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Evaluation of Optimal Parameters for Surface Roughness Using Single Objective Taguchi Method

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ABSTRACT
Medium carbon steel EN8 has a wide variety of applications in oil, gas and tool industries. It is most commonly used where high tensile strength is required. In the present work, an attempt has been made to explore the effect of machining parameters on Surface Roughness (R_a). Taguchi's single objective optimization technique is used to optimize the machining parameters in EDM for EN8 steel. For the experimentation Taguchi's L27 Orthogonal array has been used. The input parameters selected are Pulse on time (P_{ON}), Pulse off time (P_{OFF}), Wire tension (WT) and Wire feed (WF). From the Taguchi results, optimal combination of machining parameters for Surface Roughness is found at Pulse-on time (P_{ON}) level 3(131µs), Pulse-off time (P_{OFF}) level 2 (58µs), Wire tension (WT) level 1(2 Kg-f) and Wire feed rate (WF) level 1(4m/min). ANOVA was used to find the influence of machining parameters on Surface Roughness. From the results, it is found that wire feed rate (WF) has high influence (F = 47.16) and Pulse-off time (T_{OFF}) has very low influence (F = 1.57) in effecting the Surface Roughness. Regression model for Surface Roughness has been prepared by using MINITAB-16 software. Experimental values and Regression values of Surface Roughness were compared and from the graph, it is clear that both the values are very close to each other. Hence, Regression model prepared is accurate, adequate and it can be used for the prediction of Surface Roughness.
Keywords - EN8 steel, Surface Roughness (R_a), Taguchi, ANOVA.

I. INTRODUCTION

Electro Discharge Machining (EDM) is a Non-conventional machining process. It has ability to machine hard, difficult-to-machine materials and the parts with complex internal shapes by using precisely controlled sparks. In EDM while machining the sparks will occur between an electrode and a work piece in the presence of a Di-electric fluid. EDM involves complex physical and chemical process including cooling and heating. In EDM the spark produced while machining removes material from both the electrode and work piece. In EDM, Di-electric material is used to maintain the sparking gap between the electrode and work piece, to cool the heated material to form the EDM chip and for removing EDM chips from the sparking area. Di-electric material commonly used is a fluid. Various machining parameters commonly used in EDM are Pulse-on time (P_{ON}), Pulse-off time (P_{OFF}), Peak current, Spark gap voltage, Wire tension (WT), Wire feed (WF) and Flushing pressure of dielectric fluid etc. EDM also referred to as spark machining, spark eroding, burning, die-sinking or wire erosion. [1][2][3]

It is difficult to consider all the parameters as inputs, as the number of input parameters increases the number of experiments to be conducted also will increases. In the present study, among all the parameters of EDM Pulse-on time (P_{ON}), Pulse-off time (P_{OFF}), Wire tension (WT) and Wire feed rate (WF) are taken as variables and Peak current, Spark gap voltage and Flushing pressure of dielectric fluid are considered as fixed parameters. [4][5] For the optimization of EDM parameters single objective Taguchi method was used. Taguchi's parametric design is an effective tool for robust design. It offers a simple and systematic qualitative optimal design at a relatively low cost. The greatest advantage of this method is to save the experimental time and cost involved. Taguchi has used a special design of orthogonal array to study the entire parameter space with a small number of experiments only. One of the important steps involved in Taguchi's technique is selection of an Orthogonal array (OA). An OA is a small set from all possibilities which helps to determine least number of experiments, which will further helps to determine the optimum level for each process parameters and establish the relative importance of individual process parameters. To obtain optimum process parameters Taguchi suggested Signal-to-Noise (S/N) ratio, this ratio considers both the mean and variance. Taguchi has proposed three performance characteristics; they are Larger-the-better, lower-the-better and nominal-the-better. In the present work lower the better characteristic was used for Surface Roughness. [6][7][8] Lower-the-better: S/N ratio = -10 log $[R_a^2]$

In the present work, an attempt has been made to explore the effect of EDM machining parameters on Surface Roughness. Medium carbon steel EN8 has taken as a work piece. EN8 steel has high industrial applications in tool, oil and gas industries. EN graded materials are most commonly used where high tensile strength property is required. They commonly used for axial shafts, propeller shafts, crank shafts, high tensile bolts and studs, connecting rods, riffle barrels and gears manufacturing etc. [9][10] The machining was done on ULTRACUT with Pulse generator ELPULS EDM machine as per Taguchi's L27 orthogonal array. For the experimentation, Pulse on time (P_{ON}), Pulse off time (P_{OFF}), Wire tension (WT) and Wire feed (WF) are considered as input parameters and Surface Roughness (R_a) is considered as response. For the optimization, Taguchi's single objective method was used. The influence of machining parameters was studied by using ANOVA. The Regression model for the Surface Roughness has been prepared by using MINITAB-16 software and the model is checked for their accuracy and adequacy. Finally, the experimental and Regression results were compared.

