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Application of Regression Analysis and Taguchi Method for Prognostication and Optimization of EDM Process

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ABSTRACT

Prognostication and optimization of Electrical Discharge Machining (EDM) process parameters is an important achievement for almost all of the modern manufacturing industries to obtain a quality of the product. This paper utilizes Regression Analysis method to predicting the process parameters and Taguchi method to optimize the process parameters for Material Removal Rate (MRR)and Surface Roughness (SR) of the EDM process. The composite material used to conduct the experiment is Aluminium LM 25 and 10% SiC.There are six machining parameters like Discharge voltage, Discharge current, Pulse-ON time, Pulse-OFF time, Gap between the tool and work piece and Oil pressure is used for getting the output parameter Material removal rate and Surface finish. Based on this research a result found for Regression analysis is 0.442 mg/sec average error for material removal rate and 0.6434 μm average error for surface roughness when compared with the experimental result and the optimum values of the Taguchi method in case of Material Removal Rate is, Discharge voltage 75 V, Discharge current 15 A, Pulse-ON time 45 sec, Pulse-OFF time 9 sec, Gap between the tool and work piece 0.2 mm and Oil pressure 2 Kg/cm² and for Surface Roughness is Discharge voltage 65 V, Discharge current 5 A, Pulse-ON time 15 sec, Pulse-OFF time 7 sec, Gap between the tool and work piece 0.3 mm and Oil pressure 1.5 Kg/cm².

Keywords: Electrical Discharge Machining, Regression Analysis, Taguchi Method, Material Removal Rate, Surface Roughness.

1. INTRODUCTION

In order to machining difficult to machine hard conductive materials and high strength alloys to procure very high accuracy, Electrical Discharge Machining occupies an indispensable role in industries. Electrical Discharge Machining is one of the unconventional machining process in which the material is removed from the work piece in the form of erosion, where the high temperature electric spark discharge is produced by the electrical energy is used for erosion of the material to get the required shape. From the literature survey, Jong Hyuk Jung and Won Tae Kwon, [1] develop a Taguchi method for found out the relation between the process parameters and process characteristics of EDM process and they consider input voltage, capacitance, resistance, feed rate and spindle speed as input parameters.Mohid.Junaid Mir, Khalid Sheikh, Balbir Singh and NavdeepMalhotra, [2] consider pulse time on, discharge current and concentration of aluminum powder added in to the dielectric fluid as input process parameters and investigate a parametric optimization of surface roughness study on the powder mixed EDM of H11 Steel. U. Esme, A. Sagbas and F. Kahraman, [3] has been consider pulse duration, open voltage, wire speed and dielectric flushing pressure for WEDM process parameters and using neural network and regression analysis for prediction of surface

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roughness.Krishankant, Jatin Taneja, Mohit Bector, Rajesh Kumar, [4] optimizing the material removal rate in turning process by using Taguchi method. Rama Rao.S, Padmanabhan. G., [5] optimizing the process parameters for matel removal rate using Taguchi method, Signal to Noise ratio, Analysis of Variance and Regression Analysis.Chandramouli S., ShrinivasBalraj U and Eswaraiah K., [6] optimizing the EDM parameters Material Removal Rate, Tool Wear Rate and Surface Roughness using Taguchi method and ANOVA with the consideration of current, pulse on time, pulse off time.KompanChomsamutr, SomkiatJongprasitpom, [7] has been optimizing the turning opearation by Taguchi method and Response Surface Methodology. In this paper both the method producing almost close values.Vishal Parashar, A. Rehman, J.L. Bhagoria, Y.M. Puri, [8] consider gap voltage, pulse ON time, pulse OFF time, wire feed and dielectric flushing pressure as input parameters for statistical and regression analysis of material removal rate of WEDM.Singaram Lakshmanan, Prakash Chinnakutti, Mahesh Kumar Namballa, [9] has been utilizing pulse on time, pulse off time, pulse current and voltage as input parameters for optimizing the process of surface roughness of EDM by Response Surface Methodology.Md. AshikurRahman Khan, M.M. Rahman, K. Kadirgama, M.A. Maleque and M. Ishak, [10] the effect of the peak ampere, pulse on time and pulse off time on surface roughness of the EDM process has been investigated and optimize using RSM. Based on the deep literature survey the ultimate aim of this paper is to conduct an experiment in Electrical Discharge Machining operation with increasing the input process parameters up to six numbers and develop a model for Prognostication and Optimization of EDM process for Material Removal Rate and Surface Roughness using Regression Analysis and Taguchi Method.

