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Parameter Optimization of Gas Metal Arc Welding Process for Welding Dissimilar Steels

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Abstract: Welding is a method of joining similar and dissimilar metals through the use of coalescence. GMAW is a semi-mechanized, fully-mechanized, or automatic process that is widely used in fabrication. GMAW is expected to evolve further to allow for better arc control, bead contour control, deposition control, and higher productivity. The goal of this study is to enhance welding process variables for dissimilar steel metal joints made of duplex stainless steel (DSS) to ASTM/UNS S32205 and erosional steel CORTEN-A to ASTM A242. Such a dissimilar metal joint finds use in the transportation sector, particularly in the construction of rail cars. The square butt joint between two 2 mm-thick sheets was investigated using the gas metal arc welding (GMAW) process with CO_2 as the shielding gas and flux-cored wire of grade 309L as the filler material. The L_9 Taguchi array was used to optimize the tensile strength of the resulting weld joint, which was the desired quality characteristic. GMAW process parameters such as voltage, wire feed rate, and welding speed are optimized at three levels. Using ANOVA, the effects of each factor have been studied. It was found that the ideal set of parameters exists and that the voltage is the most crucial factor. A confirmation test was performed to validate the results, and it was accompanied by a figure and tables.

Keywords: CORTEN Steel, Dissimilar Welding, Duplex Stainless Steel, GMAW Process, Optimization

1. Introduction

Duplex stainless steel which has advantages like high strength to weight ratio, easy to form, good weldability characteristics is presently under consideration for rail coach fabrication [1]. DSS, owing to its appealing aesthetic and other qualities mentioned above, find wide application in the side wall, end wall and roof assemblies of rail car. CORTEN steel is well known for its atmospheric corrosion resistance properties and is widely used for fabrication of under gear and floor side assemblies of the rail car. Hence joining of these dissimilar steel finds lot of application in rail coach fabrication. Also, joining dissimilar metal is indispensable in manufacturing, constructing advanced equipment's, and machinery. Fusion Welding is a widely used method for joining dissimilar steels. Optimization of weld parameters for such fusion weld joints will help in achieving a sound weld joint free from defects [1, 2]. Since such kinds of joints are widely used, this study assumes a lot of significance in terms of safety, quality and life cycle improvement of the product.

GMAW is widely used in fabrication activity as a semi mechanized, fully mechanized or automatic process. It is expected that GMAW will continue to evolve to allow better arc control, better bead contour control, better deposition control and higher productivity. GMAW process will retain its dominant position and the latest research supports the application and further development of these processes [2].

A Successful weld between dissimilar metals is one that is as strong as the weaker of the two metals being joined, i.e., possessing sufficient tensile strength and ductility so that the joint will not fail in the weld. The dissimilar weld joint showing higher resistance than the base metal in the tensile test and good performance in the bend test shows soundness of the joint [3].

The study employs Taguchi Orthogonal Array Technique for arriving optimum value of process parameters with higher the better characteristics for the quality characteristic. The experimental design proposed by Taguchi involves use of orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varied. Instead of having to test all possible combinations like the factorial design, Taguchi method tests pairs of combinations. This allows for the collection of the necessary data to determine which factors most affect product quality with a minimum amount of experimentation, thus saving time and resources [4-8].

The objective of this project work is to study and optimize the process parameters for dissimilar welding involving Duplex stainless steel and Weathering Steel to grade CORTEN-A using GMAW process to get a sound weld joint. An Orthogonal array, signal to noise (S/N) ratio and analysis of variance (ANOVA) are employed to arrive at the optimum value of the parameters.

2. Materials and Methods

2.1. Experimental Setup

Square butt weld joint using 2mm thick Base Metals was studied in this experiment. A KEMPPI (Finland) make GMAW power source of 300Amps capacity with mechanized torch movement was used for making the weld joint. The mechanized torch movement ensured precise control over the weld speed. Voltage and wire feed rate are set at the GMAW power source which has provision to set these values to one decimal place precision. Flux Cored Wire Electrode of diameter 1.2mm of specification AWS5.22 E309L T1-1 suitable for this dissimilar welding was used as filler material with CO_2 as shielding gas. Welding was done in down hand position. Gas flow rate of 15 LPM, stick-out of 20mm and a root gap of 1 to 1.1mm were maintained.

2.2. Materials

Chemical composition study for both DSS and CORTON steel samples were carried out using Atomic Emission Spectrophotometry. The Chemical Composition of the samples obtained is as tabulated below in table 1.