II. EXPERIMENTAL DETAILS

Medium carbon steel EN8 has been considered in the present work. The chemical composition, Mechanical and physical properties of EN8 steel are given in the tables 1 and 2. All the experiments were conducted on ULTRACUT with Pulse generator ELPULS EDM machine as per Taguchi's L27 orthogonal array. Brass wire and water were used as tool electrode and Di-electric fluid respectively. After machining, Surface Roughness values of machined work pieces were measured by using SJ-301 (Mutituyo) gauge. EN8 specimen used for machining is shown in figure 2.1. The Parameters and their range of CNC EDM machine was given in the table3.

Table1 Chemical Composition of EN8 steel

Element	C	Mn	Si	S	P	Cr	Ni	Mo
% Weight	0.36-0.44	0.6-1.0	0.10-0.40	0.05 max	0.05 max	-	-	-

Table2 Mechanical Properties of EN8 steel

Property	Maximum Stress (N/mm^2)	Yield Stress (N/mm^2)	Elongation (%)	Impact (J)	Hardness (BHN)
Value	700-850	465	16	28	201-255

Figure 2.1 EN8 specimen

Figure 2.2 EDM machine

Figure 2.3 EDM machine

Table 3 Parameters range available on CNC EDM machine

S.No.	Parameters	Range	Units
1	Pulse on time (T_{ON})	115-131	µs
2	Pulse off time (T_{OFF})	40-63	µs
3	Peak current	180-230	Ampere
4	Spark gap voltage	10-20	Volts
5	Wire feed (WF)	0-10	m/min
6	Wire tension (WT)	0-5	Kg-f
7	Flushing pressure	3-15	Kg/cm^2

III. METHODOLOGY

In the present work, Taguchi's single objective method was used for the optimization of machining parameters. The most important step in Taguchi method is the selection of Orthogonal Array. For the present study L27 OA has been selected for conducting experiments. Taguchi has proposed three types of performance characteristics in the analysis of Signal-to-Noise ratio; they are Larger-the-better, Smaller-the-better and Nominal-the-better. For the analysis of Surface Roughness Lower-the-better characteristic has been used. In addition to Taguchi method, Analysis of variance (ANOVA) was used to find the influence of machining parameters on Surface Roughness. The selected machining parameters with their levels and L27 Orthogonal Array were given in the tables 4 and 5.

Three Signal-to-Noise characteristics given by Taguchi are

(a) Larger-the-better: it is used where the larger value of response is desired.

S/N ratio = $-10 \log_{10} [1/y_i^2]$

Where, y_i is observed response.

(b) Smaller-the-better: it is used where the smaller value of response is desired.

S/N ratio = $-10 \log_{10} [y_i^2]$

Where, y_i is observed response.

(c) Nominal-the-better: it is used where the nominal or target value and variation about that value is minimum.

S/N ratio = $-10 \log_{10} [\mu^2/ \sigma^2]$

Where, µ is mean and σ is variance.

Taguchi suggested a standard procedure for optimizing any process parameters. The steps involved are

a) Determination of the quality characteristics to be optimized.
b) Identification of the noise factors and test conditions.
c) Identification of the control factors and their levels.
d) Designing the matrix experiment and defining the data analysis procedure.
e) Conducting the matrix experiment.
f) Analyzing the data and determining the optimum levels of control factors.
g) Predicting the performance at these levels.

