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Optimization of Process Parameters of Gas Metal Arc Welding to Improve Quality of Weld Bead Geometry

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Abstract: In this work, a grey-based Taguchi method is adopted to optimize the Gas Metal Arc Welding Process parameters. Many quality characteristic parameters are combined into one integrated quality parameter by using grey relational grade or rank. The welding process parameters considered in this analysis are voltage, wire feed rate, Welding Speed, Nozzle to Plate Distance and Gas Flow. The quality parameters consider are Penetration, Reinforcement, and Bead Width. Analysis of variance has been performed to find out the effect of individual process parameter on the quality parameters. Experiments with the optimized parameter settings, which have been obtained from the analysis, are given to validate the results

Keywords: GMAW, Orthogonal Array, Taguchi Method, Grey Relational Analysis, ANOVA

I. Introduction

Welding technology is used in every branch of manufacturing. To consistently produce high quality of welds, arc welding requires experienced welding personnel to avoid distortion. Quality of a weld depends on welding input parameters. Optimum ranges of welding parameters are required for better economy and for improving productivity and profitability. This can be achieved by conducting experiment and developing the mathematical relationships between input and output process parameters.. The Optimum welding Parameter combination was obtained by using analysis of signal to noise (S/N) ratio. The S/N ratio calculated and used to obtain the optimum level for every input factor. Using Analysis of Variance (ANOVA) the adequacy of develop model is checked and significant coefficient for each input factor on weld bead geometry were determined and validated using MINITAB 15 Software.

In this work, a grey-based Taguchi method is adopted to optimize the Gas Metal Arc Welding Process parameters. Many quality characteristic parameters are combined into one integrated quality parameter by using grey relational grade or rank.(5) The welding process parameters considered in this analysis are voltage, wire feed rate, Welding Speed, Nozzle to Plate Distance and Gas Flow. The quality parameters consider are Penetration, Reinforcement, and Bead Width. Analysis of variance has been performed to find out the impact of individual process parameter on the quality parameters. Experiments with the optimized parameter settings, which have been obtained from the analysis, are given to validate the results. Confirmation Experiments are conducted on the GMAW welding set-up. Stainless steel plates of AISI 410 grade of 12mm thickness as a base metal.

GAS Metal Arcs welding (GMAW) process is an important component in many industrial operations. The GMAW welding parameters are the most important factors affecting the quality, productivity and cost of welding. This work presents the influence of welding parameters like welding current, welding voltage, welding speed on Penetration, Bead Width, and Bead Height of AISI 410 material during welding. A Design of experiments based on Taguchi technique is used to acquire the data. An Orthogonal array, signal to noise (S/N) ratio and analysis of variance (ANOVA) are employed to investigate the welding characteristics of AISI 410 material & optimize the welding parameters. Finally the conformation tests has is been carried out to compare the predicated values with the experimental values.

II. Experimentation Setup

The experiments were conducted at Sinhgad Institute of Technology, Lonavala, Pune on Structural steel plates of AISI 410 grade of steel 12mm thickness were cut into the required size of 70 mm×25 mm plates using stainless steel flux cored wire of 1.2 mm diameter. Experiments were carried out using the Advani Welding Machine (KTM400) under the shield of commercial argon gas. Fig1 shows a schematic diagram of the semimechanised welding station used during experimentation.

