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Gas Metal Arc Welding Process Variables Enhancement for Welding Significantly different Steels

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Abstract
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 2mm thick sheets was investigated using the gas metal arc welding (GMAW) process with CO2 as the shielding gas and flux cored wire of grade 309L as the filler material. The L9 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.

Introduction

Duplex stainless steel which has advantageous 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]. 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. GMAW is expected to evolve further to allow for better arc control, bead contour control, 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, that is, it has enough tensile strength and ductility to prevent the joint from failing during the weld. The dissimilar weld joint demonstrating higher resistance than the base metal in the tensile test and good performance in the bend test demonstrates the joint's soundness [3]. The Taguchi Orthogonal Array Technique is used in the study to arrive at the optimum value of process parameters with higher the better characteristics for the quality characteristic. Taguchi's experimental design calls for the use of orthogonal arrays to organize the process parameters and the levels at which they should be varied. As opposed to the factorial design, which requires testing every possible combination, the Taguchi method only needs to test pairs of combinations. This permits the gathering of the necessary data to identify the variables that have the greatest impact on product quality with the least amount of experimentation, saving time and resources [4-6]. The purpose of this study is to look into and optimize the process parameters for dissimilar welding with Duplex stainless steel and Weathering Steel to grade CORTEN-A using the GMAW process in order to obtain a sound weld joint. To determine the optimal value of the parameters, an orthogonal array, signal to noise (S/N) ratio, and analysis of variance (ANOVA) are used.

Materials and Methods

Experimental setup

This experiment examined a square butt weld joint using base metals that were 2mm thick. For the welding joint, a GMAW power source with a 300 Amp capacity and a mechanized torch movement was used. The precise control of the weld speed was made possible by the mechanized torch movement. The GMAW power source allows for the setting of voltage and wire feed rate with a precision of one decimal place. With CO2 acting as the shielding gas, a flux cored wire electrode with a diameter of 1.2mm and a specification of AWS5.22 E309L T1-1 was used as the filler material. The hands were in a down position while welding. A root gap of 1 to 1.1mm, a stick-out of 20mm, and All were kept at a gas flow rate of 15 LPM.

Materials
Chemical composition study for both DSS and CORTON steel samples were carried out using Atomic Emission Spectrophotometry Table .1 shows the chemical compositions of the specimens (samples) obtained.

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*	*Nh*
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	0.016

Preparation of Weld Coupon
With the aid of a universal testing machine, standard specimens taken from test coupons can be put through bend and tensile tests in accordance with ISO 5173:2009 and ISO 4136:2001, respectively, to determine the ductility and strength of a weld joint. 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 tests are used for determine the ductile behavior of a specimen over such a given radius as well as provide information about the material's modulus of elasticity and bending strength. 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.

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

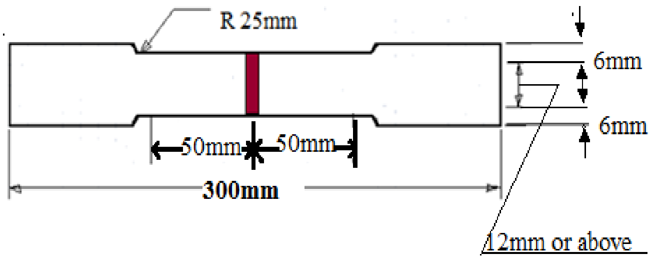

Figure.1, Test sample for Transverse tensile test

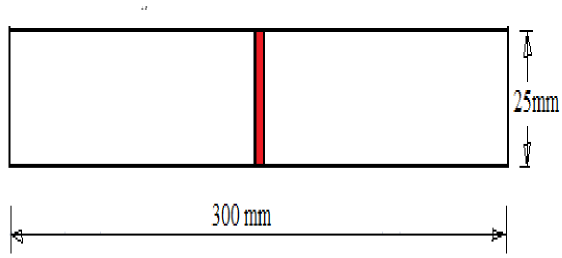

Figure.2, Test sample for Bend Tests

Results and Discussion
Design of Taguchi's orthogonal array
When there are between three and fifty variables, there are few interactions between the variables, and only a few variables significantly contribute, the Taguchi method works best. how many parameters there are [variables] and levels determines which arrays are used [states]. The advantages of the orthogonal array method include [a] conclusions that are valid across the entire region covered by the control factors and their settings, [b] significant experimental effort savings, and [c] straightforward analysis.

