MULTI-VARIBLE OPTIMIZATION OF STAINLESS STEEL 304,310 WELDING USING GREY TAGUCHI METHOD AND RESPONSE SURFACE METHOD

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Abstract

Gas Tungsten Arc welding is one mostly preferred welding technique used for welding stainless steel because of concentrated heat source, very stable arc, calm welding pool of small size, sound and pure weld. Therefore for the present experimentation, TIG welding technique is used to join stainless steel 304,310.

The experimentation is done on AISI 304,310 and analyses are performed to get Maximum Penetration and Minimum HAZ and Bead width. Since these output variables are inversely proportional (minimized and maximized at the same time), we have chosen Grey-taguchi method to optimize these variables. The process parameters chosen for the experimentation are pulse current, pulse frequency, welding speed, Arc force.

Methodology of grey-taguchi method starts with Grey Relational Analysis. Using grey relational analysis, we find Grey Grade which inturn is used to find the optimal Range for the given parameters. Using S/N ratio graph, we can find the level of the process parameters which yield the required results. These values are checked for significance using RSM.

Keywords: *GTAW, AISI 304, AISI 310, Grey-taguchi method, Response surface method.*

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1. INTRODUCTION

1.1 TIG Welding

TIG (tungsten inert gas) welding is the process of blending together reactive metals, which uses non-consumable electrode and shielding gas (generally inert so they do not combust or interact with welding process). It takes a higher degree of skill with proper training to produce smoother and cleaner welds.

Welding is done with the arc, which is generated between a pointed tungsten electrode and the area to be welded along with the shielding gas which prevents oxidization as well as maintains clean weld. For high quality manual welding, this is commonly used.

Electrical current is channeled through the metal tip of electrode which generates high intensity arc which melts the metal. Compared to consumable electrodes, where probe is slowly burned away, in TIG welding the electrode is not consumed. So it doesn't need to replace.

1.2 Selection of Material

Stainless steel are classified into austenitic, ferritic, martens tic etc. Most widely used nonmagnetic stainless steel is Austenitic steel. It has high amount of chromium and nickel, which make it ductile and provide high resistance to corrosion. It also has added advantage to welding due to its large scale of service temperature and good weld ability. For our experimentation, we chose stainless steel 304, 310 considering it low thermal conductivity, high toughness, tendency to be sticky and poor chip-breaking characteristics.

The chemical Composition of SS 304 & SS 310 is as listed in below tables.

Table -1: Chemical Composition of SS 304

Grade		C	Mn	Si	P	S	Cr	Ni	N
304	Min	-	-	-	-	-	18	8.0	-
	Max	0.08	2	0.75	0.045	0.03	20	10.5	0.1

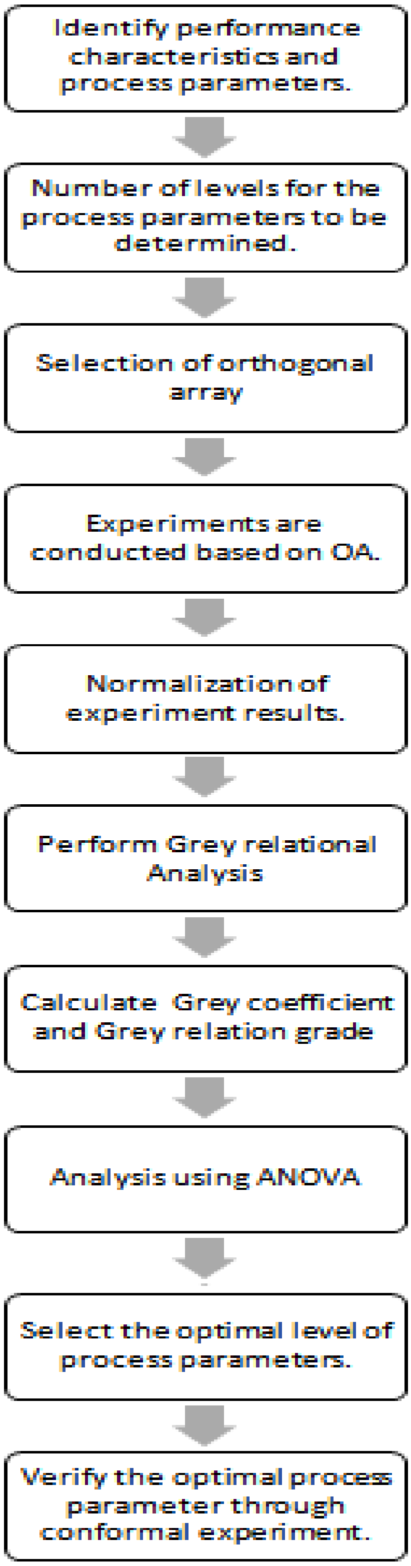
Table -2: Chemical Composition of SS 310

Grade		C	Mn	Si	P	S	Cr	Ni
310	Min	-	-	-	-	-	24	19
	Max	0.25	2.0	1.5	0.045	0.03	26	22

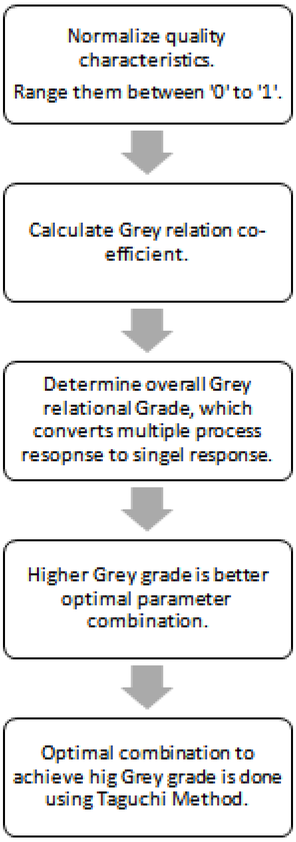
2. TAGUCHI METHOD

Orthogonal array (OA) of experiments is a technique developed Japanese scientist Genichi Taguchi. It is widely used in engineering to optimize the process parameters. It is possible to integrate DOE with parametric optimization of process in Taguchi method. The procedure can be described as OA provides set of well-balanced experiments and Taguchi's logarithmic functions of desired output provides signal to noise(S/N) ratio, serving as objective functions for optimization. We can determine the best quality characteristic for particular applications by OA and S/N, which studies the effect of control factors and noise factors. Taguchi method was designed to optimize single performance characteristics.