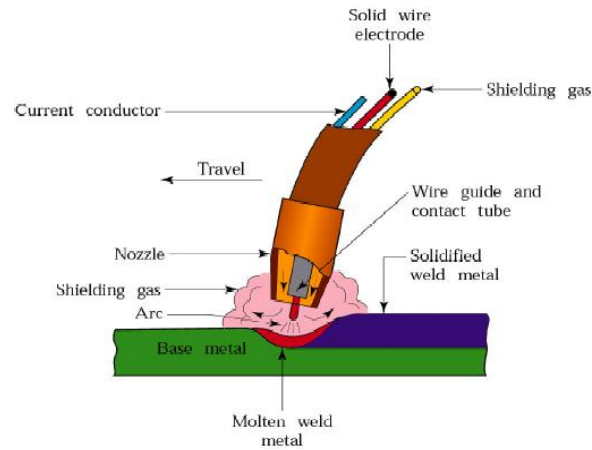


Fig 1: Experimental Setup

III. Materials & Composition

The base material selected for the experimentation is selected as Martensitic Stainless steel AISI 410 AWS A5.9 Grade and Stainless Steel Wire Electrode ER 410 is use for trials Confirm to AISI 410 (AWS A5.9) Grade and the data related to chemical composition, as shown in Table I & II .

Table I: Chemical Compositions of Base Material

410	Composition	C	Mn	Si	P	S	Cr	Ni
	Percent	0.15	1.00	1.00	0.040	0.030	11.5-13.5	0.75

Table II: Chemical Compositions of Electrode Wire

ER410	C	Mn	Si	Cr	Ni	Mo	Cu	S	P
	0.11	0.52	0.35	12.3	0.10	0.02	0.03	0.015	.015

IV. Research Methodology

The research work can be carried to predict and obtain the optimum solution of process parameters of GMAW using following steps:

- Identification of input and output welding process control parameters and their limits as shown in Table III.
- Development of design matrix and conducting experiments as per design matrix.
- Recording the responses.
- Developing the mathematical models.
- Checking the adequacy of the models developed using ANOVA.
- Conducting the trials using optimal combination setting.

Table III: Process Parameters and their levels

Process Parameters	Notation	Limits				
		-2	-1	0	+1	+2
Open Circuit Voltage (V)	V	26	28	30	32	34
Wire Feed Rate (m/min)	F	3	3.5	4	4.5	5
Welding Speed (cm/min)	S	20	25	30	35	40
Nozzle to plate distance (m)	N	9	10	11	12	13
Gas Flow Rate (lit/min)	G	16	17	18	19	20

The coded values for intermediate ranges were calculated using the following equation:

$$X_i = 2\{2X - (X_{\max} + X_{\min})\} / (X_{\max} - X_{\min})$$

a) Taguchi Method

Taguchi Method is developed by Dr. Genichi Taguchi, a Japanese quality management consultant. The method explores the concept of quadratic quality loss function and uses a statistical measure of performance called Signal-to-Noise (S/N) ratio. The S/N ratio takes both the mean and the variability into account. The S/N ratio is the ratio of the mean (Signal) to the standard deviation (Noise). The ratio depends on the quality characteristics of the product/process to be optimized. The standard S/N ratios generally used are as follows: - Nominal is Best (NB), Lower the Better (LB) and Higher the Better (HB). The optimal setting is the parameter combination, which has the highest S/N ratio.

$$\eta = 10 \ln_{10} \frac{1}{n} \sum_{i=1}^n \mu^2 \quad \text{-----(1)}$$

(Quality characteristics is usually a nominal out, say Diameter)

Taguchi's S/N Ratio for (LB) Lower-the-better

(Quality characteristic is usually a nominal output, say Defects)

$$\eta = -10 \ln_{10} \frac{1}{n} \sum_{i=1}^n y_i^2 \quad \text{----- (2)}$$

Taguchi's S/N Ratio for (HB) Higher-the-better

(Quality characteristics is usually a nominal output, say Current)

$$\eta = -10 \ln_{10} \frac{1}{n} \sum_{i=1}^n \frac{1}{y_i^2} \quad \text{-----(3)}$$

Table IV: Orthogonal Array Design

The left screenshot shows the Minitab 'Taguchi Orthogonal Array Design' window. It displays the design 'L25(5**5)' with 5 factors and 25 runs. Below, it lists the columns of the L25(5**6) array as 1, 2, 3, 4, 5.