Process Parameters for the Study
Process Parameters that influences quality of weld joint is dealt in EN ISO 15609-1:2004[E] standards. Welding arc voltage, welding current, wire feed rate, and welding travel speed are variables that must be properly considered for GMAW process optimization based on this and the advice of field experts. GMAW process is having constant voltage characteristics in which the welding current is decided by wire feed rate. Consequently, the procedure parameters that are to be optimized for the current study are chosen to be arc voltage, travel speed, and wire feed rate.

Experiments Based on Taguchi's Orthogonal Array
As explained above, process parameters to be optimized for the present study are Welding Speed [S], welding voltage[V] and wire feed rate [F]. 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.

The CORTEN-A material experienced ductile failure during trial welding of the dissimilar samples, but outside of the weld and heat affected zone, proving that the weld metal is stronger than the weaker of the two base metals. The above-mentioned 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 below. Experimenting with these three parameters each with three [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 orthogonal array's degrees of freedom should be greater than or equal to the degrees of freedom of all process parameters. The interaction effect of the parameters is ignored. All process parameters have a total degree of freedom of eight. As a result, a L9 [3(3)] orthogonal array with 8 degrees of freedom was chosen.

Table 2: Parameters of the process & experimental level

Parameters of the process	*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

The orthogonal array was used in the study

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

Table 3: Orthogonal array used

Exp. No	Voltage (V)	Wire feed rate	Weld 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 4: L9 array with parameter values used for the experiment

Exp. No	Voltage (V)	Wire feed rate (F)	Weld speed (S)
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	HAZ and Fusion line	Opened cavity	Opened cavity
9	471.70	HAZ CS	Satisfactory	Failed HAZ CS

The loss function and the S/N ratio

Weld strength is a higher-is-better quality characteristic, as was previously mentioned. The objective functions for optimization that aid in data analysis and the forecasting of the best outcomes are the signal to noise ratios [S/N], which are log functions of the desired output. Generic expression for S/N ratio as per TAGUCHI method is

$n = -10 \log10 [C_i]$[1]

Where Ci is the Average (mean) of the reciprocals of the measured data's sum of squares.

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]	Measured 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	53.916	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		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

Factor effects

A factor level's effect is defined as the deviation it causes from the overall mean. Using the S/N ratio data from Table 5, 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. Figure 3 below shows are commonly called the main effects in graphic form.

Table 7: Average of each level of the three factors

Factors	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

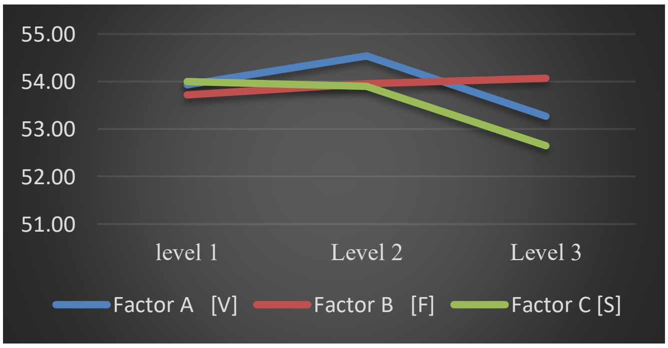

Figure 3, S/N ratio graph

Analysis of variance

Different factors influence the quality characteristic, that is, tensile strength, to varying degrees in this study. Table 6 above lists the relative magnitude of the factor effects. The decomposition of variance, also known as analysis of variance (ANOVA), is tabulated in table 8 below and provides a clearer understanding of the relative impact of the various factors.