Table 4 Experiment input parameters and their levels

S. no	Parameters	Units	Level 1	Level 2	Level 3
1	Pulse on time(TON)	µs	115	123	131
2	Pulse off time, (TOFF)	µs	53	58	63
3	Wire tension (WT)	Kg-f	02	03	04
4	Wire feed rate (WF)	m/min	04	05	06

Table 5 L27 Orthogonal Array

Run No.	Pulse on time (T_{ON}) µs	Pulse off time (T_{OFF}) µs	Wire tension (WT) Kg-f	Wire feed rate (WF) m/min
1	115	53	2	4
2	115	53	3	5
3	115	53	4	6
4	115	58	2	5
5	115	58	3	6
6	115	58	4	4
7	115	63	2	6
8	115	63	3	4

9	115	63	4	5
10	123	53	2	5
11	123	53	3	6
12	123	53	4	4
13	123	58	2	6
14	123	58	3	4
15	123	58	4	5
16	123	63	2	4
17	123	63	3	5
18	123	63	4	6
19	131	53	2	6
20	131	53	3	4
21	131	53	4	5
22	131	58	2	4
23	131	58	3	5
24	131	58	4	6
25	131	63	2	5
26	131	63	3	6
27	131	63	4	4

IV. RESULTS AND DISCUSIONS

A series of experiments were conducted on medium carbon steel EN8 material with a brass wire on EDM machine as per Taguchi's L27 array. The components after machining are tested for Surface Roughness and measured by using SJ-301. The experimental results of Surface Roughness R_a of each sample and corresponding S/N ratios are given in the table 6. The mean values of Surface Roughness were calculated and given in the table7.

Table 6 Experimental results and S/N ratios of R_a

S.NO	R_a (µm)	S/N (R_a)
1	2.527	-8.0521
2	5.102	-14.1548
3	7.235	-17.1888
4	4.325	-12.7197
5	6.121	-15.7364
6	3.024	-9.6116
7	7.140	-17.0740
8	4.216	-12.4980
9	5.244	-14.3933
10	3.736	-11.4481
11	7.526	-17.5313
12	3.245	-10.2243
13	4.260	-12.5882
14	3.205	-10.1166
15	5.714	-15.1388
16	2.765	-8.8339
17	4.173	-12.4090
18	6.911	-16.7908
19	5.462	-14.7470
20	3.527	-10.9481
21	4.921	-13.8411
22	2.305	-7.2534
23	3.843	-11.6934
24	6.254	-15.9232
25	4.217	-12.5001
26	5.106	-14.1616
27	3.729	-11.4318

Table 7 Mean values of Surface Roughness (R_a)

Level	T_{ON}	T_{OFF}	WT	WF
1	4.993	4.809	4.082	3.171
2	4.615	4.339	4.758	4.586
3	4.374	4.833	5.142	6.224
Delta	0.619	0.494	1.060	3.052
Rank	3	4	2	1

From the mean values of Surface Roughness values Main effect plot was drawn and shown in figures 4.1 and 4.2. From the plots it is observed that the main effect on Surface Roughness is due to Wire feed rate. We can observe a significant change in Surface Roughness with the change in levels of wire feed rate whereas it is less in case of other parameters. The optimal process parameters with their levels were given in the table 8.

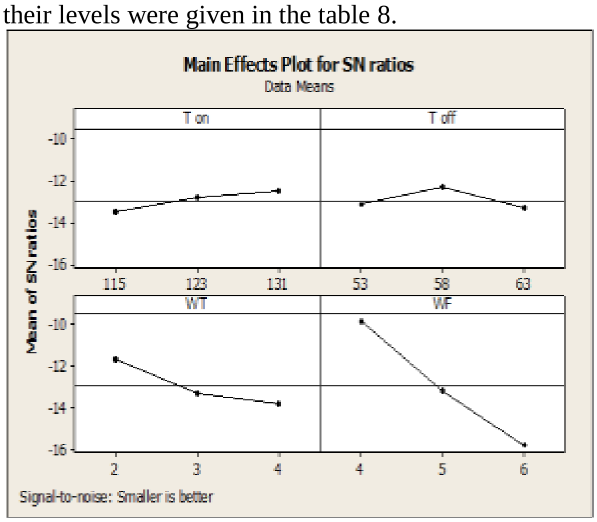

Figure 4.1 Main Effects Plot for S/N ratios of R_a

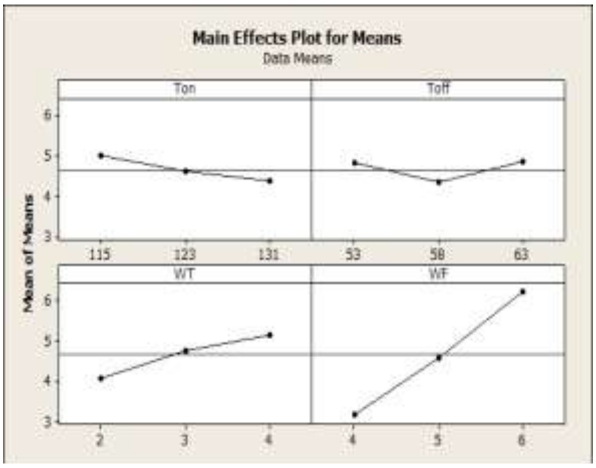

Figure 4.2 Main Effects Plot for means of R_a

Table 8 Optimal combination of process parameters for R_a

S. No.	Parameter	Units	Level	Value
1	Pulse on time (T_{ON})	µs	3	131
2	Pulse off time (T_{OFF})	µs	2	58
3	Wire Tension (WT)	Kg-f	1	2
4	Wire Feed (WF)	m/min	1	4

