Application Of Grey-based Taguchi Method For Optimising Gas Metal Arc Welding Of Stainless Steels

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ABSTRACT

Gas Metal Arc Welding (GMAW) is widely used in industry to obtain high quality welds with high deposition rate. Carbon di-oxide is used in this work for GMAW, the process known as metal active gas (MAG) welding. In this experimental investigation, 1.2 mm diameter of stainless steel electrode is employed maintaining a root gap of 1.3 mm and 15 bar gas pressure. Welding voltage, welding current, and welding speed are varied to weld stainless steel specimens to make square butt joint. Experimental design is made using Taguchi's L9 orthogonal array design, and signal-to-noise ratio is used to derive objective functions to be optimized within experimental domain. Objective functions selected include weld bead reinforcement, depth of penetration, weld metal hardness and bending load at a bend angle of 100. Grey relational analysis is applied to solve this multi-response optimization problem. Within the experimental domain, optimum weld is found with a weld current of 160 amp and a weld voltage of 30 volt with 327 to 554 mm/min weld traverse speed.

Keywords: GMAW, MAG, orthogonal array, signal-to-noise ratio, Taguchi approach, Grey relational analysis.

INTRODUCTION

Gas Metal Arc Welding (GMAW) is considered to have adaptability to weld different metals to produce welds of high quality restricting the problems of flux, moisture and slag entrapment. This semiautomatic process is mainly used where high quality welding is needed with high deposition rate. Several process parameters interact in a complex manner in GMAW resulting in direct or indirect influence on bead geometry, mechanical properties and metallurgical features of the weldment as well as on the weld chemistry [1,2,3]. Hence, it is necessary to find out an optimal process condition capable of producing desired quality weld. Multi-response optimization needs be performed in such a way that all objectives are fulfilled simultaneously.

Welding researchers are mainly concerned with the improvement in the quality and reliability of the weldment made of a wide category of metals and alloys. Kacar and Kokemli [4] studied the effect of controlled atmosphere on the MIG-MAG arc weldment properties, and found high toughness of the weld metal under controlled atmosphere, without gas porosity and inclusion. Tusek and Suban [5] observed that the effect of hydrogen in argon as a shielding gas in arc welding of austenitic stainless steel increases melting rate and melting efficiency of the arc. Datta and others [6] carried out experimental investigation to evaluate effect of current and consumable on bead geometry in submerged arc welding. Murugan et al. [7] have investigated the effects of process parameters on angular distortion of gas metal arc welded structural steel plates. They have found that the number of passes has a strong effect on angular distortion. Kim et al. [8] have described the steps to model the electrode heat transfer of GMAW process to establish a strong theoretical background. The Analytical Hierarchy Process (AHP) has also been used [9] to optimise process parameters in GMAW. Taguchi method with Grey-based analysis has been found to be a useful tool for optimisation of process parameters in GMAW [1,10].

TAGUCHI METHOD

Taguchi's philosophy is an efficient tool for the design of high quality manufacturing system. Dr. Genichi Taguchi, a Japanese quality management consultant, has developed a method based on orthogonal array experiments, which provides much-reduced variance for the experiment with optimum setting of process control parameters. Thus the integration of design of experiments (DOE) with parametric optimization of process to obtain desired results is achieved in the Taguchi method [11]. Orthogonal array (OA) provides a set of well-balanced experiments (minimum experimental runs) and signal-to-noise (S/N) ratios, which are logarithmic functions of desired output serve as objective functions for optimization. This technique helps in data analysis and prediction of optimum results. Signal-to-noise (S/N) ratio is used to evaluate optimal parameter settings. It is the ratio of the mean (signal) to the standard deviation (noise). This means that a large value of S/N ratio indicates a good relationship between the change of response parameters with little deviations, or noise, in experimental data. On the other hand, a small value of S/N ratio signifies lack of a clear trend between the response parameter and the input variable.

The S/N ratio depends on the quality characteristics of the product/ process to be optimized. Standard S/N ratios are as follows: Nominal is best (NB), lower the better (LB) and higher the better (HB). The optimal setting is chosen to be the parameter combination corresponding to the highest S/N ratio.

THEORY OF GREY RELATIONAL ANALYSIS

In Grey relational analysis, measured parameters are first normalized ranging from zero to one [1]. This process is known as Grey relational generation. Based on the 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 a single response optimization situation with the objective function using overall Grey relational grade [1,10]. The optimal parametric combination is then evaluated which would result highest Grey relational grade. The optimal factor setting for maximizing overall Grey relational grade can be performed by Taguchi method.