The introduction of Grey relational Analysis to taguchi will help resolve the issue and optimize multiple performance characteristics. The procedure is described below.



3. GREY RELATIONAL ANALYSIS



4. EXPERIMENTAL WORK AND TEST RESULTS

In this study of TIG welding of stainless steel is done by taking "Four" parameters namely Pulse Current, Pulse Frequency, Welding Speed, Arc Force, which are to be optimized in order to maximize "Area of Penetration" and minimize "HAZ" and "Bead Width". The process parameters with levels are shown in the table.

Table: 3 Selected Factors and their Levels

Factors	Units	L 1	L 2	L 3
Pulse Current (F_1)	A	60	80	100
Pulse Frequency (F_2)	Hz	2	2.5	3
Welding Speed (F_3)	Cm/min	10	20	30
Arc force (F_4)	Mm	1.5	2	2.5

4.1 Selection of Orthogonal Array

Based on the levels of the four parameters appropriate Orthogonal Array is to be selected for the design of experiments. Here in this study the level of each parameter taken is "three". So based on four parameters with three levels combination L9 Orthogonal Array is selected and the design of experiments is shown in the table below.

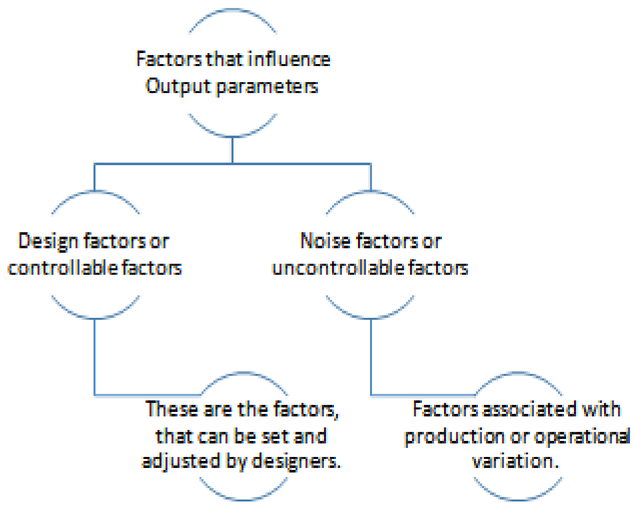
Table: 4 Orthogonal Array (OA) L9

Exp. No	Pulse current (F1)	Pulse Frequency (F2)	Welding Speed (F3)	Arc force (F4)
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table: 5 Experimental Results of P, HAZ, BW for the Given Orthogonal Array L9

S.No	F_1	F_2	F_3	F_4	P	HAZ	BW
1	60	2	10	1.5	1.88	1.90	5.21
2	60	2.5	20	2	1.32	1.02	4.81
3	60	3	30	2.5	0.96	0.86	3.63
4	80	2	20	2.5	1.23	2.03	5.64
5	80	2.5	30	1.5	1.04	1.03	4.94
6	80	3	10	2	1.07	2.18	5.32
7	100	2	30	2	1.37	2.88	5.13
8	100	2.5	10	2.5	1.98	3.08	6.74
9	100	3	20	1.5	1.45	2.01	5.09

4.2 Signal to Noise Ratio



The setting of control factors to be best is essential as they influence the output parameters through experiment. After the experiment the quality is measure by the deviation of functional characteristic from its target values. The loss of quality is due to uncontrollable factors which can cause deviations, these are named as Noises. Taguchi methods leads to robust design by reducing the effect of noises leading to optimization through quality loss function. This function efforts to continually reduce the variation in a product's functional characteristics.

The loss function transformed into signal-to-noise (S/N) ratio.

- 'Signal':- is the change in quality characteristics under investigation in response to a factor introduced in the experimental design.
- 'Noise':- The outcome of the quality characteristics under the effect of external factors (uncontrollable factors).

Therefore S/N ratio is the sensitivity of the quality characteristic. The aim of any experiment is always to determine the highest possible S/N ratio for the result irrespective of the quality characteristics. Depending upon the type of response, the following three types of S/N ratios are employed in practice:

Larger (S/N) Ratio:-

$$S/_N\,(n) = -10log_{10}(1/_n)\sum_{i=1}^{n}\frac{1}{y^2{}_{ijk}} \qquad (1)$$

Smaller (S/N) Ratio:-

$$S/_N\,(n) = -10log_{10}(1/_n)\sum_{i=1}^{n}y^2{}_i \qquad (2)$$

Nominal (S/N) Ratio:-

$$S/_N\,(n) = -10log_{10}(\frac{\mu^2}{\sigma^2}) \qquad (3)$$

For the present experiment, we need to have "Smaller Signal to Noise ratio" for HAZ and Bead width and "Larger Signal to Noise ratio" for Penetration.

