF**	**Δ SR**	**Δ MRR**	**Δ GI**
1	0.8949	0.5924	0.3757	0.5217	0.105	0.4075	0.6242	0.4782
2	0.9243	0.5801	0.3928	0.3043	0.0756	0.4198	0.6071	0.6956
3	1	0.6486	0.281	0.0869	0	0.3513	0.7189	0.9130
4	0.231	0.8397	0.112	0	0.7689	0.1602	0.8879	1
5	0.6302	0.5243	0.186	0.0652	0.3697	0.4756	0.8139	0.9347
6	0.7983	0.8033	0.113	0.1739	0.2016	0.1966	0.8869	0.8260
7	0.4621	1	0.1191	0.1956	0.5378	0	0.8808	0.8043
8	0.6008	0.7456	0.0768	0.0217	0.3991	0.2543	0.9231	0.9782
9	0.6848	0.7706	0	0.1739	0.3151	0.2293	1	0.8260
10	0.5462	0.4765	0.5449	0.9347	0.4537	0.5234	0.455	0.0652
11	0.2436	0.3002	0.7197	0.6956	0.7563	0.6997	0.2802	0.3043
12	0.4117	0.0661	0.4663	0.7173	0.5882	0.9338	0.5336	0.2826
13	0.4201	0	0.7398	0.6521	0.5798	1	0.2601	0.3478
14	0.4117	0.5309	0.7592	0.5	0.5882	0.4690	0.2407	0.5
15	0.6008	0.4505	0.6623	0.4347	0.3991	0.5494	0.3376	0.5652
16	0.4957	0.9777	0.3157	0.2173	0.5042	0.0222	0.6842	0.7826
17	0.5168	0.6992	0.3339	0.4347	0.4831	0.3007	0.666	0.5652
18	0.6092	0.6085	0.245	0.2173	0.3907	0.3914	0.7549	0.7826
19	0	0.1082	1	0.9782	1	0.8917	0	0.0217
20	0.3487	0.0184	0.59	0.6956	0.6512	0.9815	0.4099	0.3043
21	0.21	0.0009	0.8111	1	0.7899	0.9990	0.1888	0
22	0.4957	0.6808	0.4112	0.5869	0.5042	0.3191	0.5887	0.4130
23	0.3361	0.5040	0.6023	0.9565	0.6638	0.4959	0.3976	0.0434
24	0.3991	0.5858	0.5474	0.8913	0.6008	0.4141	0.4525	0.1086
25	0.4411	0.3891	0.5711	0.8260	0.5588	0.6108	0.4288	0.1739
26	0.4621	0.1721	0.5784	0.7391	0.5378	0.8278	0.4215	0.2608
27	0.5252	0.3730	0.2336	0.2173	0.4747	0.6269	0.7663	0.7826

A higher grey relational grade results better product quality. On the basis of the grey relational grade, the factor effect is predictable and the optimal level for each process parameter can also be determined [12].The Gray Relationship generating approach is adopted to change the original sequence factor space into measurable space. It generates a comparable sequence with three different comparability types: Larger-the-Better, Smaller-the-Better, Nominal-the-Better [13]. The machining may be used for rough cutting where accuracy may not be as important as the MRR. WEDM can be used to obtain final component by finish cutting using small weights for MRR and relatively higher importance to dimensional accuracy in terms of KW and SR. Grey optimization is conducted for both cutting scenarios. In case of optimization for rough cutting, value of 0.40 is selected as weight for MRR, 0.1 for KW, 0.1 for SR and 0.4 for GI. In case of optimization for finish cutting, value of 0.10 is selected as weight for MRR, 0.4 for KW, 0.4 for SR and 0.1 for GI.