In Grey relational generation, lower the better criterion can be expressed as

$$x_i(k) = \frac{\max y_i(k) - y_i(k)}{\max y_i(k) - \min y_i(k)} \quad (1)$$

For larger-the-better criterion, Grey relational generation can be expressed as

$$x_i(k) = \frac{y_i(k) - \min y_i(k)}{\max y_i(k) - \min y_i(k)} \quad (2)$$

For nominal is best criterion, Grey relational generation can be expressed as

$$x_i(k) = 1 - \frac{|y_i(k) - y_i(k)|}{\max y_i(k) - \min y_i(k)} \quad (3)$$

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 kth response, and max $y_i(k)$ is the largest value of $y_i(k)$ for the kth response and y_i is the target value which have to achieve. An ideal sequence is $x_0(k)$ (k = 1, 2, 3...) 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 all sequences [$x_0(k)$ and, $x_i(k)$ for i = 1, 2, 3...]. The Grey relational coefficient can be calculated as

$$\xi_i(k) = \frac{\Delta_{\min} + \Delta_{\max}}{\Delta_{0i}(k) + \psi\Delta_{\max}} \quad (4)$$

where, $\Delta_{0i}(k)$ = $\|x_0(k) - x_i(k)\|$ = difference of absolute value $x_0(k)$ and $x_i(k)$; ψ is the distinguishing coefficient ($0 \le \psi \le 1$). After averaging the Grey relational coefficients, the Grey relational grade $\gamma_i(k)$ can be computed as

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n}\xi_i(k) \quad (5)$$

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. The mean response for the Grey relational grade with its grand mean and the main effect plot of Grey relational grade are very important because optimal process condition can be evaluated from this plot [1].

In this work, Grey based relational analysis is done on MAG welding of stainless steel specimens under different process conditions designed using Taguchi's method to evaluate the optimum condition within the experimental domain.

EXPERIMENTAL DETAILS AND RESULTS OBTAINED

MAG welding, a GMAW process using CO_2 as shielding gas, is a multi-factor metal fabrication technique. Various process parameters influence the quality of the weldment. The present work has been planned to vary three process parameters, such as welding current, welding voltage and traverse speed, at three different levels. Taguchi's L9 orthogonal array has been chosen to restrict the number of tests. Welding tests have been done along a guided path of straight line using an automatic device. Different process conditions along with details of the set up and details of the joint used are given in Table 1. Flat rectangular pieces have been butt-welded after making the specimens free from rust and grease, and after grind-finishing the faying surfaces. A root gap of 1.3 mm is maintained between the specimens. Compositions of the workpiece and electrode material are given in Table 2 and Table 3 respectively. Experimental runs and corresponding parameter settings selected are listed in Table 4, following Taguchi's L9 orthogonal array [11].

Quality of the weldment is judged through visual inspection, hardness test, bend test and weld bead geometry. The visual inspection reveals presence of pore, spatter, undercut, non-uniformity of weld, etc. Observations made are detailed in Table 5 and Table 6 for two sets of repeat tests. Weld bead

Table 1 : Details of the experimental set-up

Basic equipment	:	Gas Metal Arc Welding Machine Make: Esab India Limited, Kolkata, Model No.: AutoK 400				
Shielding	:	Gas shielding with CO_2, Gas flow rate: 15 litre/min				
Electrode used	:	Aluminium coated stainless steel, Diameter: 1.20 mm				
Workpiece used	:	Material: Stainless steel, Hardness: 285 BHN Size: 100 mm x 50 mm x 6 mm				
Type of the welded joint	:	Square butt joint of similar rectangular pieces				
Process variables	:	Parameters	Unit	Levels of factors		
				1	2	3
		Current	Amps	130	140	160
		Voltage	Volt	22.5	25	30
		Traverse speed	mm/min.	327	554	723
Welding Position	:	Flat (downhand) position with the torch angle of 75°				
Joint preparation	:	Rust free, ground finish				
Gap between the faying surfaces	:	1.3 mm				
Pre/ Post treatment of weldment	:	No pre-heating/ post heating				
Cooling	:	In open air				

Table 2 : Chemical composition of parent metal

C (%)	Si (%)	Mn (%)	P (%)	S (%)	Cr (%)	Mo (%)
0.0607	0.539	8.74	0.0121	<0.0011	13.219	0.1492
Ni (%)	Al (%)	Co (%)	Cu (%)	Nb (%)	Ti (%)	V (%)
1.128	0.0064	0.1116	0.3561	0.0292	0.0047	0.0614
W (%)	Pb (%)	Sn (%)	As (%)	Ce (%)	B (%)	
<0.0130	0.0073	<0.0021	<0.0040	0.0312	<0.0010	