2. EXPERIMENTAL DETAILS

For machining the material, design the experiment for various working inputs in different sequence is an important role for conducting an experiment. In this paper utilizes MINITAB software for designing, predicting as well as optimizing the process parameters. The experimental design is based on Box-Behnken type of design in Response Surface Methodologyas shown in the Fig 1. The number of factors consider for machining the work piece in Electrical Discharge Machining is six. For six numbers of factors the available designs in Box-Behnken type of design is fifty four set of runs for both unblocked and blocked design. There are three levels of readings Low level, Medium level and High level can be set for each number of input parameter which is tabulated in the Table.1. Based on the experimental design the experiments are carried out in an Electrical Discharge Machining process by using the composite material Aluminium LM 25 and 10% Sic. The work piece is manufactured by using the stir casting furnace. The dielectric medium used for this experimental work is kerosene which having poor conductivity of electricity and copper electrode is used as a tool for machining the work piece with a dimension of 10mm diameter and 1mm depth of cut. The schematic view of the Electrical Discharge Machining setup and the machined work piece is shown in the Fig 2 and Fig 3. The machining time for each and every set of readings should be noted for calculating the Material Removal Rate. The Material Removal Rate is calculated by using the formula as given below.

$$\text{MRR} = \frac{w_1 - w_2}{T}\,\text{mg/sec}$$

Where,

w_1 – Weight before Machining

w_2 – Weight after Machining

T – Time taken for Machining

The surface roughness could be measured by using a Portable Surface Roughness Tester SJ-201. The average of the four set of reading is noted as a surface roughness value. The experimental process parameters and their corresponding outputs MRR and SR are shown in the table 2.

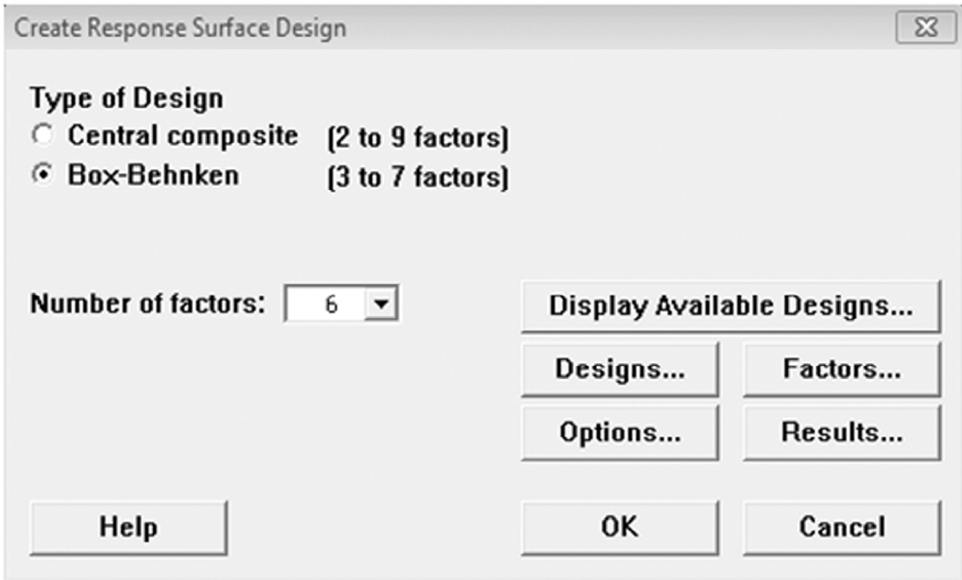

Figure 1: Selection of design

Table 1
Parameters and levels of Box-Behnken design

Sl. No.	*EDM Parameters*	*Low level(-1)*	*Medium level(0)*	*High level(1)*
1.	Voltage (V)A	60	65	75
2.	Current (A) B	5	10	15
3.	Pulse ON (sec) C	15	30	45
4.	Pulse OFF (sec) D	5	7	9
5.	Gap (mm) E	0.1	0.2	0.3
6.	Oil Pressure (Kg/cm²) F	1	1.5	2