The right screenshot shows the 'Columns of L25(5**6) Array' window. It displays a table with 25 rows (runs) and 8 columns (C1 to C8). The first five columns correspond to the factors V, F, S, N, and G. The table shows the levels for each factor across the 25 runs.

	C1	C2	C3	C4	C5	C6	C7	C8
	V	F	S	N	G			
14	3	4	1	3	5			
15	3	5	2	4	1			
16	4	1	4	2	5			
17	4	2	5	3	1			
18	4	3	1	4	2			
19	4	4	2	5	3			
20	4	5	3	1	4			
21	5	1	5	4	3			
22	5	2	1	5	4			
23	5	3	2	1	5			
24	5	4	3	2	1			
25	5	5	4	3	2			
26								
27								
28								
29								

V. Recording the responses and its S/N Ratio

As per the design of matrix 25 trails were conducted at random to avoid any systematic error creeping in to system. The specimen were cross-sectioned at the centre transversely along the bead so as to trace the bead profile. The cross sectioned specimen were ground, polished and inspected using digital vernier calliper. In order to measure clad bead geometry of transverse section of each weld overlays weld were cut from midlength. Position of the weld and end faces were machined and grinded. The specimen and faces were polished and

etched using a 5% vital solution to display bead dimensions. The clad bead profiles were traced using an optical profile projector at a magnification of X10, at Sinhgad Institute of Technology, Lonavala. The profile of the weld beads were traced using an optical profile projector and bead dimensions viz. penetration (P), bead width (W) and reinforcement (R) were recorded. The design of matrix and the recorded responses are tabulated as shown table no V. The testing results shown in table have been conducted in Sinhgad Institute of Technology Lonavala Pune.

Table V:Response and its S/N Ratio

SR No	Penetration	S/N Ratio	Reinforcement	S/N Ratio	Bead width	S/N Ratio
1	11.78	21.42	3	-9.54	14.88	-23.45
2	11.8	21.43	1.5	-3.52	13.3	-22.47
3	9.69	19.72	2.5	-7.95	14.71	-23.35
4	11.15	20.94	1.7	-4.6	12.44	-21.89
5	8.75	18.84	2.5	-7.95	14.35	-23.13
6	10.3	20.25	2.5	-7.95	11.49	-21.206
7	10.8	20.66	3	-9.54	16.86	-24.53
8	11.9	21.51	1	0	13.81	-22.803
9	10.87	20.72	1.6	-4.08	19.87	-25.95
10	10.89	20.74	4.8	-13.62	17.12	-24.67
11	10.82	20.68	3	-9.54	18.31	-25.25
12	12	21.58	1	0	14.87	-23.44
13	11.3	21.06	3.01	-9.57	15.95	-24.05
14	11.34	21.09	3.03	-9.62	17.01	-24.61
15	10.3	20.25	2.4	-7.604	18.31	-25.25
16	12	21.58	1.8	-5.105	17.05	-24.63
17	10.95	20.78	2.5	-7.95	16.81	-24.51
18	10.98	20.81	2	-6.02	16.35	-24.27
19	11.12	20.92	1.7	-4.608	16.4	-24.29
20	11.67	21.34	3.8	-11.59	16.16	-24.16
21	12	21.58	2.3	-7.234	17.03	-24.62
22	11.72	21.37	1.6	-4.08	15.53	-23.82
23	11.82	21.45	1.3	-2.27	11.13	-20.92
24	10.52	20.44	1.85	-5.343	13.8	-22.79
25	11.3	21.06	2	-6.02	15.89	-24.022

VI. Grey-based Taguchi methods for optimization of process parameters

a) Theory of Grey relational analysis

In Grey relational analysis, experimental data i.e. measured features of quality characteristics are the first normalized range from zero to one. This process is known as Grey relational generation. Next, based on normalized experimental data, Grey relational coefficient is calculated to represent the correlation between the desired and actual experimental data. Then overall Grey relational grade is determined by averaging the Grey relational coefficient corresponding to selected responses. The overall performance characteristics of the multiple response process depend on the calculated Grey relational grade. This approach converts a multiple response process optimization problem into single response optimization situation with the objective function is overall Grey relational grade. The optimal parametric combination is then evaluated which would results highest Grey relational grade..