Table 8: ANOVA table

Factors	Level-1	Level-2	Level-1	DOF	Sum of squires	Mean squire = Sum of squires/degree of freedom	% ge contribu tion
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

Confirmation tests

Tests are now being conducted to verify the improvement of characteristic quality by using the optimal level of welding's process of parameters like; welding voltage at level-2, wire feed rate at level- 3, and welding speed at level-1. The resultant UTS value is around 555N/mm2. As a result, optimal inputs determine greater weld tensile strength. The failure does not occur at the weld joint, according to the root and bend tests.

Fig-4, Tensile Test Specimens

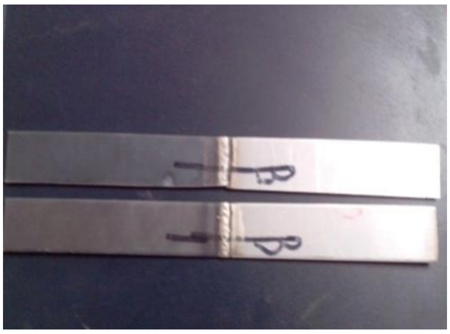

Fig-5,Test specimens for bend tests

Figure-6, Test Specimens showing failure at CS side away from weld and HAZ

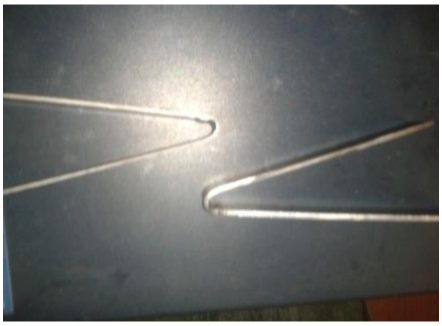

Figure-7, Test Specimens showing satisfactory weld properties

The hardness survey on the above referred joint carried out using a Vickers hardness testing machines with a load of 10kg has given the values as mentioned 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.

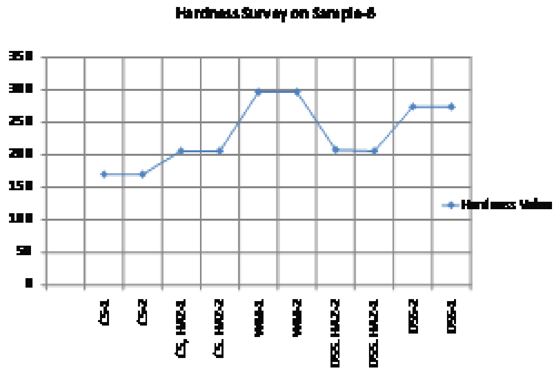

Figure-8, Hardness profile at various regions

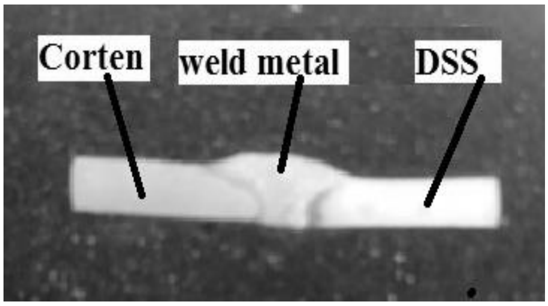

Figure-9, Macrograph of the weld Joint

Conclusions

The optimal welding parameters for welding dissimilar metal joints of 2mm thick DSS-2205 and Corten-steel steel sheets were determined. The optimal GMAW process parameter settings 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 CO2 as shielding gas are found to be voltage = 25Volts, Wire Feed = 5.7 meter per minute and Welding Speed = 55 meter per hour.

Tensile strength test samples with optimum welding parameters failed at the weaker of the two parent metals, namely Corten-A steel, and this failure occurred far 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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