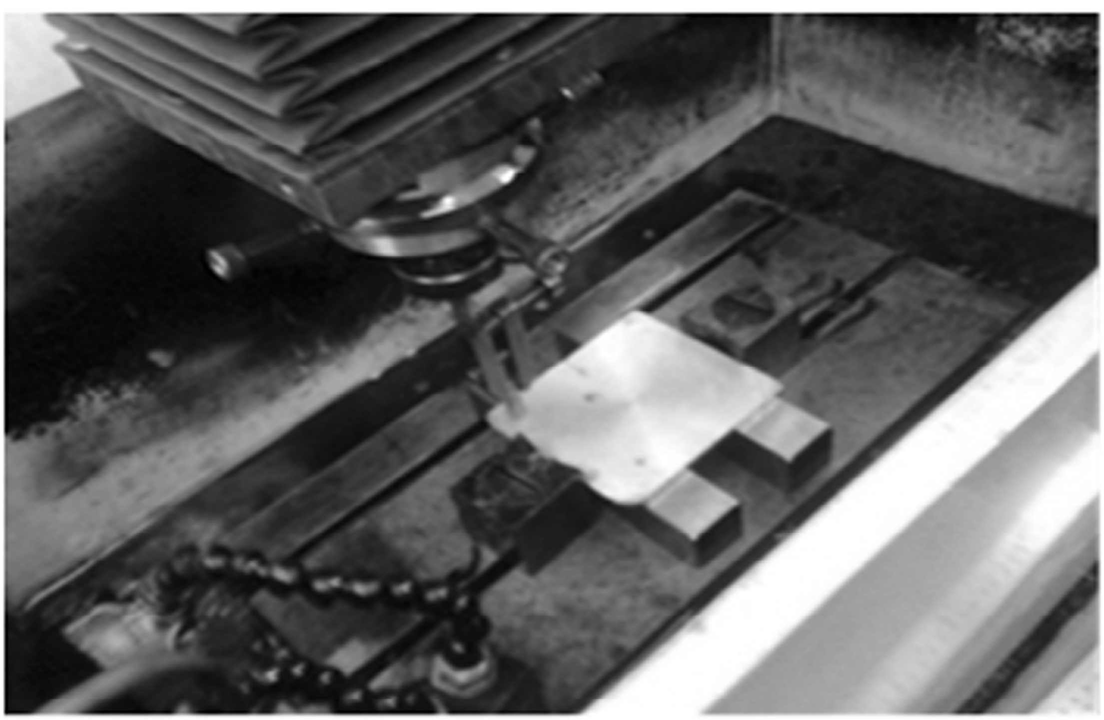

Figure 2: Electrical Discharge Machining setup

Figure 3: Machined Work pieces

Table 2
Machining Process Parameters and Their Experimental Responses

Sl. No.	*Voltage (V) A*	*Current (A) B*	*Pulse ON (sec) C*	*Pulse OFF (sec) D*	*Gap (mm) E*	*Oil Pressure (Kg/cm²) F*	*MRR (Mg/sec) G*	*SR (µm) H*
1.	65	5	15	7	0.3	1.5	1.435	3.01
2.	75	10	45	7	0.2	2.0	5.803	6.09
3.	75	10	30	9	0.1	1.5	4.954	5.82
4.	65	15	45	7	0.3	1.5	8.831	6.86
5.	75	15	30	5	0.2	1.5	7.812	5.88
6.	75	5	30	5	0.2	1.5	2.083	4.43
7.	65	10	15	9	0.2	1.0	3.357	4.32
8.	75	15	30	9	0.2	1.5	7.966	5.22
9.	75	10	45	7	0.2	1.0	6.448	6.27
10.	65	5	45	7	0.3	1.5	2.655	6.16
11.	60	10	30	9	0.1	1.5	5.208	6.20
12.	60	5	30	5	0.2	1.5	1.991	4.41
13.	60	10	30	5	0.3	1.5	4.616	5.77
14.	60	10	30	9	0.3	1.5	4.514	6.47
15.	65	5	30	7	0.1	1.0	2.184	5.69
16.	65	10	30	7	0.2	1.5	4.954	5.39
17.	60	10	45	7	0.2	2.0	6.063	6.36
18.	65	5	30	7	0.3	2.0	2.138	4.35
19.	65	10	15	5	0.2	2.0	3.385	4.86
20.	60	5	30	9	0.2	1.5	2.208	4.91
21.	75	10	30	5	0.1	1.5	5.276	5.79
22.	65	15	15	7	0.1	1.5	5.345	4.12
23.	75	5	30	9	0.2	1.5	2.282	4.87
24.	75	10	30	5	0.3	1.5	4.954	6.17
25.	75	10	15	7	0.2	2.0	3.502	5.18
26.	65	10	15	9	0.2	2.0	3.250	5.14

(contd...)

(*Table 2 contd...*)

Sl. No.	Voltage (V) A	Current (A) B	Pulse ON (sec) C	Pulse OFF (sec) D	Gap (mm) E	Oil Pressure (Kg/cm²) F	MRR (Mg/sec) G	SR (μm) H
27.	65	5	30	7	0.1	2.0	2.149	5.09
28.	65	10	45	5	0.2	2.0	4.779	7.44
29.	65	5	30	7	0.3	1.0	1.907	4.30
30.	65	15	30	7	0.1	1.0	7.386	6.39
31.	65	15	30	7	0.3	2.0	7.523	6.33
32.	65	10	30	7	0.2	1.5	5.276	5.10
33.	65	10	45	9	0.2	1.0	6.348	5.60
34.	60	10	15	7	0.2	1.0	3.385	3.74
35.	65	10	45	9	0.2	2.0	6.348	5.60
36.	65	10	45	5	0.2	1.0	6.771	8.19
37.	65	5	15	7	0.1	1.5	1.685	4.20
38.	75	10	15	7	0.2	1.0	2.861	5.31
39.	65	15	30	7	0.1	2.0	6.659	8.12
40.	65	15	15	7	0.3	1.5	3.869	4.01
41.	65	10	30	7	0.2	1.5	4.616	6.82
42.	75	10	30	9	0.3	1.5	4.145	7.08
43.	65	10	30	7	0.2	1.5	4.514	6.49
44.	65	10	30	7	0.2	1.5	4.724	6.51
45.	65	15	45	7	0.1	1.5	9.448	7.77
46.	60	15	30	5	0.2	1.5	6.771	7.70
47.	60	10	45	7	0.2	1.0	5.489	7.98
48.	65	15	30	7	0.3	1.0	5.208	8.02
49.	60	15	30	9	0.2	1.5	6.448	7.31
50.	65	10	30	7	0.2	1.5	3.944	5.01
51.	65	10	15	5	0.2	1.0	2.745	4.91
52.	60	10	15	7	0.2	2.0	2.987	4.97
53.	65	5	45	7	0.1	1.5	2.041	5.28
54.	60	10	30	5	0.1	1.5	4.779	6.54

