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MULTI RESPONSE OPTIMIZATION OF GAS METAL ARC WELDING PROCESS PARAMETERS

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Abstract

In this competitive world, the customers perceive the most reliable, high quality with low cost product. In order to satisfy the customers demand, the manufacturing industries are being forced to continuously optimize their process parameters. Gas Metal Arc Welding famously abbreviated GMAW, is one of the most important metal joining process done on mild steel. The selection of improper GMAW process parameters increases the power consumption, material consumption, man power and cost of the product. So that the optimization of GMAW process parameters is most important to produce effective products. In spite of very high costing techniques, Taguchi method with grey relational analysis is used to reduce more number of unwanted iterations, money and time. In this work the parameters such as, i) Welding current, ii) voltage, iii) welding speed are selected and setting into three levels for each parameters. Here L9 orthogonal array is selected to do the analysis. L9 orthogonal array assist to determine, how many trials are necessary and levels of each parameter in every trial. Bead width and bead height are optimized based on signal to noise ratio. Optimum parameters are identified by grey relational grades and significant factors are also obtained by ANOVA. Observations of this study may be used in fabrication of shipbuilding, automotive sub-assemblies and pressure vessels.

Keywords:*—Gas Metal Arc Welding, Orthogonal array, Taguchi method, Signal to noise ratio, Grey Relational Analysis, ANOVA.*

1. Introduction

GMAW is one type of electric arc welding process. In this process an electric arc forms between electrode and the base metals and it heats the work piece to melt and join them. A shielding gas feeds along with the wire electrode, through the welding nozzle, which shields the welding region from air contaminants. No flux is used but the arc and molten metal are shielded by an inert gas, which may be argon, helium, carbon dioxide or a gas mixture. Gas Metal Arc Welding (GMAW), is the most common industrial welding process, referred to by its sub category types such as Metal Active Gas Welding (MAGW) and Metal Inert Gas Welding (MIGW). GMAW has got wide-ranging of applications in industries for its capability, productive, high trustworthiness to weld in all position, easy to handle and economic [1, 2].

GMAW is a process has many interconnected process parameters which are affecting the quality of the weld. Welding current, voltage and travel speed are identified as the maximum influenced process parameters [3]. Das et al. [4] selected the parameters such as welding current, arc voltage and welding speed and welded mild steel specimens by MIGW and showed the effectiveness of various welding process parameters. With the help of surface plots, penetration was observed and the effectiveness of the welding parameters are also analyzed.

Arya et al. [5] studied the influence of welding parameters like welding voltage, current, welding speed, gas flow rate and wire diameter. Weld penetration, bead geometry, tensile strength, and heat affected zone (HAZ) were selected as responses. Taguchi method with grey relational analysis was adopted for optimization of parameters for tensile strength and heat affected zone. Datta et al. [6]

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performed a multi objective optimization in submerged arc welding on MS specimens. Their input welding parameters were voltage, speed, stick out and wire feed rate while bead width, bead height, penetration and HAZ were taken as output responses. Na et al. [7] studied the influence of MIG welding parameters on the weld bead during the welding of S400 steel plates. For the prediction of bead geometry, neural network optimization techniques were used. Karadeniz et al. [8] investigated the influence of welding parameters like welding speed, voltage and current on depth of penetration in butt welded Erdemir 6842 steel by GMAW. Modenesi et al. [9] have studied the effectiveness of wire diameters in GMA welding in samples of ER70S-6. They found that the most affected factors are welding current and short circuit factor. Nagesh et al. [10] have investigated the influence of electrode feed rate, voltage, current and arc length on bead width and bead height. Estimated values of artificial neural network were compared with the experimental values and they have good agreement with them. It was observed that high arc travel rate leads to poor fusion. Hooda et al. [11] examined the welding parameters like current, wire feed rate, gas flow rate and voltage and proposed a mathematical model for the prediction of tensile strength for MIG welding carbon steel plates. Effect of welding parameters such as electrode wire diameter, wire feed rate and welding current on hardness in welding of carbon steel plates was investigated by Patel et al. [12]. The input parameters were optimized by Grey Relational Analysis (GRA) and observed that the most influencing factor is welding current.