Table: 6:- Signal to Noise Ratio's

S.No	S/N of P	S/N of HAZ	S/N of BW
1)	5.483	-5.575	-14.336
2)	3.664	-3.66	-14.003
3)	1.888	-2.544	-13.253
4)	1.866	-3.761	-13.768
5)	1.515	-3.251	-13.790
6)	1.346	-4.072	-13.920
7)	1.519	-5.281	-13.961
8)	1.88	-6.168	-14.387
9)	2.010	-6.156	-14.360

4.3 Grey Relational Analysis (GRA)

This Technique is effective, which can be used for decision making of multiple attributes. In GRA, the experimental results of Penetration, Heat Affected Zone and Bead Width are normalized in the range between zero to one.

Heat Affected Zone(HAZ), Bead Width(BW) is normalized to smaller the better touchstone, represented by below formula.

$$x_i{}'(j) = \frac{\{max_j y_{ij} - y_{ij}\}}{\{max_j y_{ij} - min_j y_{ij}\}} \qquad (4)$$

Area of Penetration(P) follow larger-the-better , represented by below

$$x_i{}'(j) = \frac{\{y_{ij} - min_j y_{ij}\}}{\{max_j y_{ij} - min_j y_{ij}\}} \qquad (5)$$

Touchstone is determined as largest value in normalized data.
where $x_0{}'(j)$ - Grey relational generation,
min y_{ij} - smallest value of y_{ij} ,
max y_{ij} - largest value of y_{ij} ,

Table: 7 :- Normalized values of P, HAZ, BW

S.No	P	HAZ	BW
1)	1	0.8363	0.9550
2)	0.5644	0.3092	0.6613
3)	0.131	0	0
4)	0.1256	0.3359	0.4543
5)	0.04084	0.19528	0.4731
6)	0	0.42168	0.5879
7)	0.04186	0.75539	0.6244
8)	0.12912	1	1
9)	0.16069	0.9968	0.9758

The Grey relational coefficient $\xi i(j)$ can be calculated as:

$$\xi i(j) = \frac{\Delta_{min} + \zeta\,\Delta_{max}}{\Delta_{oi} + \zeta\,\Delta_{max}} \qquad (6)$$

Where,
ζ (0 ≤ ζ ≤ 1) – distinguishing coefficient, the value is 0.5 because this value usually provides moderate distinguishing effects and good stability ,

and $\Delta_{0i}(j) = |x_0{}'(j) - x_i{}'(j)|$,

$x_0{}'(j) = max_{i=1}^{n} x_i{}'(j)$, $x_i{}'(j)$ is normalized value.

$\Delta_{min} = |x_0{}'(j) - x_i{}'(j)|$ is smallest value of $\Delta_{0i}(j)$

$\Delta_{max} = |x_0{}'(j) - x_i{}'(j)|$ is largest value of $\Delta_{0i}(j)$.

$\Delta_{oi}\ Table:-$

Table 8:- Δ_{oi} values

S.No	P	HAZ	BW
1)	0	0.1637	0.045
2)	0.4356	0.69079	0.3386
3)	0.869	1	1
4)	0.8744	0.6641	0.5456
5)	0.9591	0.80472	0.5269
6)	1	0.5783	0.4121
7)	0.95814	0.2446	0.3756
8)	0.87088	0	0
9)	0.83931	0.0032	0.0242

Grey Relation Co-efficient Table:-

Table 9:- Grey Relation Co-efficient Table

S.No	P	HAZ	BW
1)	1	0.7533	0.9910
2)	0.5344	0.4198	0.5962
3)	0.3637	0.4295	0.4781
4)	0.3637	0.4295	0.4781
5)	0.3426	0.38322	0.4869
6)	0.3333	0.4636	0.5481
7)	0.3429	0.6715	0.5710
8)	0.3647	1	1
9)	0.3733	0.9936	0.9538

Grey Relation Grade:-

$$\gamma = \frac{1}{n}\sum_{k=1}^{n}\xi_i(j) \quad (7)$$

Table 10:- Grey Relation Grade

S.No	GRG
1)	0.9147
2)	0.5168
3)	0.3439
4)	0.4237
5)	0.4042
6)	0.4483
7)	0.5284
8)	0.7882
9)	0.7735

The grey relational grade obtained for different Welding parameters. The larger the grey relational grade, the closer the product quality is to ideal value, making the larger grey relation grade as desired for optimum performance. Therefore, the optimal level of Welding parameters setting for improved penetration and minimum Heat Affected Zone (HAZ) and Bead Width is (A_3, B_2, C_1, D_3).

4.4 Optimal Factor Level Determination

The optimal factor level is assigning the level at which the results are optimized. This is done by taking all the grey grade at level 1 for the factor 1 and then dividing the value by number of values at level 1. This is illustrated as below.

$$OFL_{1,1} = \frac{0.9147 + 0.5168 + 0.3439}{3} = 0.5918$$

Table 11:- Optimal Factor Level Determination

Level	Factor 1	Factor 2	Factor 3	Factor 4
1	0.5918	0.6222*	0.7170*	0.6974*
2	0.4254	0.5697	0.5713	0.4978
3	0.6967*	0.5219	0.4255	0.5186

According to the above, the level which gives highest value at each factor is the optimal level for the factor. From the above figure, we can say the optimal level for the parameters are A_3, B_1, C_1, D_1.

5. RESPONSE SURFACE METHODOLOGY

It's a methodology derived from collection of mathematical and statistical technique in which output is influenced by different input variables. The objective is to find the correlation between the response and the variables. Least square error fitting of response surface is used to model these relations.