3. RESULTS AND DISCUSSIONS

3.1. Regression Analysis

For investigating and modeling the relationship between the experimental parameters and one or more predictor's regression analysis is used. MINITAB software having three types of estimation methods like least squares, partial least squares and logistic regression procedure. In this paper least square type estimation method is used to develop the regression equation. For getting the parameter estimates least square regression minimizes the sum of squared errors. The regression equation for the output parameters Material Removal Rate and the Surface Roughness are given below.

$$\text{MRR (G)} = -4.35 + 0.0230\,A + 0.488\,B + 0.0923\,C + 0.0222\,D - 2.22\,E + 0.041\,F$$

$$\text{SR (H)} = +3.98 - 0.0187\,A + 0.175\,B + 0.0718\,C - 0.0740\,D - 1.03\,E - 0.099\,F$$

From the predicted results, the average error for predicted MRR is 0.442 mg/sec and the average error for the predicted SR is 0.6434 μm. The normal probability plot of the residuals for MRR and SR are shown

Table 3
Experimental and Predicted Responses

Sl. No.	*Experimental MRR (Mg/sec) G*	*Predicted MRR (Mg/sec) G*	*Experimental SR (µm) H*	*Predicted SR (µm) H*
1.	1.435	0.5204	3.01	3.741
2.	5.803	6.2019	6.09	6.637
3.	4.954	5.0633	5.82	5.564
4.	8.831	8.1694	6.86	7.645
5.	7.812	7.1925	5.88	6.632
6.	2.083	2.3125	4.43	4.882
7.	3.357	3.2063	4.32	4.621
8.	7.966	7.2813	5.22	6.336
9.	6.448	6.1609	6.27	6.736
10.	2.655	3.2894	6.16	5.895
11.	5.208	4.7183	6.20	5.845
12.	1.991	1.9675	4.41	5.163
13.	4.616	4.1855	5.77	5.935
14.	4.514	4.2743	6.47	5.639
15.	2.184	2.3284	5.69	5.074
16.	4.954	4.5669	5.39	5.796
17.	6.063	5.8569	6.36	6.917
18.	2.138	1.9254	4.35	4.769
19.	3.385	3.1585	4.86	4.818
20.	2.208	2.0563	4.91	4.867
21.	5.276	4.9745	5.79	5.860
22.	5.345	5.8444	4.12	5.697
23.	2.282	2.4013	4.87	4.586
24.	4.954	4.5305	6.17	5.654
25.	3.502	3.4329	5.18	4.483
26.	3.250	3.2473	5.14	4.522
27.	2.149	2.3694	5.09	4.975
28.	4.779	5.9275	7.44	6.972
29.	1.907	1.8844	4.30	4.868
30.	7.386	7.2084	6.39	6.824
31.	7.523	6.8054	6.33	6.519
32.	5.276	4.5669	5.10	5.796
33.	6.348	5.9753	5.60	6.775
34.	3.385	3.0469	3.74	4.862
35.	6.348	6.0163	5.60	6.676
36.	6.771	5.8865	8.19	7.071
37.	1.685	0.9644	4.20	3.947
38.	2.861	3.3919	5.31	4.582

(*contd...*)

(*Table 3 contd...*)

Sl. No.	*Experimental MRR (Mg/sec) G*	*Predicted MRR (Mg/sec) G*	*Experimental SR (μm) H*	*Predicted SR (μm) H*
39.	6.659	7.2494	8.12	6.725
40.	3.869	5.4004	4.01	5.491
41.	4.616	4.5669	6.82	5.796
42.	4.145	4.6193	7.08	5.358
43.	4.514	4.5669	6.49	5.796
44.	4.724	4.5669	6.51	5.796
45.	9.448	8.6134	7.77	7.851
46.	6.771	6.8475	7.70	6.913
47.	5.489	5.8159	7.98	7.016
48.	5.208	6.7644	8.02	6.618
49.	6.448	6.9363	7.31	6.617
50.	3.944	4.5669	5.01	5.796
51.	2.745	3.1175	4.91	4.917
52.	2.987	3.0879	4.97	4.763
53.	2.041	3.7334	5.28	6.101
54.	4.779	4.6295	6.54	6.141