In Grey relational generation, the normalized bead width, reinforcement and HAZ width, corresponding to lower-the-better (LB) criterion can be expressed as:

$$X_i(k) = \frac{\max y_i(k) - y_i(k)}{\max y_i(k) - \min y_i(k)}$$

Bead penetration should follow larger-the-better criterion, which can be expressed

$$x_i(k) = \frac{y_i(k) - \min y_i(k)}{\max y_i(k) - \min y_i(k)}$$

Where $x_i(k)$ is the value after the Grey relational generation, $\min y_i(k)$ is the smallest value of $y_i(k)$ for the k th response, and $\max y_i(k)$ is the largest value of $y_i(k)$ for the k th response. The normalized data after Grey relational generation are tabulated in table 5.1. An ideal sequence is $x_0(k)$ ($k=1, 2, 3, \dots, 25$) for the responses. The definition of Grey relational grade in the course of Grey relational analysis is to reveal the degree of relation between the 25 sequences [$x_0(k)$ and $x_i(k)$, $i=1, 2, 3, \dots$].

b) Grey relational coefficient and Grey Relational Grade & its S/N Ratio

The Grey relational coefficient $\xi_i(k)$ can be calculated as

$$\xi_i(k) = \frac{\Delta_{\min} + \eta \Delta_{\max}}{\Delta_{oi}(K) + \eta \Delta_{\max}}$$

where $\Delta_{oi} = \|x_0(k) - x_i(k)\|$ $\Delta_{\min}$ = the smallest value of Δ_{oi} ; and

$\Delta_{\max}$ = largest value of Δ_{oi} . After averaging the Grey relational coefficients, Grey relational grade γ_i can be computed as:

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

where n = number of process responses. The higher value of Grey relational grade corresponds to intense relational degree between the reference sequence $x_0(k)$ and the given sequence $x_i(k)$. The reference sequence $x_0(k)$ represents the best process sequence; therefore, higher Grey relational grade means that the corresponding parameter combination is closer to the optimal.

Table VI: Normalizing of each responses, Grey Relational Coefficient and Grey Relation Grade and its S/N Ratio