In this study, the specimens were prepared with the help of L9 orthogonal array and the influence of input welding parameters is examined based on responses. The GMA welding process parameters like welding current, voltage, and welding speed along with two responses like bead width and bead height are investigated. To obtain optimum bead width and bead height Taguchi based Grey Relational Analysis (GRA) is employed.

2. Methodology

2.1 Taguchi Method

Dr. Taguchi of Nippon Telephones and Telegraph Company - Japan has developed an optimization method based on orthogonal array experiments which gives very minimum of variance for the experiment with optimum settings of control factors or parameters. Taguchi method is robust design technique for optimization and it mostly used to optimize the input parameters on the basis of single response only. Taguchi method is not adequate for multiple output response problems. To optimize the process parameters for multiple response Taguchi method is coupled with grey relational analysis.

2.2 Grey Relational Analysis

Grey Relational Analysis (GRA) method was initiated by Deng Julong (1982) [13] for the solution of the problems which have uncertainty. In this method, "grey" means insufficient/lack of data or information in decision making process. Based on grey system theory, grey relational analysis has been broadly executed to solve the decision making problems with quantitative and qualitative data under complex criteria. Depending on the characteristics of data sequence, there are various methodologies are available for data pre-processing in GRA [14, 15]. The data pre-processing procedure is given below.

1. Identification of process parameters.
2. Determine the range and number of levels of primary parameters.
3. Selection of appropriate Orthogonal Array (OA) and assign the process parameters to the OA.
4. Conduct the experiments based on the arrangement of the OA.
5. Calculate the S/N ratio through experimental results.
6. Perform the normalized S/N ratio and calculate the grey relational coefficient.
7. Calculate the grey relational grade by averaging the grey relational coefficients.

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8. Analyze the experimental results by using the grey relational grade and ANOVA.
9. Select the optimal levels of process parameters.
10. Verify the optimal process parameters through the confirmation test.

Steps for Grey Relational Analysis

In this GRA analysis, the optimization of multiple performance characteristics can be converted into optimization of single grey relational grade. The following steps are well brought-out for grey relational analysis.

Determine the number of levels of primary parameters

In this study, three input parameters namely welding current, voltage and welding speed have been chosen on the basis of literature review. Several different combinations of welding current, voltage and welding speed were taken within the range of current from 150A to 200A, voltage from 24V to 32V and welding speed from 40 cm/min to 50 cm/min as shown in Table 1.

TABLE 1: Welding parameters and their levels

Factor notation	Parameter	Unit	Level 1	Level 2	Level 3
A	Current	Ampere – (A)	150	175	200
B	Voltage	Volt (V)	24	28	32
C	Welding Speed	Cm/min	40	45	50

Based on the above three parameters and its three levels, L9 orthogonal array was selected for this optimization process.

Step 1- Signal-to-Noise (S/N) ratio

This analysis can be achieved by employing the Signal-to-Noise (S/N) ratio, and this ratio depends on the quality characteristics of the process to be optimized. The three categories of S/N ratios are (i) larger the Better (HB), (ii) Smaller the Better (LB) and (iii) Nominal the Best (NB). The Smaller the Better type S/N ratio was calculated from the following equation,

$$S/N\ Ratio = -10\log_{10}\left(\frac{1}{j}\right)\sum_{i=1}^{j} y_i^2 \qquad (1)$$

Where,

j = Number of repetitions of the experiment and

yi=Observed response value.

Step 2 - Normalization

The S/N ratios obtained by Taguchi's method are normalized in the range of 0 and 1, and this procedure is known as grey relational generating. In Grey relational generation, the normalized bead width and bead height corresponding to lower-the-better (LB) criterion can be expressed as,

$$x_i(k) = \left(\frac{\max \eta_i(k) - \eta_i(k)}{\max \eta_i(k) - \min \eta_i(k)}\right) \qquad (2)$$

where,

k = 1 to n, n is performance characteristic and

i = 1 to 9, i is trial number.