Table 12:- RSM Central Composite Design Table

Exp.No	F1	F2	F3	F4
1	-1	-1	-1	-1
2	1	-1	-1	-1
3	-1	1	-1	-1
4	1	1	-1	-1
5	-1	-1	1	-1
6	1	-1	1	-1
7	-1	1	1	-1
8	1	1	1	-1
9	-1	-1	-1	1
10	1	-1	-1	1
11	-1	1	-1	1
12	1	1	-1	1
13	-1	-1	1	1
14	1	-1	1	1
15	-1	1	1	1
16	1	1	1	1
17	-2	0	0	0
18	2	0	0	0
19	0	-2	0	0
20	0	2	0	0
21	0	0	-2	0
22	0	0	2	0
23	0	0	0	-2
24	0	0	0	2
25	0	0	0	0
26	0	0	0	0
27	0	0	0	0
28	0	0	0	0
29	0	0	0	0
30	0	0	0	0

Experimentation Results:

Table 13:- Experimentation Results

Exp.No	P	HAZ	BW
1	1.58	1.8	5.83
2	2.24	3.12	7.019
3	1.12	1.04	5.12
4	1.34	2.8	6
5	0.69	0.9	3.82
6	1.67	2.32	5.52
7	0.34	0.09	3.63
8	0.63	1.5	5.18
9	1.74	2.32	5.94
10	2.68	3.84	7.23
11	1.48	3.21	5.58
12	1.98	1.5	6.89
13	1.43	1.22	5.09
14	1.79	2.5	5.72
15	0.4	0.5	3.71
16	1.32	2.21	5.06
17	0.99	0.3	4.32
18	1.77	3.52	6.41
19	1.9	2.43	5.89
20	0.91	1.21	5.11
21	2.21	3.012	7.07
22	0.51	1.43	3.74
23	0.97	1.84	4.99
24	1.69	2.72	6.23
25	1.45	2.52	5.43
26	1.47	2.56	5.47
27	1.42	2.54	5.41
28	1.45	2.54	5.49
29	1.41	2.5469	5.39
30	1.48	2.58	5.46

The second order response surface model for the four selected parameters is given by the equation:
For four parameters, the selected polynomial could be expressed as:

$$y = b_0 \sum_{i=1}^{4} b_i x_i + \sum_{i=1}^{4} b_{ii} x_i^2 + \sum_{\substack{i,j=1 \\ j\neq i}}^{4} b_{ij} x_i x_j$$

For four parameters, the selected polynomial could be expressed as:

$$y = b_0 + b_1 S + b_2 V + b_3 F + b_4 G + b_{11} S^2 + b_{22} V^2 + b_{33} F^2 + b_{44} G^2 + b_{12} SV + b_{13} SF + b_{14} SG + b_{23} VF + b_{24} VG + b_{34} FG$$

Where b_0 the free term of regression equation, $b_1, b_2, \ldots, b_k$ the linear terms. $B_{11}, b_{22}, \ldots b_{kk}$ the quadratic terms and $b_{12}, b_{13}, \ldots, b_{k-1k}$ the interaction terms.

5.1 Fit Summary

For Penetration:-

Sequential Model Sum of Squares for Penetration						
	Sum of		**Mean**	**F**	**p-value**	
Source	**Squares**	**df**	**Square**	**Value**	**Prob > F**	
Mean vs Total	58.97	1	58.97			
Linear vs Mean	8.37	4	2.09	99.68	< 0.0001	Suggested
2FI vs Linear	0.11	6	0.019	0.87	0.5360	
Quadratic vs 2FI	0.021	4	5.250E-003	0.20	0.9337	
Cubic vs Quadratic	0.28	8	0.035	2.32	0.1426	Aliased
Residual	0.11	7	0.015			
Total	67.87	30	2.26			

Model Summary Statistics for penetration						
	Std.		**Adjusted**	**Predicted**		
Source	**Dev.**	**R-Squared**	**R-Squared**	**R-Squared**	**PRESS**	
Linear	0.14	0.9410	0.9316	0.9087	0.81	Suggested
2FI	0.15	0.9537	0.9293	0.7926	1.85	
Quadratic	0.16	0.9561	0.9150	0.7487	2.24	
Cubic	0.12	0.9879	0.9501	-0.6756	14.91	Aliased

For HAZ:-

Sequential Model Sum of Squares for HAZ						
	Sum of		**Mean**	**F**	**p-value**	
Source	**Squares**	**df**	**Square**	**Value**	**Prob > F**	
Mean vs Total	130.70	1	130.70			
Linear vs Mean	18.79	4	4.70	16.54	< 0.0001	Suggested
2FI vs Linear	1.51	6	0.25	0.86	0.5437	
Quadratic vs 2FI	1.90	4	0.47	1.93	0.1578	
Cubic vs Quadratic	2.55	8	0.32	1.94	0.1981	Aliased
Residual	1.15	7	0.16			
Total	156.60	30	5.22			

Model Summary Statistics for HAZ						
	Std.		**Adjusted**	**Predicted**		
Source	**Dev.**	**R-Squared**	**R-Squared**	**R-Squared**	**PRESS**	
Linear	0.53	0.7257	0.6818	0.5957	10.47	Suggested
2FI	0.54	0.7841	0.6705	0.1194	22.81	
Quadratic	0.50	0.8574	0.7244	0.1792	21.26	
Cubic	0.40	0.9558	0.8167	-5.3592	164.69	Aliased