Table 1. *Chemical composition of ASTM-A 242 and ASTM-S 32205 samples.*

Element Present →	C	Mn	Si	S	P	Cu	Cr	Ni	V	Mo	Nh	N
ASTM-A 242	0.066	0.343	0.463	0.005	0.076	0.403	0.424	0.298	<0.001	<0.001	0.0007	-
ASTM-S 32205	0.026	1.570	0.676	0.001	0.017	0.158	22.56	5.59	-	2.9	0.015	0.16

2.3. Preparation of Weld Coupon

Tensile strength and ductility of a weld joint can be measured by subjecting the standard specimens drawn out from the test coupons to tensile test as per ISO 4136:2001 and bend tests as per ISO 5173:2009 respectively using Universal Testing Machine. In the case of dissimilar weld under tensile test, separation is expected to happen only at the weaker of the two parent materials and not on the weld joint. Bend test determines ductile behaviour of the specimen over a given radius and provides insight into the modulus of elasticity and the bending strength of the material. Hardness of different regions in the weld joint is measured using a Vickers hardness test as per ISO 9015-1 & 9015-2 standards. Vickers Hardness Test is used to find out the hardness of the material which can be correlated to the strength of the material [9-10].

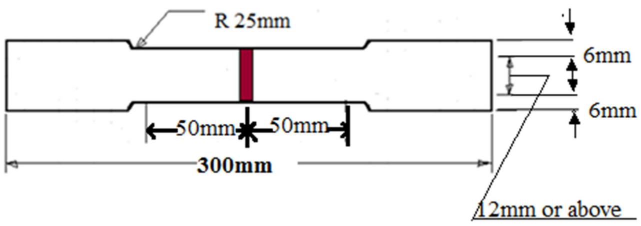

Figure 1. *Test sample for Transverse tensile test.*

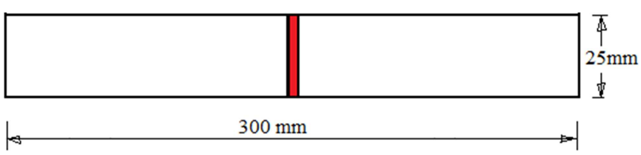

Figure 2. *Test sample for Bend Tests.*

Sample sizes of weld coupon required for testing these mechanical strength properties was finalized based on Tensile & Bend test requirements which are illustrated in Figures 1 & 2 respectively. Accordingly weld pad of size 80mm wide, 300mm long and 2mm thick with run-on and run off plates was prepared.

3. Results and Discussion

3.1. Design of Taguchi's Orthogonal Array

The Taguchi method is best used when there are an intermediate number of variables (3 to 50), few interactions between variables, and when only a few variables contribute significantly. The arrays are selected by the number of parameters (variables) and the number of levels (states). Benefits of Orthogonal Array method are (a) Conclusions valid over the entire region spanned by the control factors and their settings, (b) Large saving in the experimental effort, and (c) Analysis is easy.

3.2. Selection of Process Parameters for the Study

Process Parameters that influences quality of weld joint is dealt in EN ISO 15609-1:2004(E) standards. Based on this and field expert opinion the parameters which are variable and hence to be considered for optimization for a GMAW process are welding current, arc voltage, wire feed rate, and travel speed [10-12]. GMAW process is having constant voltage characteristics in which the welding current is decided by wire feed rate. Thus arc voltage, wire feed rate, and travel speed are selected as the process parameters that are to be optimized for the present study.

3.3. Experiments Based on Taguchi's Orthogonal Array

As explained above, process parameters to be optimized for the present study are Voltage [V], Wire feed rate [F], and welding speed [S]. Transverse Tensile Strength is selected as the quality characteristic for performance measure. Strength of the weld joint can be found out using Transverse Tensile Test.

During trial welding of the dissimilar samples, ductile failure occurred on the CORTEN-A material but beyond weld and heat affected zone which indicates that weld metal is stronger than the weaker of the two base metals. The above joint, arrived at after many screening trials was made with following process parameters, i.e., Voltage [V] = 25volts, Wire Feed rate [F] = 5.2 meter/minute with corresponding current of 102 Amps and Welding speed [S] = 60 meter / hour.

Design matrix of three welding parameters (V, F & S) each at three levels was selected for this optimization study in order to obtain a weld joint having highest possible tensile strength value. The three levels for these process parameters (factors) are tabulated in table 2 above. Experimenting with these three parameters each with 3 levels will call for a full factorial array with 27 possibilities. But using Taguchi Orthogonal array method, same can be analyzed with nine experiments instead of 27 possibilities. The degrees of freedom of the orthogonal array should be greater than or at least equal to the degrees of freedom of all the process parameters. The interaction effect between the parameters is not considered [13-15]. The total degrees of freedom of all process parameters are 8. Hence, L9 [3x3] orthogonal array was chosen which has 8 degrees of freedom.