Table 3 : Chemical composition of the electrode

C (%)	Si (%)	Mn (%)	Cr (%)	Ni (%)	Mo (%)
0.03	0.43	1.34	18.09	8.34	0.20

geometry in terms of penetration, bead width and reinforcement are obtained (Table 7) using a tool makers' microscope through suitably polished and etched samples. The weld zone is ground finished to measure Brinell Hardness Number (BHN). Hardness is measured to have an idea about the metallurgical changes caused by welding [2,3].

Table 4 : Taguchi's L9 Orthogonal Array Design

Experimental runs	Levels of process parameters		
	Welding current	Welding voltage	Traverse speed
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Table 5 : Visual Inspection for Stainless Steel (sample set 1)

Sl. No.	Spatter	Blow holes	Undercut	Melt off	Angle of distortion (degree)	Remarks
1	high	no	no	low	1	Medium bead width bead height. Lack of penetration, medium metal deposition.
2	medium	no	very low	medium	2	Medium bead width with moderate reinforcement. Uniform metal deposition, good weld surface.
3	very low	some	low	medium	5	Narrow weld bead, moderate bead height. Non uniform weld bead.
4	no	no	no	very low	3.5	Narrow weld bead, slight more weld bead height than trial 8. Non uniform weld bead, bad weld surface.
5	medium	no	very low	medium	2.5	Less wide bead with very less weld bead height. Good weld surface, non uniform weld bead.
6	low	no	no	low	1.5	Wide weld bead with very high reinforcement. High metal deposition, uniform weld bead.
7	medium	no	no	low	2	Less bead width, less bead height. Non uniform weld surface, bad in quality.
8	medium	some	no	medium	5	Medium bead width, less weld bead height. Medium metal deposition.
9	medium	no	very low	high	3	Wide weld bead with moderate bead height. Non uniform metal deposition.


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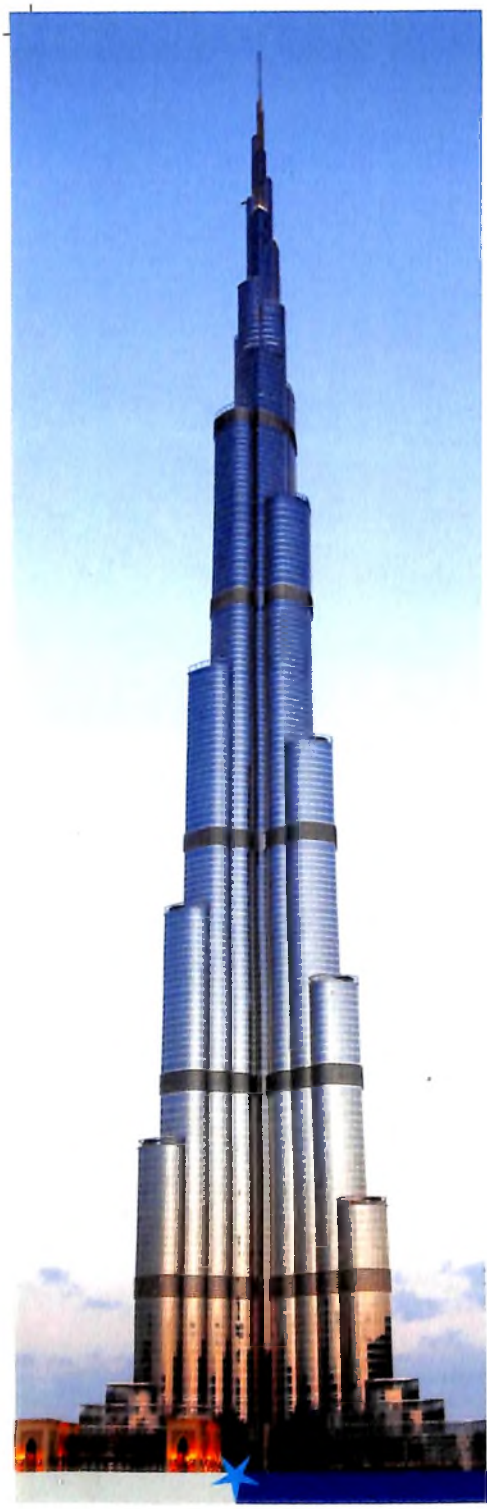