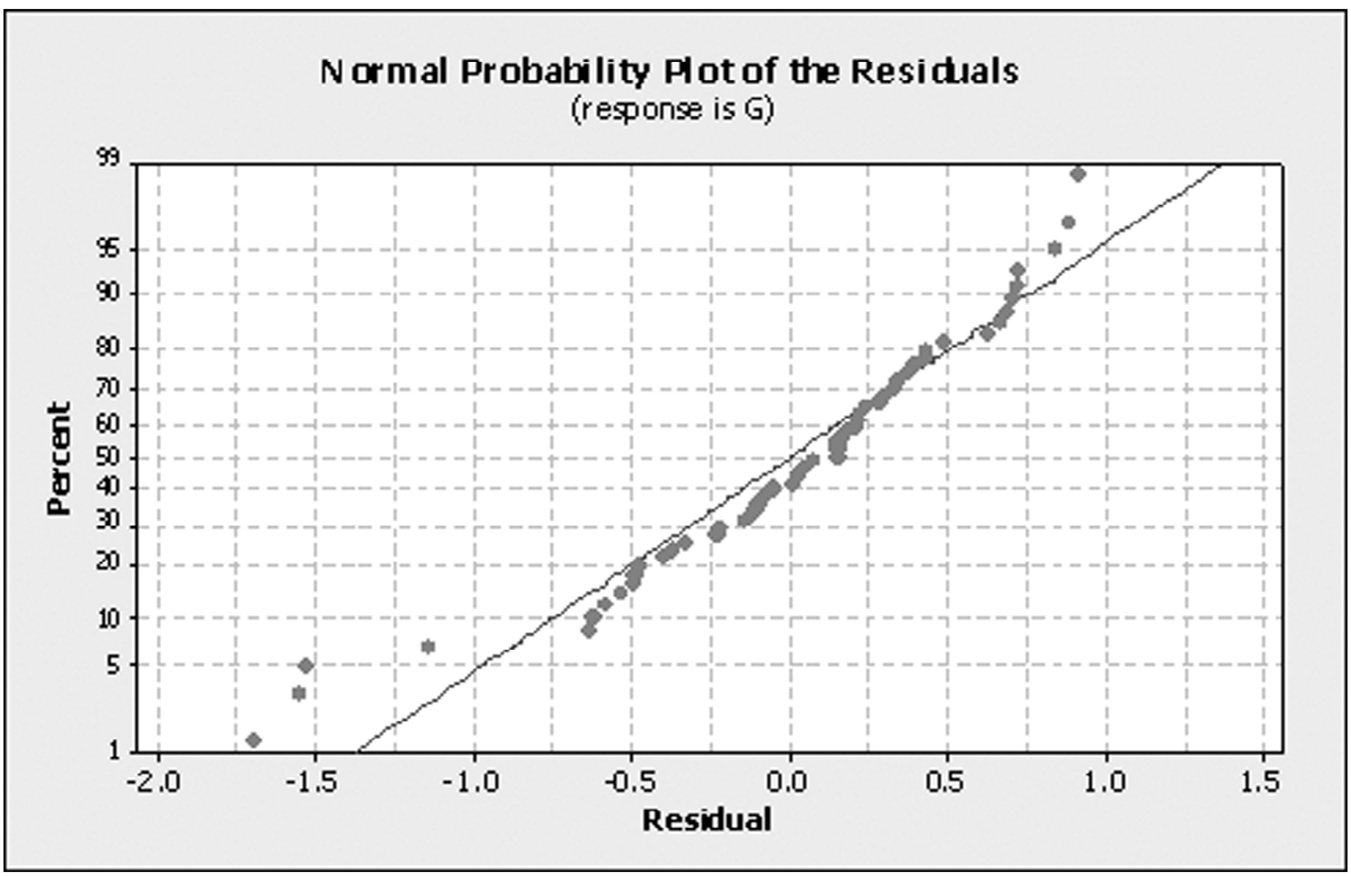

Figure 4: Normal probability plot residuals for MRR

in the Fig. 4 and Fig. 5. Both the MRR and SR residuals are plots in a straight line. It clearly shows that the errors are normally distributed.

3.2. Taguchi Method

Taguchi method is one of the efficient as well as easiest methods for determining the optimal solution. This method mainly focused on minimizing the variations and sensitivity to the noise. S/N ratios provide a