For BW:-

Sequential Model Sum of Squares for BW						
	Sum of		**Mean**	**F**	**p-value**	
Source	**Squares**	**df**	**Square**	**Value**	**Prob > F**	
Mean vs Total	893.79	1	893.79			
Linear vs Mean	25.67	4	6.42	138.59	< 0.0001	Suggested
2FI vs Linear	0.078	6	0.013	0.23	0.9620	
Quadratic vs 2FI	0.074	4	0.018	0.27	0.8900	
Cubic vs Quadratic	0.98	8	0.12	32.65	< 0.0001	Aliased
Residual	0.026	7	3.751E-003			
Total	920.62	30	30.69			

Model Summary Statistics for BW						
	Std.		**Adjusted**	**Predicted**		
Source	**Dev.**	**R-Squared**	**R-Squared**	**R-Squared**	**PRESS**	
Linear	0.22	0.9568	0.9499	0.9327	1.80	Suggested
2FI	0.24	0.9598	0.9386	0.8130	5.02	
Quadratic	0.26	0.9625	0.9275	0.7852	5.76	
Cubic	0.061	0.9990	0.9959	0.8978	2.74	Aliased

5.2 Final Equation in Terms of Coded Factors

P = 1.44667 + 0.267917 * A + -0.299583 * B + -0.387083 * C + 0.19375 * D + -0.063125 * AB + 0.014375 * AC + 0.035625 * AD + -0.035625 * BC + 0.018125 * BD + 0.000625 * CD + -0.0111458 * A^2 + -0.00489583 * B^2 + -0.0161458 * C^2 + -0.0236458 * D^2

HAZ = 2.54782 + 0.63125 * A + -0.317083 * B + -0.481417 * C + 0.22875 * D + -0.148125 * AB + 0.183125 * AC + -0.194375 * AD + -0.006875 * BC + 0.015625 * BD + -0.030625 * CD + -0.18085 * A^2 + -0.20335 * B^2 + -0.1031 * C^2 + -0.08835 * D^2

BW = 5.44167 + 0.586625 * A + -0.273292 * B + -0.772458 * C + 0.232542 * D + 0.0175625 * AB + 0.0350625 * AC + -0.0461875 * AD + -0.0088125 * BC + -0.0300625 * BD + -0.0150625 * CD + -0.0210521 * A^2 + 0.0126979 * B^2 + -0.0110521 * C^2 + 0.0401979 * D^2.

5.3 Final Equation in Terms of Actual Factors

P = 1.44667 + 0.267917 * A + -0.299583 * B + -0.387083 * C + 0.19375 * D + -0.063125 * A * B + 0.014375 * A * C + 0.035625 * A * D + -0.035625 * B * C + 0.018125 * B * D + 0.000625 * C * D + -0.0111458 * A^2 + -0.00489583 * B^2 + -0.0161458 * C^2 + -0.0236458 * D^2.

HAZ = 2.54782 + 0.63125 * A + -0.317083 * B + -0.481417 * C + 0.22875 * D + -0.148125 * A * B + 0.183125 * A * C + -0.194375 * A * D + -0.006875 * B * C + 0.015625 * B * D + -0.030625 * C * D + -0.18085 * A^2 + -0.20335 * B^2 + -0.1031 * C^2 + -0.08835 * D^2.

BW = 5.44167 + 0.586625 * A + -0.273292 * B + -0.772458 * C + 0.232542 * D + 0.0175625 * A * B + 0.0350625 * A * C + -0.0461875 * A * D + -0.0088125 * B * C + -0.0300625 * B * D + -0.0150625 * C * D + -0.0210521 * A^2 + 0.0126979 * B^2 + -0.0110521 * C^2 + 0.0401979 * D^2