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Table 6 : Visual Inspection for Stainless Steel (sample set 2)						
Sl. No.	Spatter	Blow holes	Undercut	Melt off	Angle of distortion (degree)	Remarks
1	medium	no	no	low	0	Medium bead width with medium bead height. Lack of fusion, non uniform weld surface, no metal deposition at start of the welding.
2	less	some	no	medium	1	Medium bead width with moderate reinforcement. Uniform metal deposition, good weld surface.
3	less	no	no	medium	3	Narrow weld bead moderate bead height. Non uniform weld surface, lack of fusion.
4	large	no	no	low	2	Narrow weld bead, moderate weld bead height. Bad weld surface, low metal deposition.
5	less	no	very low	medium	2	Less wide bead with very less weld bead height. Good welding, medium metal deposition.
6	medium	no	no	high	3	Wide weld bead with very high reinforcement. High metal deposition, uniform weld surface.
7	high	some	no	very low	2	Less bead width, less bead height. Non uniform weld surface, low metal deposition.
8	medium	some	low	high	2	Medium bead width, less weld bead height. High metal deposition, uniform weld surface.
9	medium	no	no	high	5	Wide weld bead with moderate bead height. High metal deposition, uniform weld surface.

Table 7 : Weld Bead Geometry of Stainless Steel						
Weld bead geometry						
Sl. No.	Sample set 1			Sample set 2		
	Penetration (mm)	Bead width (mm)	Reinforcement (mm)	Penetration (mm)	Bead width (mm)	Reinforcement (mm)
1	2.05	6.76	1.69	2.11	6.44	1.43
2	2.63	6.51	1.10	2.55	6.75	1.12
3	3.10	4.06	1.54	2.96	4.50	1.34
4	3.01	4.87	0.67	3.10	5.13	1.01
5	2.76	4.87	0.12	2.69	4.55	0.20
6	3.55	8.25	2.43	3.76	7.99	2.04
7	2.85	4.20	0.33	2.80	4.53	0.34
8	3.15	7.80	0.29	3.26	7.21	0.28
9	4.78	8.18	1.01	4.85	7.85	1.03

Table 8 : Hardness test for Stainless Steel		
	Weld metal hardness (BHN)	
Sl.No.	Sample set 1	Sample set 2
1	140	170
2	150	175
3	192	142
4	167	185
5	180	145
6	187	167
7	135	150
8	142	162
9	175	175

Table 9 : Bend test for Stainless Steel without Welding			
	Bending load (kN)		
Sl. No.	At 10°	At 20°	At 30°
1	9.6	11.6	14
2	9.2	11.2	13.2
3	10.8	13.2	15.2

Table 10 : Bend test for Stainless Steel										
Bending Load										
	Sample Set 1					Sample Set 2				
Sl. No.	At 10°	At 20°	At 30°	At failure		At 10°	At 20°	At 30°	At failure	
				Bending load	Bending Angle (Degree)				Bending Load	Bending Angle (Degree)
1	12.4	13.2	16.4	x	x	11.2	13.2	*	13.2	20
2	11.2	12.8	*	12.8	20	12	14	14	14	30
3	11.2	12.4	12.4	12.4	30	11.2	13.2	13.2	13.2	30
4	8.8	*	*	8.8	10	7.6	*	*	7.6	10
5	10.8	12.4	*	12.4	20	7.2	*	*	7.2	10
6	12.8	15.2	16	16	30	12.8	15.2	16	16	30
7	9.6	*	*	10	12	8.4	*	*	8.4	10
8	11.6	14	*	14	20	12	14.4	16	16	30
9	10	12	13.6	x	x	12	13.6	15.2	x	x

* Failure before the specified angle; x Failure does not occur up to 30°.

Table 11 : Evaluation of Experimental Samples

Sl. No.	Sample set 1				Sample set 2			
	Depth of Penetration (mm)	Reinforcement (mm)	Weld metal Hardness (BHN)	Angle at failure (Degree)	Depth of Penetration (mm)	Reinforcement (mm)	Weld metal Hardness (BHN)	Angle at failure (Degree)
1	2.05	1.69	140	12.4	2.11	1.43	170	11.2
2	2.63	1.1	150	11.2	2.55	1.12	175	12
3	3.1	1.54	192	11.2	2.96	1.34	142	11.2
4	3.01	0.67	167	8.8	3.1	1.01	185	7.6
5	2.76	0.12	180	10.8	2.69	0.2	145	7.2
6	3.55	2.43	187	12.8	3.76	2.04	167	12.8
7	2.85	0.38	135	9.6	2.8	0.34	150	8.4
8	3.15	0.29	142	11.6	3.26	0.28	162	12
9	4.78	1.01	175	10	4.85	1.03	175	12