TABLE 4: GREY RELATION GRADE AND RANK OF ROUGH AND FINISH CUTTING

Sr. No	γ_{KERF}	γ_{SR}	γ_{MRR}	γ_{GI}	Rough (w_{KERF} = 0.1, w_{SR} = 0.1, w_{MRR} = 0.4 & w_{GI} = 0.4)		Finish (w_{KERF} = 0.4, w_{SR} = 0.4, w_{MRR} = 0.1 & w_{GI} = 0.1)	
					Grade	Rank	Grade	Rank
1	0.8263	0.5509	0.4447	0.5111	0.52	14	0.6465	6
2	0.8686	0.5435	0.4516	0.4181	0.4891	16	0.6518	5
3	1	0.5873	0.4101	0.3538	0.4643	19	0.7113	1
4	0.394	0.7572	0.3602	0.3333	0.3925	27	0.5298	14
5	0.5748	0.5124	0.3805	0.3484	0.4003	25	0.5078	17
6	0.7125	0.7176	0.3605	0.3770	0.438	21	0.6458	4
7	0.4817	1	0.362	0.3833	0.4463	20	0.6672	2
8	0.556	0.6628	0.3513	0.3382	0.3977	26	0.5565	8
9	0.6134	0.6855	0.3333	0.3770	0.414	23	0.5906	7
10	0.5242	0.4885	0.5235	0.8846	0.6645	4	0.5459	9
11	0.3979	0.4167	0.6407	0.6216	0.5864	7	0.4521	24
12	0.4594	0.3487	0.4837	0.6388	0.5298	12	0.4355	26
13	0.463	0.3333	0.6577	0.5897	0.5786	8	0.4432	25
14	0.4594	0.5159	0.6749	0.5	0.5675	9	0.5076	18
15	0.556	0.4764	0.5968	0.4693	0.5297	13	0.5196	16
16	0.4979	0.9574	0.4222	0.3898	0.4703	18	0.6633	3
17	0.5085	0.6244	0.4287	0.4693	0.4725	17	0.543	10
18	0.5613	0.5608	0.3984	0.3898	0.4275	22	0.5276	13
19	0.3333	0.3592	1	0.9583	0.8525	1	0.4728	20
20	0.4343	0.3374	0.5494	0.6216	0.5456	11	0.4258	27
21	0.3876	0.3335	0.7258	1	0.7624	2	0.461	23
22	0.4979	0.6103	0.4592	0.5476	0.5135	15	0.544	11
23	0.4296	0.5020	0.557	0.92	0.6839	3	0.5203	15
24	0.4541	0.5469	0.5249	0.8214	0.6386	5	0.535	13
25	0.4722	0.4500	0.5382	0.7419	0.6043	6	0.4969	19
26	0.4817	0.3765	0.5425	0.6571	0.5657	10	0.4632	21
27	0.5129	0.4436	0.3948	0.3898	0.4095	25	0.4611	22

From Table 4, it is shown that machining operations for roughing the best rank is recognized to DOE serial 19 which relates to optimal combination of A3B1C3D2E1. The machining operations for finishing the best rank is recognized to DOE serial 3 which relates to optimal combination of A1B1C1D1E3.

3.1.2 Analysis of grey grade by ANOVA

The higher grey relational grade provides the optimal condition. In DOE first analyze the grey relational grade value by Taguchi design. For rough operation found form table and figure that most significant factor is pulse on time and most optimal combination is A3B1C3D3E1. The contribution of pulse on time and pulse off time are 44.24% and 24.26% respectively.

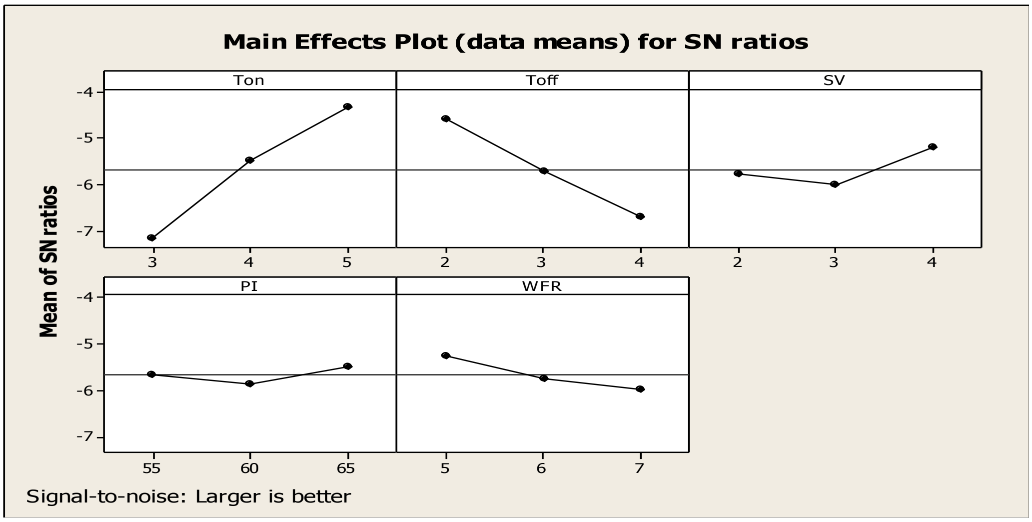

FIGURE 5: MAIN EFFECT PLOT OF ROUGHNESS FOR S/N RATIO

TABLE 5: RESPONSE TABLE FOR THE S/N GREY RELATIONAL GRADE

Level	Pulse on time	Pulse off time	Peak current	Spark voltage	Wire feed rate
1	-7.169	-4.595	-5.782	-5.658	-5.250
2	-5.488	-5.719	-6.008	-5.857	-5.760
3	-4.347	-6.691	-5.214	-5.489	-5.994
Delta	2.822	2.097	0.794	0.368	0.744
Rank	1	2	3	5	4