Step 3 - Grey relational coefficient

The x0 (k)=1, k =1, 2… 9 are the ideal sequence for bead width and bead height. The definition of the grey relational grade in the grey relational analysis is to show the relational degree

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between the sequences of x0 (k) and xi (k), (i=1, 2… 9; k= 1, 2… 9). The grey relational coefficient ζi(k) can be calculated as follows,

$$\zeta_i(k) = \left(\frac{\Delta_{\min} - \psi \Delta_{\max}}{\Delta_{0i}(k) + \psi \Delta_{\max}} \right) \tag{3}$$

where,

$\Delta_{0i} = \| x_0(k) - x_i(k) \|$ Difference of the absolute value x0(k) and xi(k)

$\Delta_{\min} = \min\limits_{\forall j \in i} \min\limits_{\forall k} \| x_0(k) - x_j(k) \|$ Smallest value of Δ0i

$\Delta_{\max} = \max\limits_{\forall j \in i} \max\limits_{\forall k} \| x_0(k) - x_j(k) \|$ Largest value of Δ0i

Ψ is distinguishing coefficient and its widely accepted value is 0.5.

Step 4 - Grey relational grade

After averaging the grey relational coefficients, the grey relational grade γ_i can be obtained as,

$$\gamma_i = \left(\frac{1}{n} \sum_{k=1}^{n} \zeta_i(k) \right) \tag{4}$$

where,

n = number of performance characteristics.

Then the grey relational grade values are ranked from heighest to lowest. The first rank experimental set up can be taken as optimum level of process parameters. In order to evaluate the influence of each selected input parameter on the responses, the S/N ratio for each output has to be calculated with the help of grey relational grades.

Step 5 - Confirmation test

After completing the identification of the optimal GMAW parameters, the confirmation test is to be conducted to check the accuracy of the analysis. In the confirmative test, the optimum combinations were set, and the trial was conducted. The predicted grey relational grade using optimum GMAW parameter can be expressed as,

$$\hat{\gamma} = \left(\gamma_m + \sum_{i=1}^{q} (\bar{\gamma}_i - \gamma_m) \right) \tag{5}$$

where,

γ_m = The total mean grey relational grade

$\bar{\gamma}_i$ = The mean grey relational grade at the optimum level

q = Number of parameters that significantly affect the bead width and height.

3. Experimental Procedure and Test Results

3.1. Sample preparation

Gas Metal Arc Welding process was carried out on mild steel plate EN10025 S 235 Grade as base material with specimen size of 200 × 80 × 3mm. The mechanical properties and chemical composition of base metal by weight % is given in Table 2. Specimens were welded by using AK600AMP welding machine and copper coated steel wire of ER70 S6 grade with 1.2 mm diameter. The mechanical properties and chemical composition of steel wire by weight % is given in Table 3. For shielding purpose, Ar-C02 gas used with percentage of Ar: 82% & CO2:18%. Butt welding on mild steel is done by the

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qualified welder and parameters of GMAW were set as per the guidelines of Taguchi's L9 orthogonal array Table 4.

Table 2 Mechanical properties and chemical composition of base metal EN10025 S 235 by weight %

Mechanical Property	**Tensile strength**			**Yield stress**			**% of Elongation**		
Value	455.67 N/mm2			398.97 N/mm2			27.45%		
Chemical Composition	**C**	**Mn**	**Cu**	**S**	**P**	**Mo**	**Ni**	**Cr**	**Fe**
wt%	0.185	0.788	0.028	0.014	0.016	0.008	0.021	0.025	Bal.

Table 3 Mechanical properties and chemical composition of copper coated steel wire of ER70 S6 grade by weight %

Mechanical Property	**Tensile strength**				**Yield stress**			**% of Elongation**			
Value	525 N/mm2				423.6 N/mm2			29.45%			
Chemical Composition	**C**	**Mn**	**Cu**	**Si**	**S**	**P**	**Mo**	**Ni**	**Cr**	**V**	**Fe**
wt%	0.075	1.478	0.18	0.88	0.006	0.012	0.002	0.035	0.035	0.006	Bal.

3.2. Test results

As per L9 orthogonal array nine specimens were prepared. Then the bead width (BW) and bead height (BH) are measured by high-speed camera with an exposure time of 50 µs and resolution of 416 X 200 pixels with 256 gray levels and a frame rate of 100 frames per second (fps). The L9 orthogonal array along with experimental results for bead height (BH) and bead width (BW) is shown in Table 4.