Weld metal hardness is measured on a Brinell Hardness Testing Machine (make- FTM, model- TSM), and results obtained are listed in Table 8. Large variations of hardness in the weld zone are seen for the first five experimental runs and the seventh experimental run between the repeat tests, mainly due to non-uniformity of weld bead. However, remaining repeat test results show less variation in the BHN within the weld zone; this may be due to uniform weld bead with good penetration observed as shown in Table 5, Table 6 and Table 7. Bend tests are done on a Universal Testing Machine (make- FTM, model- TUN 200). Stainless steel pieces without welding are bend tested, and corresponding bending loads are measured at 10^0, 20^0 and 30^0 bend angles. The test is repeated three times to check for repeatability (Table 9). Results of the bend test of the welded samples are shown in Table 10.

Transverse sections of the weld bead have been cut from the middle portion of the welded plate in a vertical milling machine. Specimens have been cold mounted, and have been polished by belt grinder, and subsequently by a series of fine grades of emery paper (grades 1/0, 3/0). Samples have then be buffed and etched with 2% nital solution for about 30 seconds. Thus, the specimens have been made ready to observe weld bead geometry. Weld bead width (W), reinforcement (R) and depth of penetration (D) have been measured by Mitutoyo-make tool makers' microscope. Reinforcement (R) is the height of the outward projection of the weld bead beyond the plate.

From the results obtained through visual observation and weld bead geometry (Table 5, Table 6 and Table 7), it is found that for experiment run Nos. 6, 8-9, welding may be considered acceptable with acceptable depth of penetration and weld bead uniformity. Less hardness is obtained in weld portion compared to that of the parent material (Table 8), and this is probably due to presence of less carbon in the wire electrode, and slow rate of cooling in open air. Therefore, considerable bending becomes possible as can be seen in Table 10.

EVALUATION OF OPTIMAL PROCESS CONDITION FOR STAINLESS STEEL

For finding out the optimum parametric combination of MAG welding for joining stainless steel specimens within the experimental domain, depth of penetration, reinforcement, weld metal hardness and bending load at 100 bend angle are selected as the response as detailed in Table 11. Response data and the quality criteria have been furnished in Table 12. Table 13 shows the normalized data for use of Grey relational grade generation, where maximum and minimum reading for each response are assigned the value of 1 and 0 respectively.

Table 12 : Evaluation Criteria Description			
Criterion	Maximum Reading	Minimum Reading	Quality Criteria
Depth of Penetration	4.85	2.05	larger-the-better
Reinforcement	2.43	0.12	lower-the better
Weld metal Hardness	192	135	larger-the-better
Bending load At 100	12.8	7.2	larger-the-better

Table 13 : Data for preprocessing of each performance characteristics (Grey relational grade generation)

Sl. No.	Sample 1				Sample 2			
	Depth of Penetration (mm)	Reinforce-ment (mm)	Weld metal Hardness (BHN)	Bending Load at 10^0 (kN)	Depth of Penetration (mm)	Reinforce-ment (mm)	Weld metal Hardness (BHN)	Bending Load at 10^0 (kN)
1	0	0.32	0.09	0.93	0.02	0.43	0.61	0.71
2	0.2	0.58	0.26	0.71	0.18	0.57	0.7	0.86
3	0.37	0.39	1	0.71	0.32	0.47	0.12	0.71
4	0.34	0.76	0.56	0.29	0.38	0.62	0.88	0.07
5	0.25	1	0.79	0.64	0.23	0.97	0.18	0
6	0.53	0	0.91	1	0.61	0.17	0.56	1
7	0.29	0.91	0	0.43	0.27	0.9	0.26	0.21
8	0.39	0.92	0.12	0.79	0.43	0.93	0.47	0.86
9	0.97	0.62	0.7	0.5	1	0.61	0.7	0.86