Analysis of variance was used to find the influence of machining parameters on Surface Roughness. The ANOVA results were given in the table9. From the results, it is concluded that Wire feed rate has high influence (F = 47.16) followed by Wire tension (F= 5.82), Pulse on time (F = 1.97) and Pulse off time has low significance (F = 1.57) on Surface Roughness.

Table 9 Analysis of variance for R_a

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Ton	2	1.7515	1.7515	0.8758	1.97	0.169
Toff	2	1.3979	1.3979	0.6990	1.57	0.235
WT	2	5.1837	5.1837	2.5919	5.82	0.011
WF	2	42.003	42.003	21.001	47.16	0.000
Error	18	8.0157	8.0157	0.4453		
Total	26	58.351				

S = 0.667320; R-Sq = 86.26%; R-Sq (Adj) = 80.16%

Prediction of optimal design

Performance of R_a when the two most significant factors are at their better level (based on estimated average).

$\mu_{A1B1} = A_1 + B_1 - T$

$A_1 = 3.171$, $B_1 = 4.082$ (From Table 7)

T = 4.660 (From Table 6)

$\mu_{A1B1} = A_1 + B_1 - T$

= 3.171 + 4.082 - 4.66 = 2.593

$CI = \sqrt{((F_{95\%,1,doferror}\ V_{error})/(\eta_{efficiency}))}$

Where, $\eta_{efficiency}$ = N/(1+dof) of all parameters associated to that level.

$\eta_{efficiency}$ = N/ (1+dof) = 27/(1+2+2) = 27/5 = 5.4

V_{error} = 0.4453, (From Table 9)

$F_{95\%,1,18}$ = 4.4139 (From F-table)

CI = $\sqrt{(4.4139 \times 0.4453) / 5.4}$ = 0.6032

The predicted optimal range of Ra at 95% confidence level is obtained as,

$2.593 - 0.6032 \le \mu_{A1B1} \le 2.593 + 0.6032$

$1.9898 \le \mu_{A1B1} \le 3.1962$

4.1 Regression Analysis

A linear regression model was developed for Surface Roughness by using MINITAB-16 software. The relation between Output parameter Surface Roughness (R_a) and input parameters Pulse-on time (T_{ON}), Pulse-off time (T_{OFF}), Wire tension (WT) and Wire feed rate (WF) is given in the following model. Regression analysis of Surface Roughness was given in the table10. From the table it is clear that the model prepared is more accurate and adequate because of low variance (s = 0.661988) and high coefficient of determination (R-Sq = 83.5%) value. The accuracy and adequacy of the model prepared was checked graphically with Normal probability plot, versus fits and versus order plots drawn and shown in figures 4.1.1, 4.1.2 and 4.1.3. From the Normal probability plot, it is clear that the residuals are very close to the straight line represents all the residuals following Normal distribution.

$\mathbf{R_a}$ = 0.06 - 0.0387 $\mathbf{T_{ON}}$+ 0.0024 $\mathbf{T_{OFF}}$ + 0.53 **WT** + 1.53 **WF**

Table 10 Regression analysis for R_a of EN8 Steel

Predictor	Coefficient	SE Coefficient	T	P
Constant	0.055	3.142	0.02	0.986
$\mathbf{T_{ON}}$	-0.03868	0.01950	-1.98	0.060
$\mathbf{T_{OFF}}$	0.00244	0.03121	0.08	0.938
WT	0.5300	0.1560	3.40	0.003
WF	1.5262	0.1560	9.78	0.000