5.4 Normal Probability Plot

For Penetration

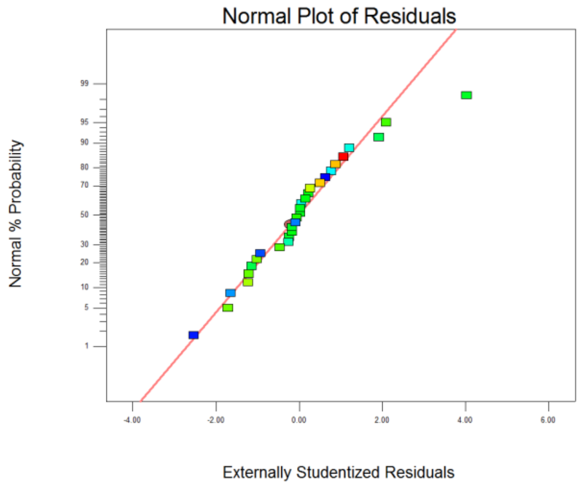


Fig 1:- Normal Probability Plot for Penetration

For HAZ

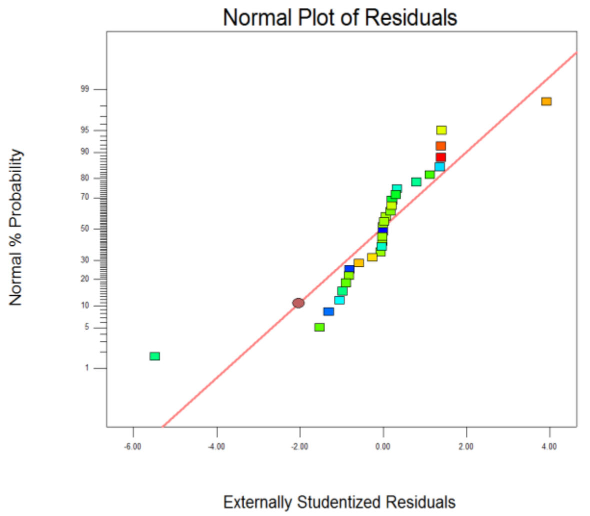


Fig 2:- Normal Probability Plot for HAZ

For BW

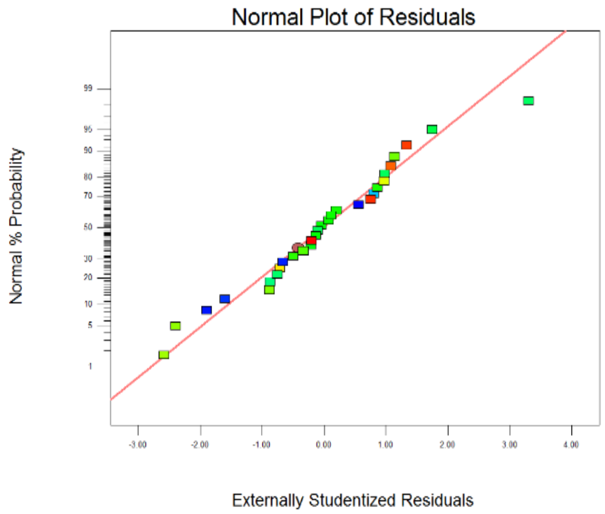


Fig 3:- Normal Probability Plot for BW

5.5 Residual vs Predicted

For penetration

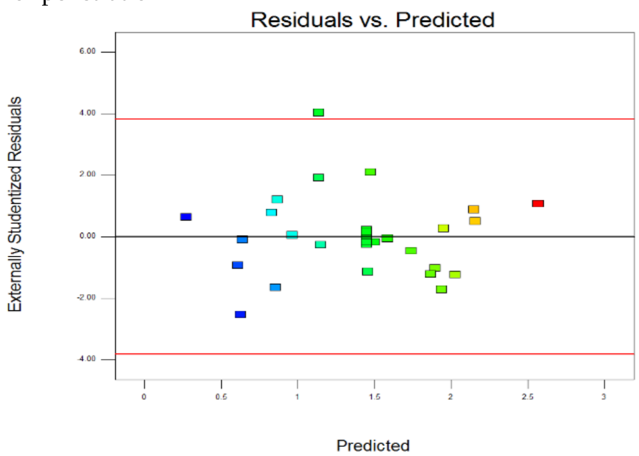


Fig 4:- Residual vs Predicted for Penetration

For HAZ

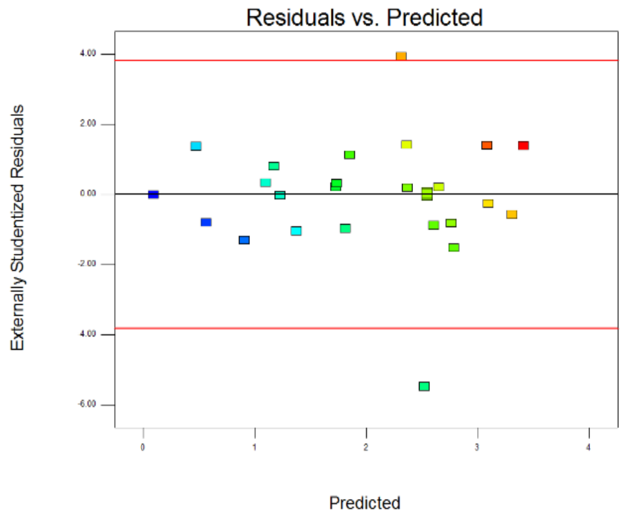


Fig 5:- Residual vs Predicted for HAZ

For BW

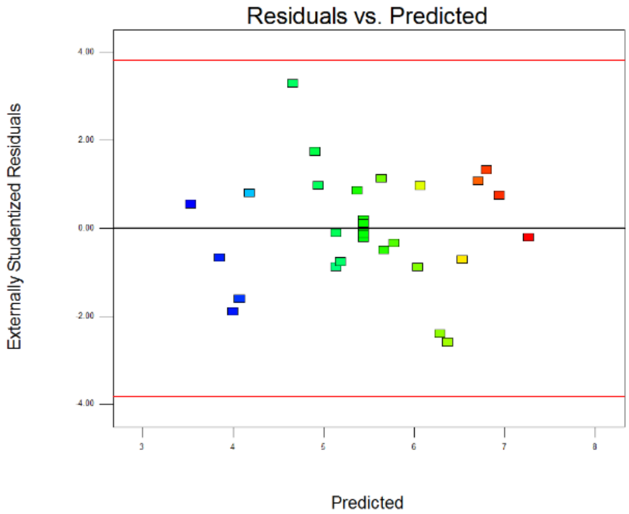


Fig 6:- Residual vs Predicted for BW

5.6 Predicted vs Actual

For penetration

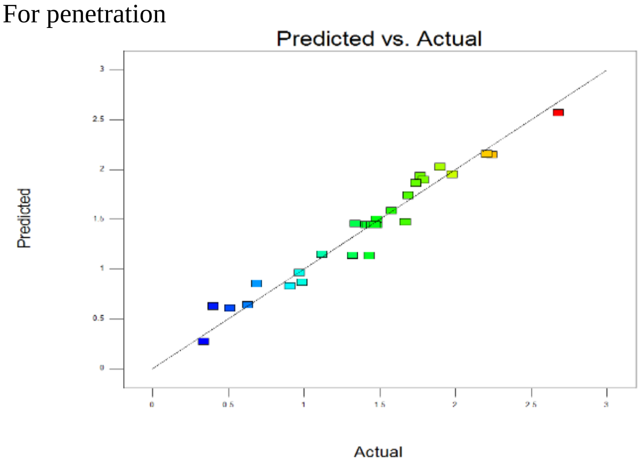


Fig 7:- Predicted vs Actual for Penetration

For HAZ

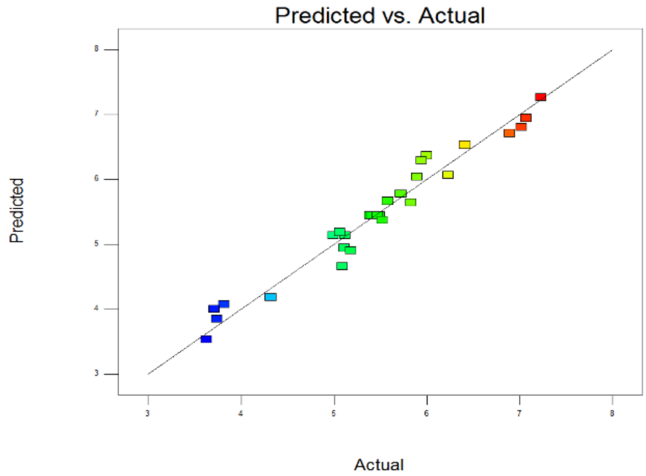


Fig 8:- Predicted vs Actual for HAZ

For BW

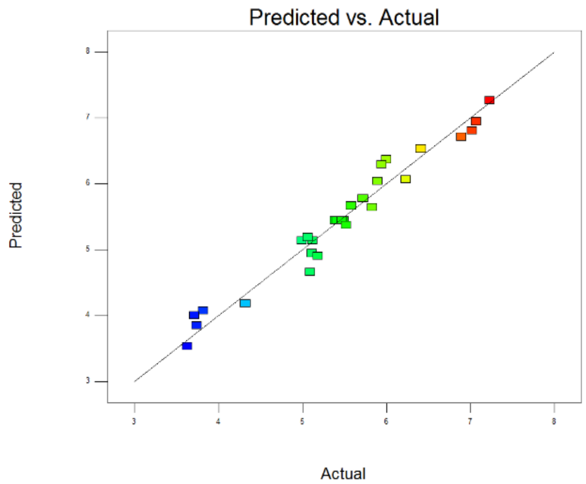


Fig 9:- Predicted vs Actual for BW

5.7.3-D Surface

For Penetration

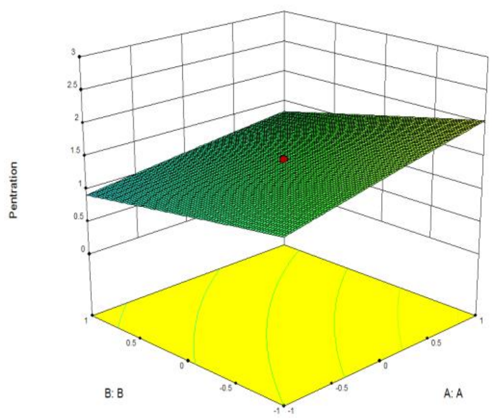


Fig 10:- 3-D Surface for Penetration

For HAZ

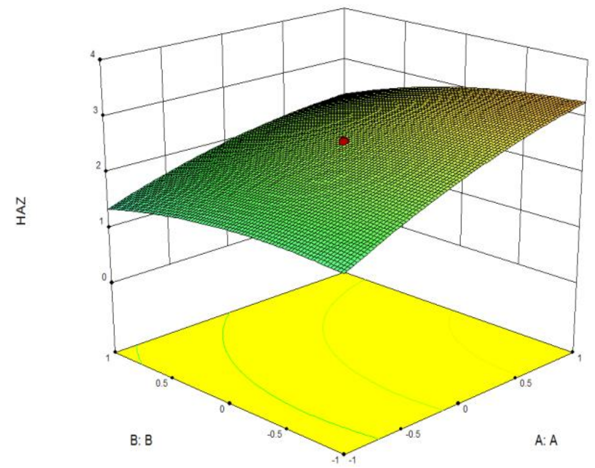


Fig 11:- 3-D Surface for HAZ

For BW

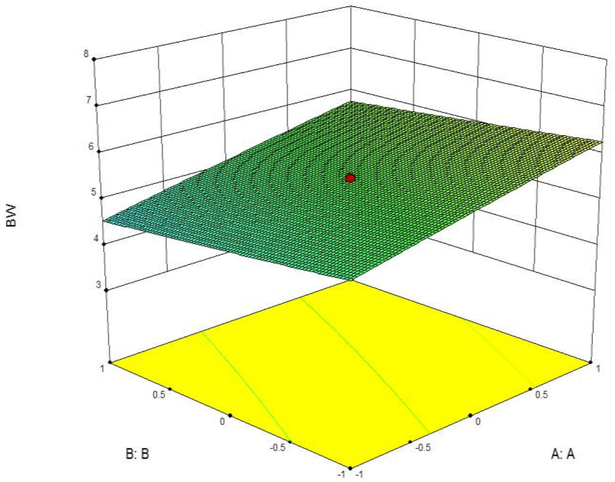


Fig 12:- 3-D Surface for BW

5.8 Anova Results

Response 1 Penetration

ANOVA for Response Surface Quadratic model						
Analysis of variance table [Partial sum of squares - Type III]						
	Sum of		**Mean**	**F**	**p-value**	
Source	**Squares**	**df**	**Square**	**Value**	**Prob > F**	
Model	8.51	14	0.61	23.31	< 0.0001	significant
A-A	*1.72*	*1*	*1.72*	*66.07*	*< 0.0001*	
B-B	*2.15*	*1*	*2.15*	*82.62*	*< 0.0001*	
C-C	*3.60*	*1*	*3.60*	*137.92*	*< 0.0001*	
D-D	*0.90*	*1*	*0.90*	*34.55*	*< 0.0001*	
AB	*0.064*	*1*	*0.064*	*2.45*	*0.1387*	
AC	*3.306E-003*	*1*	*3.306E-003*	*0.13*	*0.7267*	