Table 14 : Evaluation of Δ_{oi} for Each of the Process Response

Sl. No.	Sample 1				Sample 2			
	Depth of Penetration (mm)	Reinforce-ment (mm)	Weld metal Hardness (BHN)	Bending Load at 10^0 (kN)	Depth of Penetration (mm)	Reinforce-ment (mm)	Weld metal Hardness (BHN)	Bending Load at 10^0 (kN)
1	1	0.68	0.91	0.07	0.98	0.57	0.39	0.29
2	0.8	0.42	0.74	0.29	0.82	0.43	0.3	0.14
3	0.63	0.61	0	0.29	0.68	0.53	0.88	0.29
4	0.66	0.24	0.44	0.71	0.62	0.38	0.12	0.93
5	0.75	0	0.21	0.36	0.77	0.03	0.82	1
6	0.47	1	0.09	0	0.39	0.83	0.44	0
7	0.71	0.09	1	0.57	0.73	0.1	0.74	0.79
8	0.61	0.08	0.88	0.21	0.57	0.07	0.53	0.14
9	0.03	0.38	0.3	0.5	0	0.39	0.3	0.14

It is observed that weld metal hardness is less than parent metal hardness. So weld metal hardness should be maximized for sound welding. For optimization, bending load at 100 bend angle is considered to maximize, as at a higher bend angle, few specimens fail during the test. Penetration should be maximized to avoid voids and to increase strength. To reduce the weld metal consumption, reinforcement should be minimized. The optimization criteria are given in the Table 13. Optimization has been carried out according to the Grey-based Taguchi method [1,11]. Evaluation of the factor, is made (Table 14), and grey relational coefficient of each performance characteristics (Table 15) is found out. Grey relational grade (Table 16) and response table for signal-to-noise ratio (Table 17) are next obtained. Plots indicating the variation of process variables on the response parameters are shown in Fig. 1 through Fig. 3. Main effect plots (Fig. 4 and Fig. 5) and interaction effect plots (Fig. 6) depict the effect between all the relevant process parameters and

Table 15 : Grey Relational Coefficient of each performance characteristics (with = 0.5)

Sl. No.	Sample 1				Sample 2			
	Depth of Penetration (mm)	Reinforce-ment (mm)	Weld metal Hardness (BHN)	Bending Load at 10^0 (kN)	Depth of Penetration (mm)	Reinforce-ment (mm)	Weld metal Hardness (BHN)	Bending Load at 10^0 (kN)
1	0.33	0.42	0.35	0.88	0.34	0.47	0.56	0.64
2	0.36	0.54	0.40	0.64	0.38	0.54	0.63	0.78
3	0.44	0.45	1.00	0.64	0.42	0.49	0.36	0.64
4	0.43	0.68	0.53	0.41	0.44	0.57	0.80	0.35
5	0.40	1.00	0.70	0.58	0.39	0.94	0.38	0.33
6	0.52	0.33	0.85	1.00	0.56	0.38	0.53	1.00
7	0.41	0.85	0.33	0.47	0.41	0.84	0.40	0.39
8	0.45	0.87	0.36	0.70	0.47	0.87	0.49	0.78
9	0.95	0.57	0.63	0.50	1.00	0.56	0.63	0.78

Table 16 : Grey relational grade

Sl. No.	Sample 1	Sample 2
1	0.497	0.502
2	0.492	0.580
3	0.632	0.477
4	0.513	0.541
5	0.672	0.510
6	0.675	0.618
7	0.514	0.509
8	0.595	0.651
9	0.661	0.741

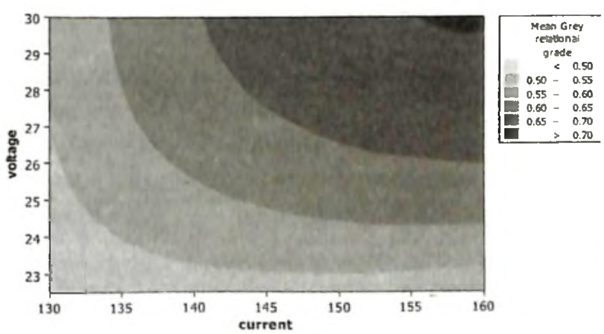

Fig. 1 : Contour plot of grey relational grade with respect to weld voltage and current

Fig. 1 shows the mapping of mean grey relational grade in the domain of weld current and weld voltage. It is observed that mean grey relational grade is the highest corresponding to maximum weld current (160 Amp) and weld voltage (30 Volt), and hence, in this consideration, these are the optimum welding parameter settings. Similar plot of mean grey relational grade in the domain of weld current and weld traverse speed is depicted in Fig. 2. In this figure, maximum value of mean grey relational grade is seen in the mid portion of the right hand side. This corresponds to a weld current of 160 Amp and weld traverse speed in the range of 430 to 560 mm/min, indicating the optimum range of process parameters. In the domain of weld voltage and weld traverse speed, mean grey relational grade is mapped in Fig. 3, where it is also found that maximum value of mean grey relational grade corresponds to the dark region at the right hand side middle portion of the map. This is the optimum region given by a weld voltage of 30 Volt and weld traverse speed in the range of 430 to 560 mm/min.