Exp. No.	Penetration	Reinforcement	Bead Width	Δ_{oi} for Penetration	Δ_{oi} for Reinforcement	Δ_{oi} for Bead Width	Grey Relation Grade(γ_i)	S/N Ratio
1	0.932307692	0.43902439	0.570938215	0.06769231	0.5609756	0.42906179	0.630066839	-4.01222
2	0.938461538	0.804878049	0.751716247	0.06153846	0.195122	0.24828375	0.759301641	-2.39171323
3	0.289230769	0.56097561	0.590389016	0.71076923	0.4390244	0.40961098	0.498371226	-6.04894
4	0.738461538	1	0.850114416	0.26153846	0	0.14988558	0.808643951	-1.84485
5	0	0.56097561	0.631578947	1	0.4390244	0.36842105	0.48051948	-6.36578
6	0.476923077	0.56097561	0.958810069	0.52307692	0.4390244	0.04118993	0.6483598	3.763678408
7	0.630769231	0.43902439	0.344393593	0.36923077	0.5609756	0.65560641	0.493052958	-6.142128
8	0.969230769	0.926829268	0.693363844	0.03076923	0.0731707	0.30663616	0.811409189	-1.8152
9	0.652307692	0.780487805	0	0.34769231	0.2195122	1	0.539361749	-5.36239713
10	0.658461538	0	0.314645309	0.34153846	1	0.68535469	0.449765971	6.940268122
11	0.636923077	0.43902439	0.178489703	0.36307692	0.5609756	0.8215103	0.476313995	-6.4421
12	1	0.926829268	0.57208238	0	0.0731707	0.42791762	0.803727121	-1.8978
13	0.784615385	0.436585366	0.448512586	0.21538462	0.5634146	0.55148741	0.548208361	-5.221086
14	0.796923077	0.431707317	0.327231121	0.20307692	0.5682927	0.67276888	0.535179243	-5.43
15	0.476923077	0.585365854	0.132723112	0.52307692	0.4146341	0.86727689	0.467026283	-6.6613
16	1	0.731707317	0.322654462	0	0.2682927	0.67734554	0.691825937	-3.2
17	0.676923077	0.56097561	0.350114416	0.32307692	0.4390244	0.64988558	0.524923346	-5.59808
18	0.686153846	0.682926829	0.402745995	0.31384615	0.3170732	0.59725401	0.560663344	-5.02595
19	0.729230769	0.756097561	0.397025172	0.27076923	0.2439024	0.60297483	0.591384415	-4.5626024
20	0.898461538	0.243902439	0.424485126	0.10153846	0.7560976	0.5755149	0.564717972	-4.96336
21	1	0.609756098	0.324942792	0	0.3902439	0.67505721	0.662385011	-3.577
22	0.913846154	0.780487805	0.496567506	0.08615385	0.2195122	0.50343249	0.682074417	-3.323
23	0.944615385	0.853658537	1	0.05538462	0.1463415	0	0.891287305	-0.99964
24	0.544615385	0.719512195	0.694508009	0.45538462	0.2804878	0.30549199	0.594904357	-4.51105
25	0.784615385	0.682926829	0.455377574	0.21538462	0.3170732	0.54462243	0.59650229	-4.4877

VII. SELECTION OF OPTIMAL PARAMETER SETTING

The experimental data given in Table 4.8 are then normalized by using VIII & IX and the corresponding grey relational coefficients is calculated by using X. Thereafter, the grey relational grade corresponding to each experiment is calculated using XI.

This completes the overall representation of all the quality parameter. Thus multi-criterion optimization has been transferred into a single equivalent objective optimization problem by using the combination of Taguchi and grey relational analysis approach.

The S/N ratios corresponding to grey relational grades are calculated by following Higher The Better (HB) criterion as follow:

$$(S/N)_i = -10 \log_{10} \left[\frac{1}{\Gamma_i^2} \right],$$

Where $(S/N)_i$ is the S/N ratio of the i^{th} experiment, and Γ_i is the overall Grey relational grade of the i^{th} experiment.

VIII. RESULTS AND DISCUSSION

The developed mathematical models can be used to predicted the dimensions of weld bead geometry. Based on the mathematical model developed for predicting the bead geometry the effect of welding process parameter on the bead parameter such as Penetration, Reinforcement, Bead width are presented graphically in figs 3,4,5.

Based on the Grey based Taguchi analysis, it is observed that The optimal parametric combination for this multi-criterion optimization problem is found to be at levels 5-3-4-1-4 of Voltage, Feed Rate, Welding speed, Nozzle to Plate Distance and Gas Flow Rate resp as shown in fig 2.

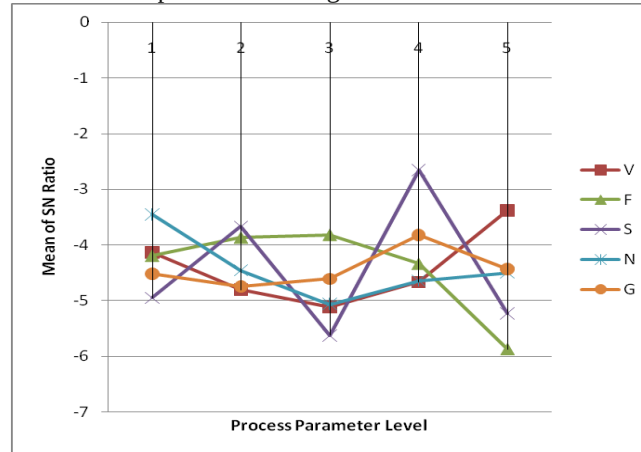


Fig 2: Main effect plot for S/N Ratio

As the analysis of variance suggests that welding is the most significant factor with **Rank I** and the Gas flow rate is least significant factor with **Rank V**. From the mean gray relation grades in Table VII, It is found that the most influencing factor to the weld quality is welding speed and least influencing factors is Gas flow rate.