3.3 Discussion on Optimization Results

To obtain Grey relational generation experimental data have been normalized by using Equations (2). Smaller-the-better (SB) is selected for bead width and bead height. Normalized value, Grey relational coefficient, Grey relational grade, S/N ratio and its rank for each response is presented in Table 5.

Table 4 Experimental layout using L9 orthogonal array with coded and original level values with output responses

Test No.	**Parameters**						**Responses**	
	Current (Ampere)		**Voltage (Volt)**		**Welding Speed (Cm/min)**		**Bead Width (BW)**	**Bead Height (BH)**
	Coded value	**Actual value**	**Coded value**	**Actual value**	**Coded value**	**Actual value**	**(mm)**	**(mm)**
1.	1	150	1	24	1	40	10.65	3.99
2.	1	150	2	28	2	45	11.4	4.95
3.	1	150	3	32	3	50	11.95	3.82
4.	2	175	1	24	2	45	9.85	4.25
5.	2	175	2	28	3	50	10.85	3.76
6.	2	175	3	32	1	40	11.92	4.45

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7.	3	200	1	24	3	50	10.39	3.91
8.	3	200	2	28	1	40	12.57	4.57
9.	3	200	3	32	2	45	10.95	3.12

Now, grey relational coefficient for each response is computed on the basis of equation (3). The value of distinguishing coefficient is taken as 0.5 for each response [16, 17 and 18]. After computing grey relational coefficients, the grey relational grade is calculated with the help of equation (4).

After calculating grey relational grades the welding process parameters are optimized by using Taguchi method corresponding to smaller-the-better (LB) criterion. The S/N ratio for each output has been calculated with the help of grey relational grade. The grey relational grade is converted in to signal to noise ratio. The maximum Grey relational grade is the optimum level, because a low value of signal-to-noise ratio indicates that the signal is much higher than the random effects of the noise factors. [19, 20] Table 5 shows the S/N ratios for welding current, arc voltage and welding speed. As per Table 5, the 9th combination has first rank and shows the closer optimum level for input welding parameters.

The difference between the maximu and the minimum value (Max–Min) of the grey relational grade is also indicated in Table 6. The maximum of Max–Min value is the most effective factor affecting the multi-performance characteristics. The maximum of the Max–Min value is 0.193, and the corresponding control factor, voltage has the strongest effect on multi-performance characteristics. The order of importance of the controllable factors can be listed as: factor B (Voltage), factor C (Welding Speed) and factor A (Current), i.e. 0.193> 0.189 > 0.104. Factor B is the most controllable factor in this welding study for the multi- performance characteristics. From the Table 6, the optimal parameters levels for bead width and bead height current 200 A (level 3), voltage 24 V (level 1), and welding speed 45 cm/min (level 2), for a plate of 3 mm thickness which is shown in Figure 1.

Table 5 Normalized value, Grey relational coefficient, Grey relational grade, S/N ratio and its rank

Test No.	**Response I (BW)**		**Response II (BH)**		**Grey relational grade**	**S/N Ratio**	**Rank**
	Normalized Value	**Grey relational coefficient**	**Normalized S/N ratio**	**Grey relational coefficient**			
1.	0.705882	0.62963	0.52459	0.512605	0.571117	4.865	5
2.	0.430147	0.467354	0	0.333333	0.400344	7.951	8
3.	0.227941	0.393064	0.617486	0.566563	0.479814	6.379	6
4.	1	1	0.382514	0.447433	0.723716	2.809	2
5.	0.632353	0.576271	0.650273	0.588424	0.582348	4.696	4
6.	0.238971	0.396501	0.273224	0.407572	0.402037	7.915	7
7.	0.801471	0.715789	0.568306	0.536657	0.626223	4.065	3
8.	0	0.333333	0.20765	0.386892	0.360113	8.871	9
9.	0.595588	0.552846	1	1	0.776423	2.198	1

Mean grey relational grade = 0.547

Table 6 Response of average grey relational grade

Factor Notation	**Control Factor**	**Average grey relational grade by factor level**			**Max–Min**
		Level 1	**Level 2**	**Level 3**	
A	Current	0.483758	0.569367	0.587586*	0.104

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B	Voltage	0.640352*	0.447601	0.552758	0.193
C	Welding Speed	0.444422	0.633494*	0.562795	0.189