From the Contour Plots (Fig. 1 through Fig. 3), it can be concluded that mean grey relational grade is high at high current, high voltage and low to medium speed, and hence, may be considered the optimal welding condition within the experimental domain. Table 17 also shows similar findings corresponding to the maximum S/N ratio (larger-the-better).

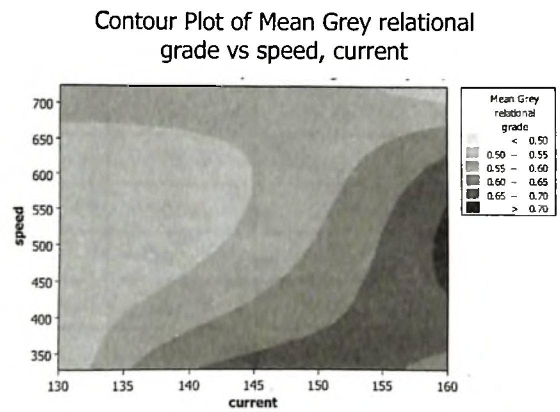

Fig. 2 : Contour plot of grey relational grade with respect to traverse speed and weld current

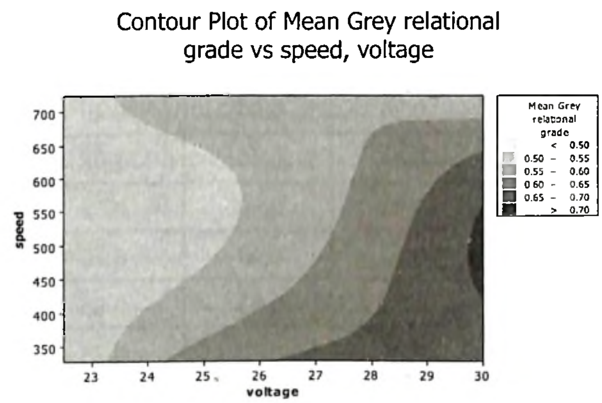

Fig. 3 : Contour plot of grey relational grade with respect to traverse speed and weld voltage

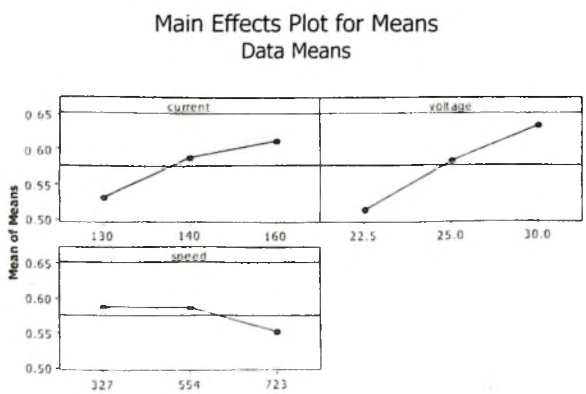

Fig. 4 : Main effect plot for means - grey relational grade of stainless steel

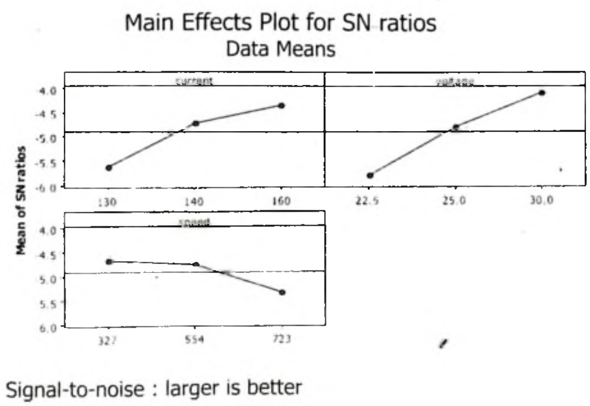

Fig. 5 : Main effect plot for SN ratios - grey relational grade of stainless steel

Table 17 : Response Table for Signal to Noise Ratios (Larger is better)			
Level	Current	Voltage	Speed
1	-5.637	-5.810	-4.660
2	-4.736	-4.818	-4.736
3	-4.361	-4.105	-5.337
Delta	1.276	1.706	0.678
Rank	2	1	3