TABLE 6: ANOVA OF ROUGHNESS

Source	DOF	Seq. SS	Adj. AA	Adj. MS	F	P	%contribution of process parameter
Pulse on time	2	36.285	36.285	18.142	12.42	0.019	44.24
Pulse off time	2	19.820	19.820	9.910	6.78	0.052	24.16
Peak current	2	3.013	3.013	1.507	1.03	0.435	3.67
Spark voltage	2	0.612	0.612	0.306	0.21	0.819	0.74
Wire feed rate	2	2.606	2.606	1.303	0.89	0.478	3.17
Pulse on time* Wire feed rate	4	1.024	1.024	0.256	0.18	0.940	1.24
Pulse off time * Wire feed rate	4	8.039	8.039	2.010	1.38	0.382	9.80
Spark voltage * Wire feed rate	4	4.772	4.772	1.193	0.82	0.575	5.81
Residual Error	4	5.843	5.843	1.461			7.12
Total	26	82.014					100

For finishing operation it is found form table and figure that most significant factor is pulse on time and most optimal combination is A1B3C1D1E1.The contribution of pulse on time and peak current are 45.19% and 25.68% respectively

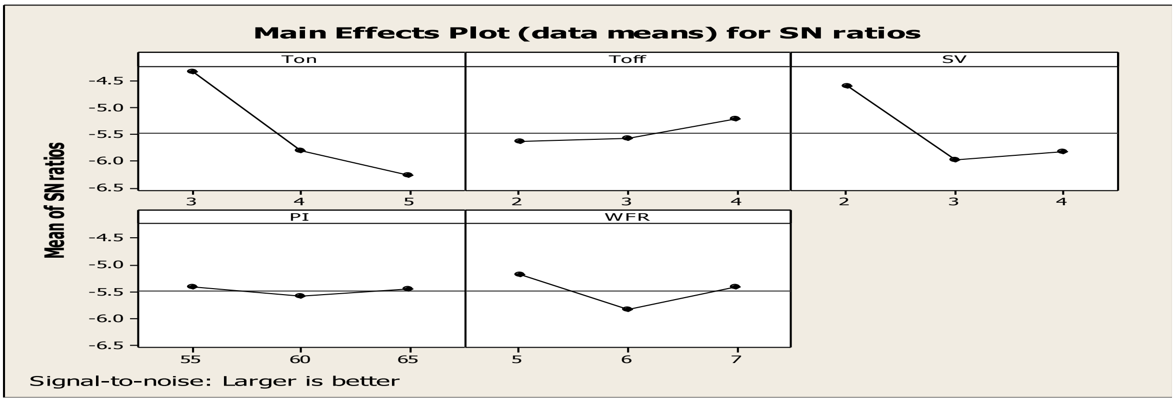

FIGURE 6: MAIN EFFECT PLOT FINISH FOR SN RATIO

TABLE 7: RESPONSE TABLE FOR S/N GREY RELATIONAL GRADE OF FINISH

Level	Pulse on time	Pulse off time	Peak current	Spark voltage	Wire feed rate
1	-4.346	-5.631	-4.607	-5.412	-5.189
2	-5.815	-5.584	-5.993	-5.579	-5.839
3	-6.267	-5.214	-5.829	-5.438	-5.400
Delta	-1.921	-0.417	-1.386	-0.167	-0.650
Rank	1	4	2	5	3

TABLE 8: ANOVA OF FINISHING

Source	DOF	Seq. SS	Adj. AA	Adj. MS	F	P	% contribution of process parameter
Pulse on time	2	18.1593	18.1593	9.0797	171.46	0.000	45.19
Pulse off time	2	0.9400	0.9400	0.4700	8.88	0.034	2.33
Peak current	2	10.3198	10.3198	5.1599	97.44	0.000	25.68
Spark voltage	2	0.1453	0.1453	0.0726	1.37	0.352	0.36
Wire feed rate	2	1.9811	1.9811	0.9906	18.71	0.009	4.93
Pulse on time* Wire feed rate	4	1.8236	1.8236	0.4559	8.61	0.030	4.53
Pulse off time * Wire feed rate	4	3.8550	3.8550	0.9638	18.20	0.008	9.59
Spark voltage * Wire feed rate	4	2.7453	2.7453	0.6863	12.96	0.015	6.83
Residual Error	4	0.2118	0.2118	0.0530			0.52
Total	26	40.1812					100