S= 0.661988; R-Sq = 83.5%; R-Sq (Adj) = 80.5%

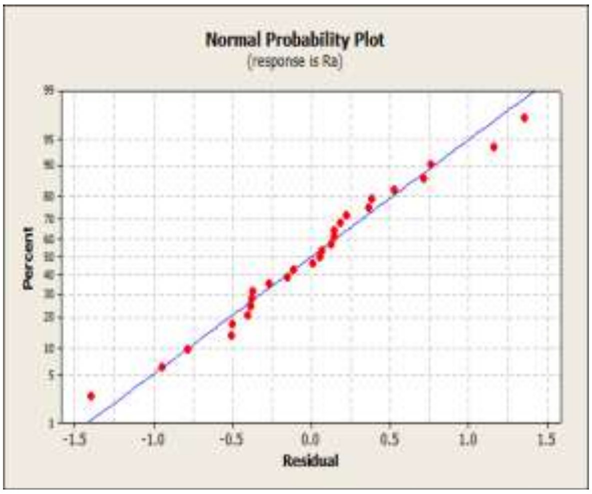

Figure 4.1.1 Normal probability plot for R_a

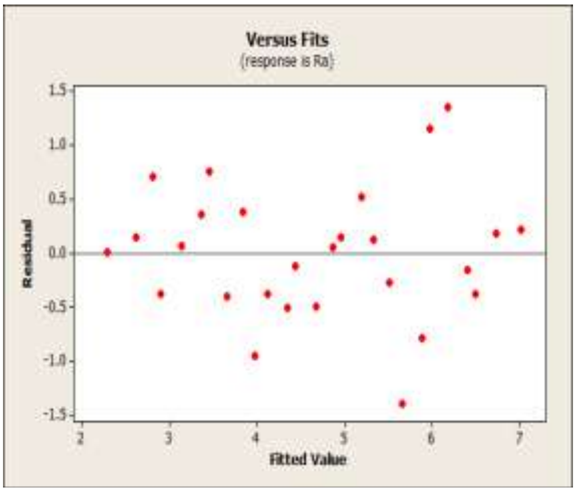

Figure 4.1.2 Versus Fits plot for R_a

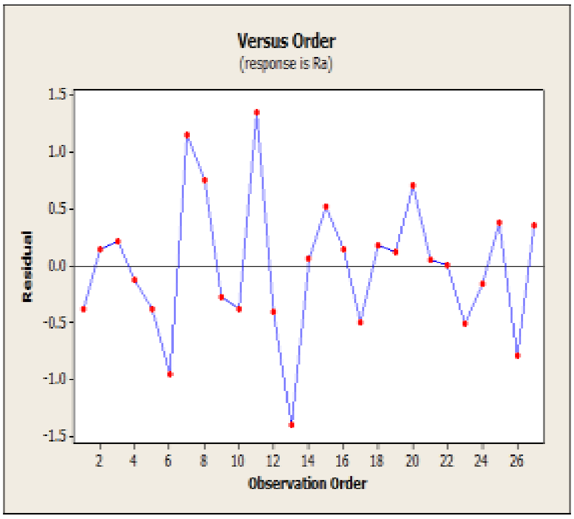

Figure 4.1.3 Versus Order plot for R_a

The surface plots were drawn by using MINITAB-16 software to find the relation between Response variable and input parameters and shown in figures 4.1.4 and 4.1.5. Surface plots are useful for establishing desirable response values and operating conditions and shows how a response variable relates to two factors based on model equation. Figure 4.1.4 shows how the Pulse on time (T_{ON}) and Pulse off time (T_{OFF}) related to Surface Roughness (R_a). To minimize R_a, we have to choose low values of T_{ON} and $T_{OFF.}$ Similarly, Figure 4.1.5 shows how the Wire Tension (WT) and Wire Feed (WF) related to Surface Roughness (R_a). To minimize R_a, we have to choose low values of both Wire tension and Wire feed.