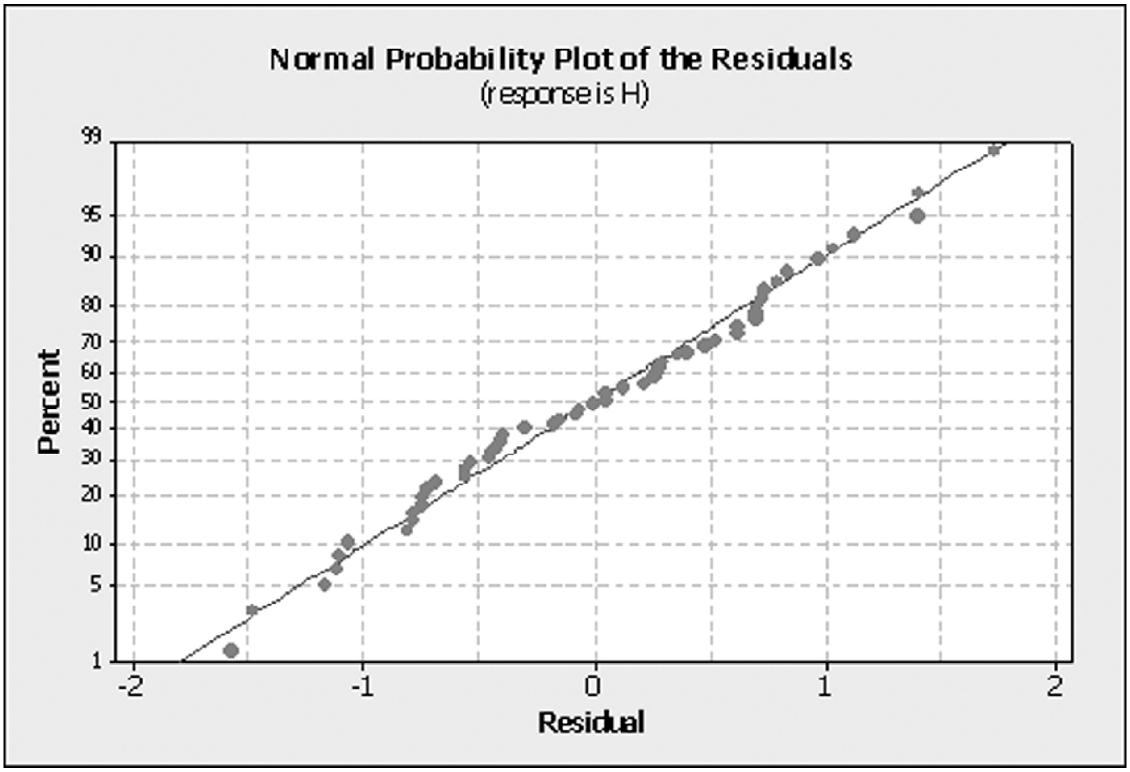

Figure 5: Normal probability plot residuals for SR

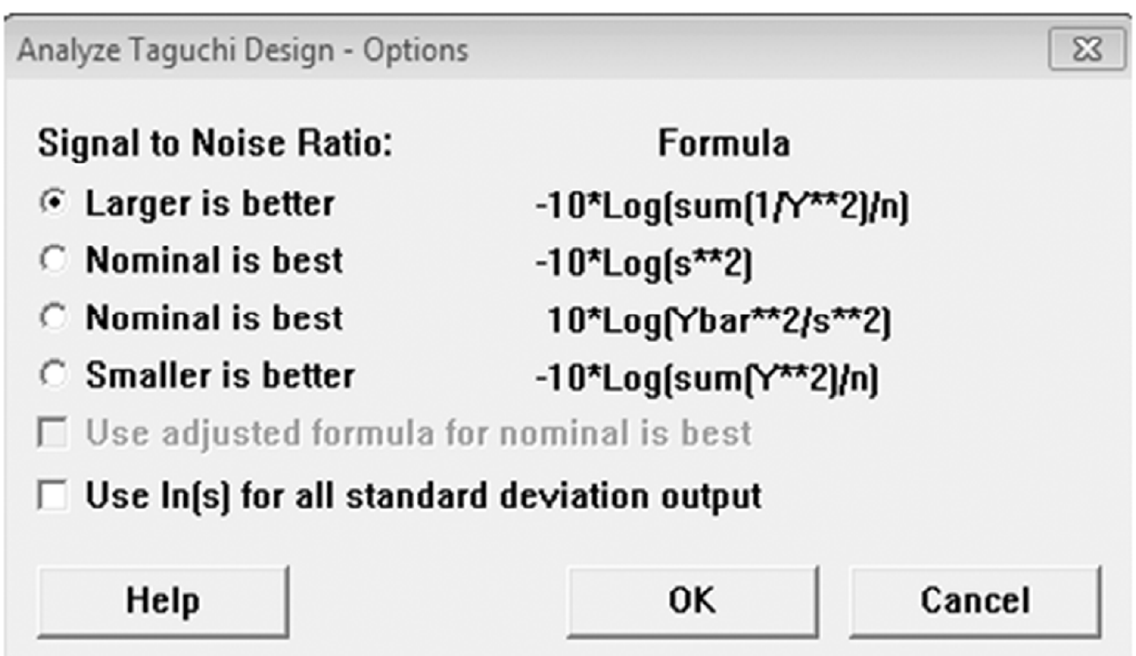

Figure 6: Selection of S/N ratio for MRR

measure of robustness. Signal to noise ratio can be classified in to three types namely, Larger is better, Nominal is better and Smaller is better. For all these types of S/N ratios having a separate formula and for Optimizing the process parameter for Material removal rate, Larger is better is selected as shown in the Fig. 6. Table.4 shows the response table for signal to noise ratios for the three levels of the process parameters of MRR. From the Fig. 8 it clearly shows that the Material Removal Rate is better, when the voltage is at 75 V, current is at 15 A, pulse ON time is at 45 sec, pulse OFF time is at 9 sec, Gap is at 0.2 mm and Oil pressure is at 2 Kg/cm².

For optimizing the process parameter of Surface Roughness, Smaller is better is selected as shown in the Fig. 8. Table.5 which shows the response table for signal to noise ratios for the three levels of the process parameters of SR and the Fig. 9 it clearly shows that the Surface Roughness is better, when the voltage is at 65 V, current is at 5 A, pulse ON time is at 15 sec, pulse OFF time is at 7 sec, Gap is at 0.3 mm and Oil pressure is at 1.5 Kg/cm².