Table 2. *Process Parameters and its levels for the experiment.*

Process Parameters	Level 1	Level 2	Level 3
Voltage [V]	23.0	25.0	27.0
Wire Feed rate [F]	4.8	5.2	5.7
Welding speed [S]	55.0	60.0	65.0

3.4. Orthogonal Array Used for the Study

Each of the 9 experiments is conducted with a pre-specified combination of voltage, wire speed and welding speed as shown in table 3 below. Table 4 shows the actual values used and Table 5 shows the results of the experiment.

Table 3. *Orthogonal array used.*

Exp. No	Voltage (V)	Wire feed rate (Meter/Min)	Weld speed (Meter/hr)
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 4. *L9 array with parameter values used for the experiment.*

Exp. No	Voltage (V)	Wire feed rate (F) (Meter/Min)	Weld speed (S) (meter/hr)
1	23	4.8	55
2	23	5.2	60
3	23	5.7	65
4	25	4.8	60
5	25	5.2	65
6	25	5.7	55
7	27	4.8	65
8	27	5.2	55
9	27	5.7	60

Table 5. *Results of Tensile and Bend Test using orthogonal array.*

Exp. No.	UTS (MPa)	Location of Failure	Result of Face bend test	Result of Root bend test
1	494.32	HAZ CS	Satisfactory	Satisfactory
2	505.01	Parent metal CS	Satisfactory	Satisfactory
3	492.56	Parent metal CS	Satisfactory	Satisfactory
4	510.01	Parent metal CS	Satisfactory	Satisfactory
5	535.45	Parent metal CS	Satisfactory	Failed at HAZ CS
6	555.25	Parent metal CS	Satisfactory	Satisfactory
7	453.32	HAZ CS	Failed	Satisfactory
8	488.66	Fusion line & HAZ	Cavity opened	Cavity opened
9	471.70	HAZ CS	Satisfactory	Failed HAZ CS

3.5. Loss Function and s/n Ratio

As discussed, the weld strength belongs to the higher-the-better quality characteristic. The signal to noise ratios (S/N), which are log functions of desired output, serve as the objective functions for optimization that help in data analysis and the prediction of the optimum results. Generic expression for S/N ratio as per TAGUCHI method is

$$n = -10 \log10 (C_i) \qquad (1)$$

Where C_i is the mean of sum of squares of reciprocals of measured data.

S/N ratio, its overall mean value, deviation from mean and square of deviation etc., are tabulated as below in table 6.

Table 6. *L9 matrix array table.*

Exp. No	[V]	[F]	[S]	Meas-ured Data [UTS]	mean of square of reciprocal [Ci]	S/N Ratio [n]	overall mean value for S/N [m]	Square of S/N	Deviation of S/N from mean (I)	square of deviation S/N to mean
1	23	4.8	55	494.32	0.00000409	53.88		2903.07	-0.097	0.009
2	23	5.2	60	505.01	0.00000392	54.06		2923.13	0.089	0.008
3	23	5.7	65	492.56	0.00000412	53.84		2899.73	-0.128	0.016
4	25	4.8	60	510.01	0.00000384	54.15		2932.39	0.175	0.030
5	25	5.2	65	535.45	0.00000349	54.57	53.916	2978.36	0.597	0.357
6	25	5.7	55	555.25	0.00000324	54.89		3012.88	0.913	0.833
7	27	4.8	65	453.32	0.00000487	53.12		2822.59	-0.849	0.721
8	27	5.2	55	458.66	0.00000475	53.23		2833.41	-0.197	0.039
9	27	5.7	60	471.70	0.00000449	53.47		2859.39	-0.503	0.253
					Total	485.24				2.267

3.6. Factor Effects

The effect of a factor level is defined as the deviation it causes from the overall mean. Using the S/N ratio data available in below *Table 7* the average of each level of the three factors is calculated. These average values are shown in table 7 below. They are separate effect of each factor and are commonly called main effects which are graphically represented in figure 3 below.

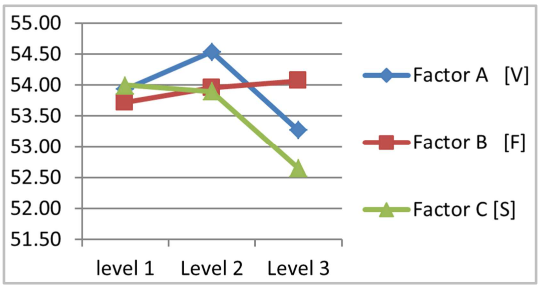

Figure 3. *S/N ratio graph.*

Table 7. *Average of each level of the three factors.*

Factor	level 1	Level 2	Level 3
Factor A [V]	53.932	54.540	53.270
Factor B [A]	53.720	53.960	54.070
Factor C [S]	54.000	53.897	52.650

3.7. Analysis of Variance

Different factors affect the quality characteristic, i.e., the tensile strength, in this study to a different degree. The relative magnitude of the factor effects are listed shows in above Table 6 (L9 matrix array table). A better feel for the relative effect of the different factors is obtained by the decomposition of variance, which is commonly called as analysis of variance (ANOVA) and is tabulated in table 8 below.