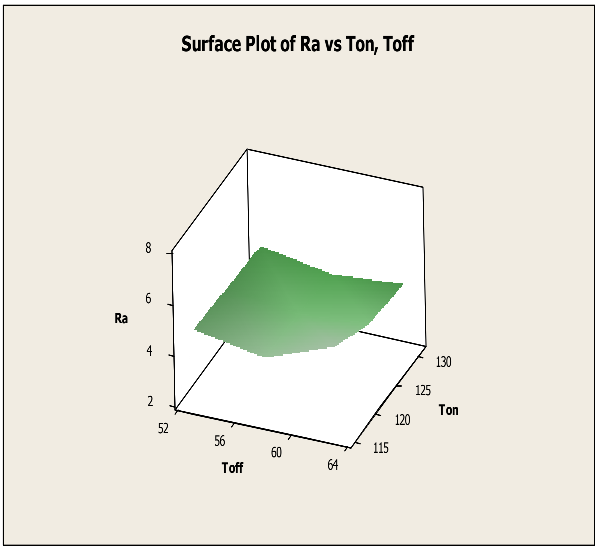

Figure 4.1.4 Surface Plot for Ra Vs T_{ON}, T_{OFF}

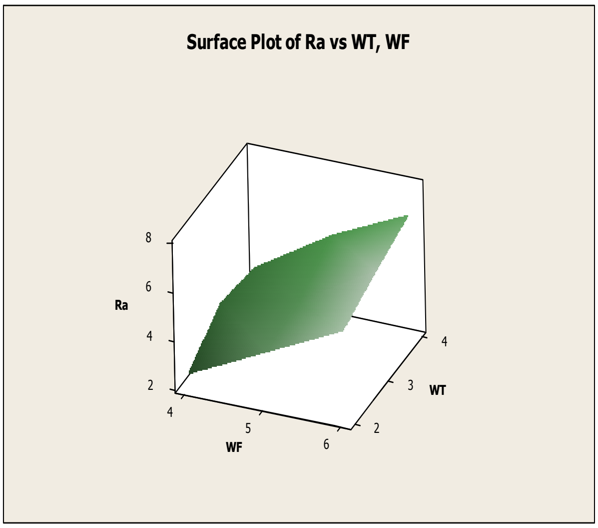

Figure 4.1.5 Surface Plot for Ra Vs WT, WF

4.2 Comparison of Regression and Experimental values of Surface Roughness.

The Experimental results were compared with the Regression model results. The experimental and Regression values of experiments were given in the table11. From the values comparison graph was drawn by taking experiment number on X-axis and Surface Roughness (R_a) on Y-axis and shown in figure 4.2.1. From the figure we can observe that both the values are very close to each other and hence, the Regression model prepared can be used for the prediction of Surface Roughness.

Table 11 Experimental and Regression values of R_a

S.No.	R_a (Experimental)	R_a (Regression)
1	2.527	2.9167
2	5.102	4.9767
3	7.235	7.0367
4	4.325	4.4587
5	6.121	6.5187
6	3.024	3.9887
7	7.140	6.0007
8	4.216	3.4707
9	5.244	5.5307
10	3.736	4.1371
11	7.526	6.1971
12	3.245	3.6671
13	4.260	5.6791
14	3.205	3.1491
15	5.714	5.2091
16	2.765	2.6311
17	4.173	4.6911
18	6.911	6.7511
19	5.462	5.3575
20	3.527	2.8275
21	4.921	4.8875
22	2.305	2.3095
23	3.843	4.3695
24	6.254	6.4295
25	4.217	3.8515
26	5.106	5.9115
27	3.729	3.3815

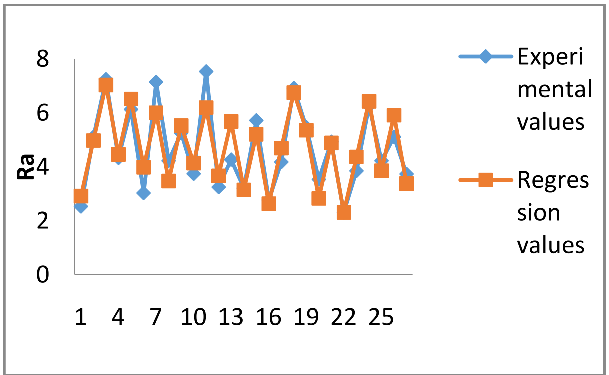

Figure 4.2.1 Comparison graph for experimental and Regression values

V. CONCLUSIONS

Based on the experimental and Regression results obtained by Taguchi and ANOVA, the following conclusions can be drawn:

1. The Optimal combination of process parameters for obtaining Low Surface Roughness values at
   Pulse on time (T_{ON}), level 3, 131 µs
   Pulse-off time (T_{OFF}), level 2, 58 µs
   Wire Tension (WT), level 1, 2 Kg-f
   Wire Feed rate (WF), level 1, 1m/min.
2. From ANOVA results it is clear that Wire feed rate is the most dominant parameter that has high influence on Surface Roughness (R_a) followed by wire tension, Pulse on time (T_{ON}) and Pulse off time (T_{OFF}) has very low influence.
3. Regression models prepared were accurate and adequate because of low variance (s = 0.661988) and high coefficient of determination (R-Sq = 83.5%) values.

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