3.1.3 Conformation test for gray relation

For rough operation the best rank is recognized to DOE serial 19 which relates to combination of A3B1C3D2E1 for a value of 5.106 mm^2/min while for the most optimal combination of A3B1C3D3E1 result is 5.338 mm^2/min.

For finish operation the best rank is recognized to DOE serial 3 which relates to combination of A1B1C1D1E3 for a value of 3.871µm while for the most optimal combination of A1B3C1D1E1 result is 3.122µm.

VI. REGRESSION ANALYSIS

3.2.1 Regression equation

Regression analysis is performed to expose the relationship between process parameter and response parameter [14]. A quadratic regression model is shown by equation no.1

Y = a*A + b*B + c*C + d*D + e*E + f + g*A^2 +h*B^2 + i*C^2 + j*D^2 +k*E^2 + l*A* E + m*B*E + n*C*E ……..(1)

In the above equation a, b, c, d, e, f, g, h, i, j, k, l, m, n etc. are the regression coefficients. These regression coefficients obtained by DataFit software. The value of Y (KW, SR, MRR and GI) is obtained with the help of pulse on time (A), pulse off time (B), peak current (C), spark voltage (D) and wire feed rate (E).

Kerf Width=0.05544*A+0.08361*B+0.09155*C+0.13336*D-0.10363*E-3.79377-0.01233*A^2- 0.00966*B^2-0.01000*C^2-0.00115*D^2-0.00366*E^+0.01383*A*E-0.00475*B*E+0.00150*D*E …… (2)

Surface Roughness = 1.472*A - 1.432*B + 1.402*C - 0.457*D - 0.867*E + 17.783 -0.131*A^2 +0.154*B^2 - 0.189*C^2+0.001*D^2-0.143*E^2+0.001*A*E+0.027*B*E+0.043*D*E …… (3)

Material Removal Rate=5.70533*A+0.54027*B-1.32888*C-0.93427*D+0.89494*E+19.18029 - 0.56744*A^2 -0.13494*B^2+0.26755*C^2+0.005895*D^2-0.20494*E^2-0.05866*A*E-0.05466*B*E+0.02966*D*E . … (4)

Gap Current = 3.766*A - 1.438*B-0.088*C - 2.884*D - 6.355*E+102.399-0.299*A^2+0.116*B^2+0.033*C^2 +0.019*D^2 - 0.000009*E^2 +0.000001*A*E+0.000001*B*E+0.101*D*E ……………………. …… (5)

3.2.2 Regression equation justification by ANOVA

The deviation of an experiment is finding out by ANOVA experimentation. For MRR, ANOVA results for regression model are shown in table, which shows that the value of P is very close to 0. This value of P indicates that the regression model is fit. Similarly for KW, SR and GI values of P indicates that the regression model is fit.

TABLE.9

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob (F)
Regression	13	24.589	1.891	9.349	0.00014
Error	13	2.63	0.202		
Total	26	27.219			

V. CONCLUSION

The research work was carried out for analysis surface roughness and material removal rate. The experiments were conducted under various parameter setting. Grey analysis is used for analyze L27 orthogonal array experimental data. Following conclusion is achieved after analysis.

1. The highest grey relation grade for rough cutting was 0.8525 for trial no. 19. The optimal combination of process parameters for rough cutting according to grey analysis was A3B1C3D2E1.
2. The optimal combination of process parameters for rough cutting was A3B1C3D3E1 according to grey -taguchi design method.
3. The highest grey relation grade for finish cutting was 0.7113 for trial no. 3. The optimal combination of process parameters for rough cutting according to grey analysis was A1B1C1D1E3.
4. The optimal combination of process parameters for rough cutting was A1B3C1D1E1 according to grey -taguchi design method.
5. It is shown that the most important parameter for rough and finishing cutting is pulse on time having contribution of 44.24% and 45.19% respectively.
6. The regression equation no. 2, 3, 4 and 5 for KW, SR, MRR and GI respectively are justified by regression-ANOVA results.

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