3.8. Confirmation Tests

Figure 4. *Tensile Test Specimens.*

Figure 5. *Test specimens for bend tests.*

Figure 6. *Test Specimens showing failure at CS side away from weld and HAZ.*

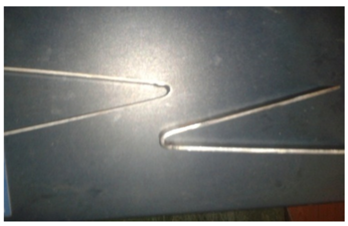

Figure 7. *Test Specimens showing satisfactory weld properties.*

Tests are now carried out to verify the improvement of quality of characteristics using the optimal level of welding process parameters such as welding voltage at level 2, wire feed rate at level 3 and welding speed at level 1. The resultant UTS value is around 555N/mm^2. Hence optimal inputs determine greater tensile strength of the weld. The root and bend tests also revealed that the failure does not occur at weld joint.

Table 8. *ANOVA table.*

factor	Level 1	Level 2	Level 3	degree of freedom	sum of squires	Mean Squire= Sum of squires/degree of freedom	% ge contribution
Factor A [V]	53.93	54.54	53.27	2	1.752	0.876	77.3
Factor B [A]	53.72	53.96	54.07	2	0.305	0.152	13.4
Factor C [S]	54.00	53.89	52.65	2	0.195	0.097	8.6
Error				2	0.015		0.7
	TOTAL			8	2.267		100.0

3.9. Hardness Survey

The hardness survey on the above referred joint carried out using a Vickers Hardness Testing Machine with a load of 10kg has given the values as mentioned shows in Figure 8. The hardness value is observed to be in accordance with the failure pattern showing that ductile failure under tensile load has occurred at the area of minimum hardness.

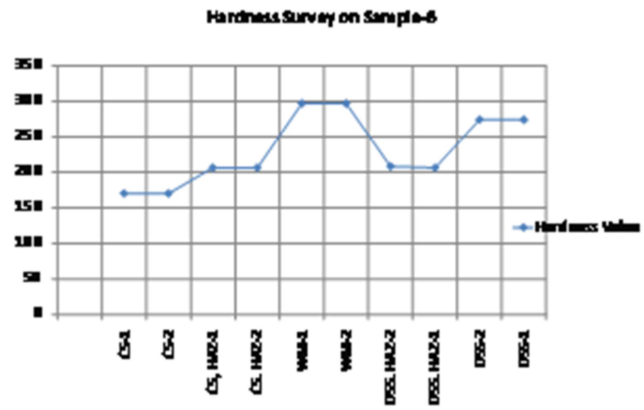

Figure 8. *Hardness profile at various regions.*

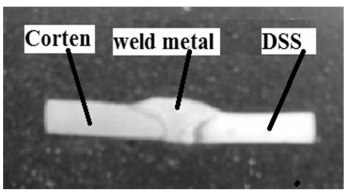

Figure 9. *Macrograph of the weld Joint.*

4. Conclusions

This study used Taguchi's experimental design to optimize the parameters of Gas Metal Arc Welding with dissimilar steel. For the response variables of Tensile Strength, the process was applied with a specific set of controllable parameters Voltage, weld speed, and wire feed rate. This study employed the L9 orthogonal array, S/N ratio, and analysis of variance. The researchers discovered that the control variables had varying effects on the response variables. The main discovery is based on the experimental results of my research, I came to the following conclusions:

1) Optimum welding parameters for welding dissimilar metal joints of 2mm thick steel sheets of DSS-2205 and Corten-steel were arrived at. The optimum values of GMAW process parameter using 1.2mm diameter flux cored electrode of 309L grade wire with mechanized torch travel for obtaining a sound dissimilar metal joint between 2mm thick DSS 2205 and CORTEN-A steel sheets with square butt joint using CO_2 as shielding gas are found to be voltage = 25Volts, Wire Feed = 5.7 meter per minute and Welding Speed = 55 meter per hour.
2) When tested for tensile strength test samples with optimum welding parameters failed at the weaker of the two parent metals, i.e., in the Corten-A steel and this failure occurred much away from the weld joint and HAZ. During bend test also there was no failure at the weld joint. Hence the weld joint obtained was strong and sound.

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