Sr.	V	F	S	N	G
1	-4.133	-4.199	-4.946	-3.447	-4.510
2	-4.805	-3.871	-3.666	-4.453	-4.742
3	-5.121	-3.822	-5.622	-5.066	-4.605
4	-4.670	-4.342	-2.649	-4.641	-3.823
5	-3.380	-5.874	-5.225	-4.502	-4.428
Mean	1.741	2.052	2.972	0.1252	0.0640
Rank	3	2	1	4	5

Table VII: Mean Response gray relation Grades

The optimum values is find out for the trails conducted and the calculations is perform which give the maximum value for Penetration and minimum Reinforcement and Bead Width are as follows

Optimum Value for Voltage – 34V ,Optimum Value for Feed Rate -4 m/min.,Optimum Value for Welding Speed - 35cm/min Optimum Value for Nozzle to Plate Distance- 12 mm, Optimum Value for Gas Flow Rate – 19 lit /min

.The comparison of the predicted overall grey relational grade with the experimental result obtained by using the optimal design parameter is given as follow.

The predicted S/N ratio by using the optimal level of the design parameter is calculated as $(S/N)_{\text{Predicted}} = (S/N)_m + \sum^F (S/N)_i - (S/N)_m$ Where $(S/N)_m$ –Mean S/N Ratio of all the experiment Runs. $(S/N)_i$ – Mean S/N Ratio at the optimal level of i^{th} parameter . F- No of Design Parameters.

Therefore predicted S/N Ratio can be used to calculate the grey relational grade as follow.

$$(S/N)_i = -10 \log_{10} \left[\frac{1}{\Gamma_i^2} \right],$$

The Comparison of the Predicted overall grey relational grade with the experimental results obtained by using the optimal design parameters shown as follow.

- The values for the optimum combination of the parameters are obtained by creating a mathematical model and using Taguchi and ANOVA techniques for the design of experiments and using Grey Based Taguchi Method for optimum Parameters and for finding the best set of values .The maximum value of Penetration, Reinforcement and bead width (theoretically) is found out to be 11.82 mm, 1.3mm and 11.13mm.
- The Estimated value for the optimum combination of Process Parameters obtained by conducting experimentally (Actual or practical value) for Penetration, Reinforcement and Bead Width is 12.92mm, 1.1mm and 10.75mm.

IX. CONCLUSION

- The Process parameters such as, depth of Penetration, Bead width and bead height are studied and optimized.
- The present study is carried to discuss an application of the Taguchi Method for investigating the effect of process parameter on Penetration, Reinforcement and Bead Width in GMAW welding process of stainless steel (AISI410).It is observed that the welding speed is most influencing factors and Gas flow rate is least influencing factor.
- The optimal parameter setting for GMAW process was selected by using grey-based Taguchi method so as to improve a cost function made of important welding quality parameters. An L25 orthogonal array was adopted to conduct the experiment suggested by MINITAB15 Statistical software
- The multiple quality characteristic parameters were combined into one integrated quality parameter by using grey relational grade or rank. ANOVA was performed to find the impact of process parameters on the individual quality parameters and also on the overall grey relational grade. It is observed that by using grey based analysis the optimum combination of the machine is found that 5-3-4-1-4 of Voltage, Feed Rate, Welding speed, Nozzle to Plate Distance and Gas Flow Rate.

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