AD	*0.020*	*1*	*0.020*	*0.78*	*0.3914*	
BC	*0.020*	*1*	*0.020*	*0.78*	*0.3914*	
BD	*5.256E-003*	*1*	*5.256E-003*	*0.20*	*0.6599*	
CD	*6.250E-006*	*1*	*6.250E-006*	*2.397E-004*	*0.9879*	
A^2	*3.407E-003*	*1*	*3.407E-003*	*0.13*	*0.7228*	
B^2	*6.574E-004*	*1*	*6.574E-004*	*0.025*	*0.8759*	
C^2	*7.150E-003*	*1*	*7.150E-003*	*0.27*	*0.6082*	
D^2	*0.015*	*1*	*0.015*	*0.59*	*0.4550*	
Residual	0.39	15	0.026			
Lack of Fit	*0.39*	*10*	*0.039*	*51.88*	*0.0002*	*significant*
Pure Error	*3.733E-003*	*5*	*7.467E-004*			
Cor Total	8.90	29				

The Model F-value of 23.31 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise.

Response 2 HAZ

ANOVA for Response Surface Quadratic model						
Analysis of variance table [Partial sum of squares - Type III]						
	Sum of		**Mean**	**F**	**p-value**	
Source	**Squares**	**df**	**Square**	**Value**	**Prob > F**	
Model	22.21	14	1.59	6.44	0.0005	significant
A-A	*9.56*	*1*	*9.56*	*38.86*	*< 0.0001*	
B-B	*2.41*	*1*	*2.41*	*9.80*	*0.0069*	
C-C	*5.56*	*1*	*5.56*	*22.60*	*0.0003*	
D-D	*1.26*	*1*	*1.26*	*5.10*	*0.0392*	
AB	*0.35*	*1*	*0.35*	*1.43*	*0.2509*	
AC	*0.54*	*1*	*0.54*	*2.18*	*0.1605*	
AD	*0.60*	*1*	*0.60*	*2.46*	*0.1379*	
BC	*7.562E-004*	*1*	*7.562E-004*	*3.073E-003*	*0.9565*	
BD	*3.906E-003*	*1*	*3.906E-003*	*0.016*	*0.9014*	
CD	*0.015*	*1*	*0.015*	*0.061*	*0.8083*	
A^2	*0.90*	*1*	*0.90*	*3.64*	*0.0756*	
B^2	*1.13*	*1*	*1.13*	*4.61*	*0.0486*	
C^2	*0.29*	*1*	*0.29*	*1.18*	*0.2936*	
D^2	*0.21*	*1*	*0.21*	*0.87*	*0.3658*	
Residual	3.69	15	0.25			
Lack of Fit	*3.69*	*10*	*0.37*	*886.54*	*< 0.0001*	*significant*
Pure Error	*2.081E-003*	*5*	*4.162E-004*			
Cor Total	25.90	29				

The Model F-value of 6.44 implies the model is significant. There is only a 0.05% chance that an F-value this large could occur due to noise. **Response 3 BW**