*Indicates optimum level of factors

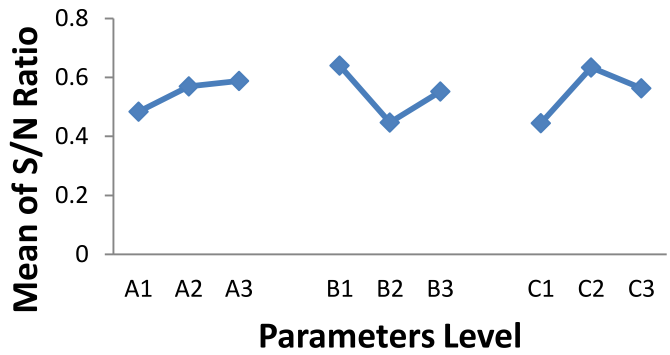

Fig. 1 Effect of controllable factors on S/N ratio

The significance of the process parameters was tested by ANOVA. Using grey relational grade value, ANOVA was formulated for identifying the significant factors [21 - 24]. The results of ANOVA are presented in Table 7 with Figure 2. By this investigation, the welding voltage (32.11%) was found as most significant factor and played a major role followed by welding speed (31.53%) and welding current (10.59%).

Table 7 Results of ANOVA

Factor Notation	Control Factor	Dof	Sum of squares	Mean squares	F value	% Contribution
A	Current	2	0.0184	0.0092	0.418182	10.59
B	Voltage	2	0.0559	0.0279	1.268182	32.11
C	Welding Speed	2	0.0548	0.0274	1.245455	31.53
D	Error	2	0.0448	0.0224		25.77
Total		8	0.1739	0.0869		100

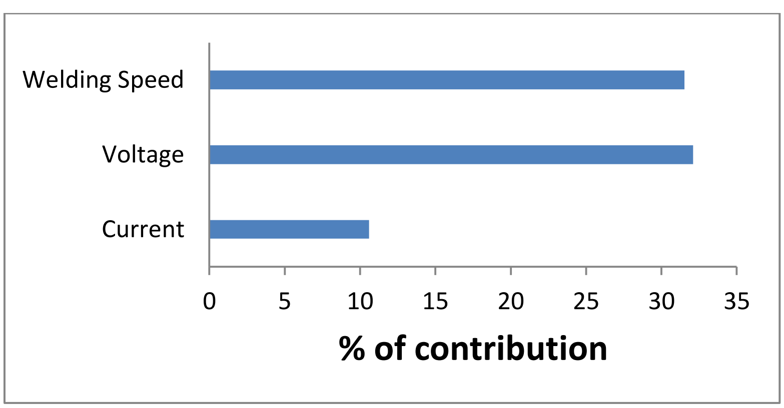

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Figure 2 Percentage of contributions for Bead width and height

3.4 Confirmation Test

The optimum level of parameters setting was found as A3 B1 C2. This optimized factor levels combination not exists within the designed experiments, for this reason it is necessary to run the confirmation test. Hence conformation test was done with optimal parameter setting and results are placed in the following Table 8.

TABLE 8 Experimental results at optimal parameter setting

Parameters			Responses	
Current (Ampere)	**Voltage (Volt)**	**Welding Speed (Cm/min)**	**Bead Width (BW)**	**Bead Height (BH)**
200	24	45	10.85	3.15

The predicted value of grey relation grade, obtained from equation 5 is 0.767; whereas the existing grey relation grade value of the confirmation test (A3 B1 C2) is 0.772. Hence the difference is only 0.005 i.e., 1% (approx.). This variation occurs due to neglecting the nonlinear effects in three factors at three levels Taguchi L9 orthogonal array.

4. Conclusions

This analysis presents the effect of current, voltage and welding speed on GMAW. Based on grey relational approach the following conclusions can be made.

- The optimum process parameters are current 200Amp, voltage 24volt and welding speed is 45cm/min.
- The largest max–min value of grey relational grade was found from the response table. These values clearly pointed out that the welding voltage is the predominant factor among the others.
- The order of importance of the factor is as follows: welding voltage, speed, and current respectively.
- This type of experimental analysis would be useful in the development process of structural components in the field of aircraft, marine and automobile applications.
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