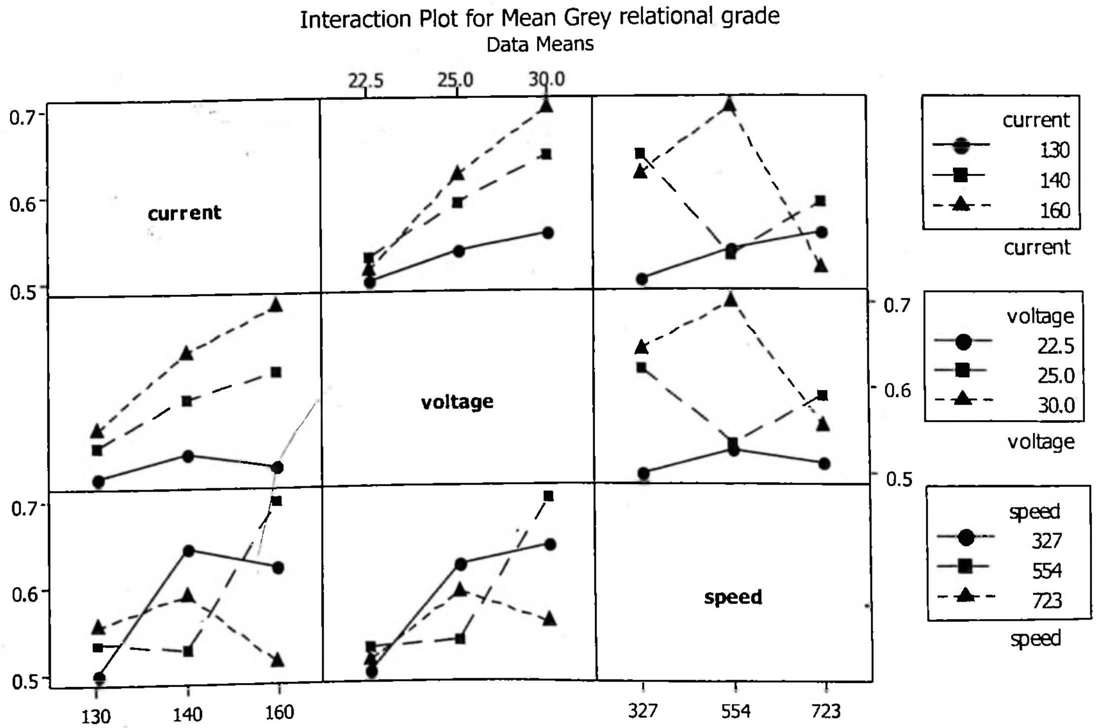

Fig. 6 : Interaction Plot for Grey relational grade for stainless steel

Main effects plots for means and S/N ratio are shown in Fig. 4 and Fig. 5. From the main effects plots, it is observed that

- The grey relational grade is increased with the increase in weld current and voltage, and it is decreased with the increase in weld traverse speed. This trend is expected as with the increase in power input through increasing current and voltage, depth of penetration should increase, thereby increasing grey relational grade. Conversely, increase in transverse speed causes lesser heat input causing less depth of penetration.
- The rate of increase in grey relational grade is found to be more with the increase in weld voltage. Weld current shows similar tendency but with lesser slope than that with the weld voltage, signifying lower significance of weld current than weld voltage. The slope in case of traverse speed is found to be minimum, even negative, and hence, is the least significant factor.

According to the Delta statistics (highest minus the lowest average for each factor), the ranking of the input parameters according to the decreasing order of effect on response is give by;

1. Weld voltage

2. Weld current
3. Weld traverse speed.

From the above discussion, it can be stated that, for high value of grey relational grade, high current (160 Amps), high voltage (30 Volt) and low-to-medium weld traverse speed (327 to 554 mm/min) can be selected.

It is further observed from the interaction plot as shown in Fig. 6 that

- If current is increased then grey relational grade is increased on the whole; grey relational grade is having clear increasing trend with voltage for all levels of current. These results are expected due to high heat input corresponding to high weld voltage and current setting.
- If the current is increased then grey relational grade first increased then decreased for all levels of traverse speed except the speed of 554 mm/min. In this case, grey relational grade first decreases and then increases with speed.
- Change in grey relational grade does not show any clear trend with the increase in weld voltage and current with varying weld traverse speeds.

CONCLUSION

Following conclusions may be drawn from the experimental investigation on metal active gas welding of stainless steel specimens;

- Grey-based relational analysis is made to optimise the welding process parameters based on the results of the experiments designed using Taguchi's L9 orthogonal array.
- The evaluated optimum condition within the experimental domain corresponds to a weld voltage of 30 Volt and a weld current of 160 Amp with the weld traverse speed between 327 mm/min and 554 mm/min.

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