Table 4
Response Table for S/N Ratios of MRR

	Response Table for Signal to Noise Ratios of MRR Larger is better					
Level	Voltage A	Current B	Pulse ON C	Pulse OFF D	Gap E	Oil Pressure F
1	12.542	6.199	9.518	12.634	12.361	12.229
2	11.765	13.065	12.344	11.749	12.512	12.174
3	12.958	16.593	14.776	12.900	11.582	12.419
Delta	1.193	10.394	5.259	1.151	0.930	0.245
Rank	3	1	2	4	5	6

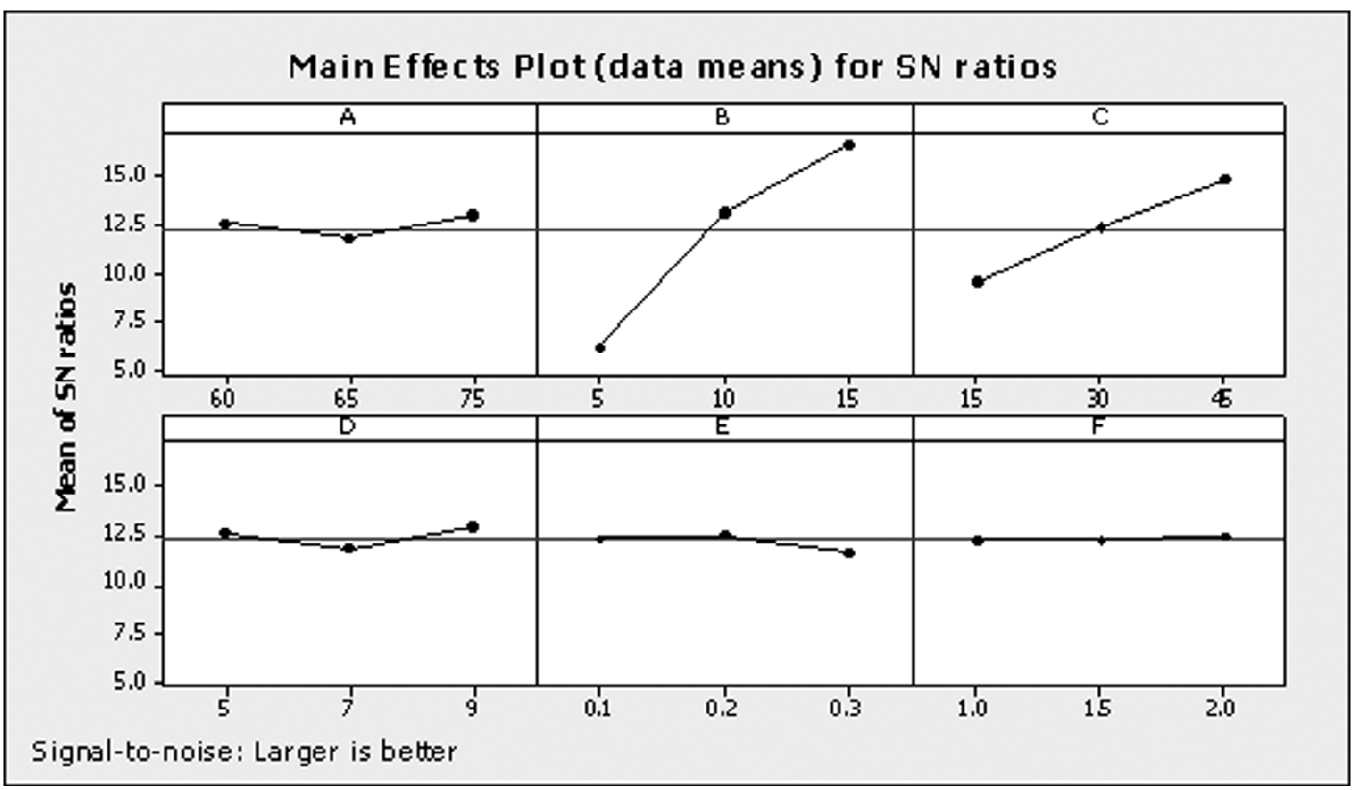

Figure 7: Selection of S/N ratio for MRR

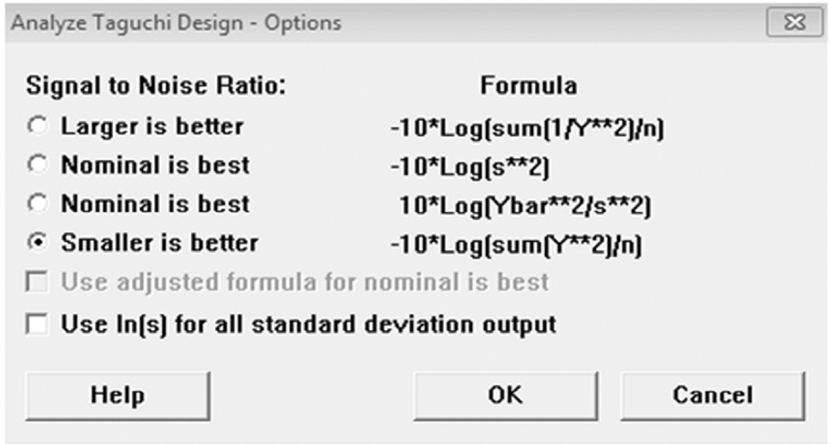

Figure 8: Selection of S/N ratio for SR

Table 5
Response Table for S/N Ratios of SR

	Response Table for Signal to Noise Ratios of SR Smaller is better					
Level	Voltage A	Current B	Pulse ON C	Pulse OFF D	Gap E	Oil Pressure F
1	-15.40	-13.36	-12.92	-15.40	-15.27	-15.14
2	-14.79	-15.30	-15.35	-14.79	-14.95	-14.87
3	-15.02	-16.00	-16.35	-15.04	-14.83	-15.12
Delta	0.61	2.64	3.42	0.61	0.44	0.27
Rank	4	2	1	3	5	6

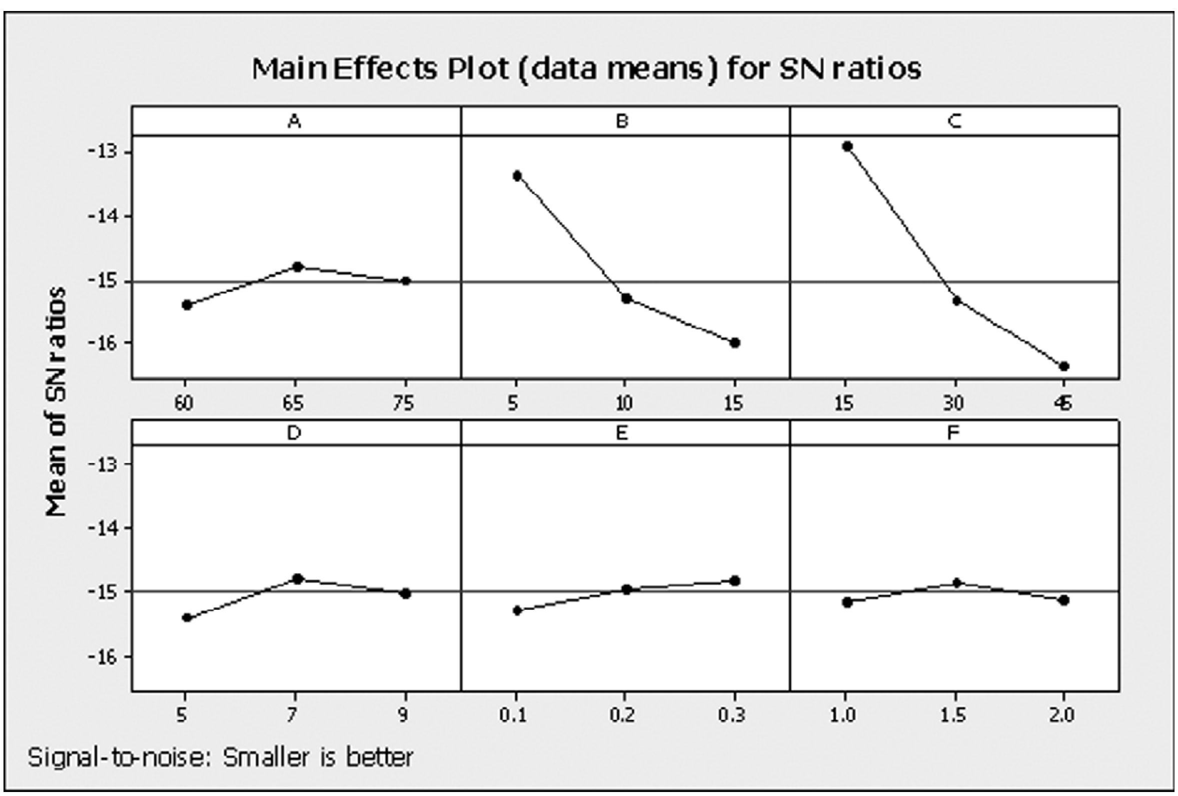

Figure 9: Selection of S/N ratio for SR

4. CONCLUSION

In this research we found the Prognostic and Optimistic parameters for the Material Removal Rate and the Surface Roughness of the Electrical Discharge Machining for a composite material Aluminium LM 25 and 10% SiC. The results found for Regression analysis is 0.442 mg/sec average error for material removal rate and 0.6434 µm average error for surface roughness when compared with the experimental results and by using Taguchi method, optimize theparameters of the Material Removal Rate is, Discharge voltage 75 V, Discharge current 15 A, Pulse-ON time 45 sec, Pulse-OFF time 9 sec, Gap between the tool and work piece 0.2 mm and Oil pressure 2 Kg/cm² and for Surface Roughness is Discharge voltage 65 V, Discharge current 5 A, Pulse-ON time 15 sec, Pulse-OFF time 7 sec, Gap between the tool and work piece 0.3 mm and Oil pressure 1.5 Kg/cm².

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