ANOVA for Response Surface Quadratic model						
Analysis of variance table [Partial sum of squares - Type III]						
	Sum of		**Mean**	**F**	**p-value**	
Source	**Squares**	**df**	**Square**	**Value**	**Prob > F**	
Model	25.82	14	1.84	27.50	< 0.0001	significant
A-A	*8.26*	*1*	*8.26*	*123.15*	*< 0.0001*	
B-B	*1.79*	*1*	*1.79*	*26.73*	*0.0001*	
C-C	*14.32*	*1*	*14.32*	*213.52*	*< 0.0001*	
D-D	*1.30*	*1*	*1.30*	*19.35*	*0.0005*	
AB	*4.935E-003*	*1*	*4.935E-003*	*0.074*	*0.7899*	
AC	*0.020*	*1*	*0.020*	*0.29*	*0.5961*	
AD	*0.034*	*1*	*0.034*	*0.51*	*0.4866*	
BC	*1.243E-003*	*1*	*1.243E-003*	*0.019*	*0.8935*	
BD	*0.014*	*1*	*0.014*	*0.22*	*0.6491*	
CD	*3.630E-003*	*1*	*3.630E-003*	*0.054*	*0.8192*	
A^2	*0.012*	*1*	*0.012*	*0.18*	*0.6763*	
B^2	*4.423E-003*	*1*	*4.423E-003*	*0.066*	*0.8008*	
C^2	*3.350E-003*	*1*	*3.350E-003*	*0.050*	*0.8262*	
D^2	*0.044*	*1*	*0.044*	*0.66*	*0.4290*	
Residual	1.01	15	0.067			
Lack of Fit	*1.00*	*10*	*0.100*	*68.56*	*0.0001*	*significant*
Pure Error	*7.283E-003*	*5*	*1.457E-003*			
Cor Total	26.83	29				

The Model F-value of 27.50 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise.

6. CONCLUSION

From the optimization model developed by using Grey-Taguchi method, it was found that when we are using the Pulse Current at level 3(100A), the Pulse Frequency at level 2(2.5Hz), the Welding Speed 3 at level 1(10 cm/min) and the Arc Force at level 3(2.5 mm), the model yields higher area of penetration, with low Heat Affected Zone, and low Bead width. The model was again retested using RSM method and the models was found to significant

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BIOGRAPHIES

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