International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Impact Factor (2012): 3.358

Parametric Optimization of TIG welding of Galvanized Steel with AA1050 using Taguchi Method

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Abstract: ***Tungsten Inert Gas welding (TIG) process is an important component in many industrial operations. The TIG welding parameters are the most important factors affecting the quality, productivity and cost of welding. Dissimilar welding of metal having different mechanical and physical properties is very difficult. The process tried here is weld brazing process. A filler rod is selected in such a way that it is compatible to both GI and Aluminium. On the aluminum side the filler rod will have proper fusion whereas on the Galvanized steel side the process will be a brazing operation in which a thin intermetallic layer is formed between the seam and the sheet. This paper presents the influence of welding parameters like welding current, welding speed and frequency on strength of Galvanized steel on AA1050 material during welding. A plan of experiments based on Taguchi technique has been 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 dissimilar joint and optimize the welding parameters. Finally the conformations tests have been carried out to compare the predicted values with the experimental values to confirm its effectiveness in the analysis of strength.***

Keywords: TIG welding, weld brazing, optimization, orthogonal array, S/N ratio

1. Introduction

Tungsten Inert Gas welding is widely used welding process in industrial applications. Quality of weld relies on the input welding parameters. Welding of dissimilar metals that to ferrous with non ferrous metals was found to be difficult earlier. But weld brazing techniques is new technique which help in producing dissimilar joints. These parameters affecting the arc and welding should be estimated and their changing conditions during process must be known before in order to obtain optimum results; in fact a perfect joint can be achieved when all the parameters are in conformity. These are combined in two groups as first order adjustable and second order adjustable parameters defined before welding process. Former are welding current, welding speed and frequency in the case of pulsed current (PCTIG) welding. These parameters will affect the weld characteristics to a great extent. Because these factors can be varied over a large range, they are considered the primary adjustments in any welding operation. Their values should be recorded for every different type of weld to permit reproducibility. Proper filler wire is selected such that the base metal is compatible to filler rod. ER4043 which is Zinc based filler rod which will enhance the intermetallic formation while brazing with galvanized steel which is having a zinc coating. There will be welding that is proper fusion on the aluminium side and brazing operation will be performed on the Galvanized steel side. Since the melting point of the steel is higher, partial fusion alone can take place rather than fusion. This plasticizing steel combines with the filler rod forming thin layers of intermetallics. Optimal current, welding speed and frequency has to be identified in order to get better defects free joint.

2. Taguchi's Design Method

Dr. Taguchi of Nippon Telephones and Telegraph Company, Japan has developed a method based on "ORTHOGONAL ARRAY" experiments which gives much reduced "variance" for the experiment with "optimum settings" of control parameters. . "Orthogonal Arrays" (OA) provide a set of well balanced (minimum) experiments and Dr. Taguchi's Signal-to-Noise ratios (S/N), which are log functions of desired output, serve as objective functions for optimization, help in data analysis and prediction of optimum results. There are 3 Signal-to-Noise ratios of common interest for optimization.

(i) Smaller-The-Better:

$n = -10\ \mathrm{Log}_{10}$ [mean of sum of squares of measured data]

(ii) Larger-The-Better:

$n = -10\ \mathrm{Log}_{10}$ [mean of sum squares of reciprocal of measured data]

(iii) Nominal-The-Best:

$$n = 10\ \mathrm{Log}_{10} \frac{\text{square of mean}}{\text{variance}}$$

3. Work material

2mm thick Galvanized steel AA1050 aluminium alloy were used. The dimensions of the work piece, length 300 mm, width 150mm. For selection of workpiece, reference of the

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procedure handbook of Arc Welding & Welding Process Technology by P. T. Houldcroft is referred. This experiment, TIG welding is done using Lincoln machine, PCTIG, Welding current, welding speed and frequency from workpiece are 78, 80, 82Amps, 2.5, 3, 3.5 mm/sec and 4, 6, 8Hz respectively, Voltage 16V, The arc distance, electrode type, electrode size and electrode tip angle were 2.4mm, EWTh-2, 3mm in diameter and Vertical respectively. Pure argon gas with 15L/min was used for preventing oxidation of molten steel. Filler wire used is ER4043.

Table 1: Welding parameters and their levels

Symbol	Welding parameters	Level 1	Level 2	Level 3
I	Welding current	78	80	82
S	Welding speed	2.5	3	3.5
H	Frequency	4	6	8

4. L9 Level Taguchi Orthogonal Array

Taguchi's orthogonal design uses a special set of predefined arrays called orthogonal arrays (OAs) to design the plan of experiment. These standard arrays stipulate the way of full information of all the factors that affects the process performance (process responses). The corresponding OA is selected from the set of predefined OAs according to the number of factors and their levels that will be used in the experiment. Table No.2 shows L9 Orthogonal array from Table1.

Table 2: L9 Orthogonal array

Expt No	Process Parameters		
	Welding current	Welding speed	Frequency
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

5. Analysis of S/N Ratio

In the Taguchi Method the term 'signal' represents the desirable value (Mean) for the output characteristic and the term 'noise' represents the undesirable value (Standard Deviation) for the output characteristic. Therefore, the S/N ratio to the mean to the S. D. S/N ratio used to measure the quality characteristic deviating from the desired value. In S/N ratio, S is defined as

$$S= -10 \log (M.S.D.)$$

where, M.S.D. is the Mean Square Deviation for the output characteristic.

To obtain optimal welding performance, higher-the better quality characteristic for strength must be taken. The M.S.D. for higher-the –better quality characteristic can be expressed as,

$$M.S.D = \sum 1/P_i^2$$

Where, P_i is the value of penetration.

Regardless of the category of the quality characteristic, a greater S/N ratio corresponds to better quality characteristics. Therefore, the optimal level of the process parameters is the level with the greatest S/N ratio. The S/N response table for strength is shown in Table No.4 as below

Table 3: Experimental results for strength and SN ratio

Expt No	Process Parameters			Tensile Strength MPa	SN ratio
	Welding Current	Welding Speed	Frequency Hz		
1	78	2.5	4	31.48	14.9
2	78	3	6	39.00	13.3
3	78	3.5	8	34.79	0.31
4	80	2.5	6	36.31	0.92
5	80	3	8	33.22	4.55
6	80	3.5	4	38.75	11.5
7	82	2.5	8	45.06	28.4
8	82	3	4	31.68	13.4
9	82	3.5	6	34.47	0.78

Calculation: (S/N Ratio)

$M.S.D = \sum 1/P_i^2$

$P_i = 37.5 \Rightarrow P_i^2 = 1406.25$

$M.S.D = \sum 1/(1406.25)^2 = 0.000711$

$S/N(X) = -10 \log(M.S.D) = -10\log(0.00071) = 31.48$

$Avg (Y)=35.35$

$\text{Sum of square} = (X-Y)^2 = (35.35-31.48)^2 = 14.97$

Total sum of square = 202.99

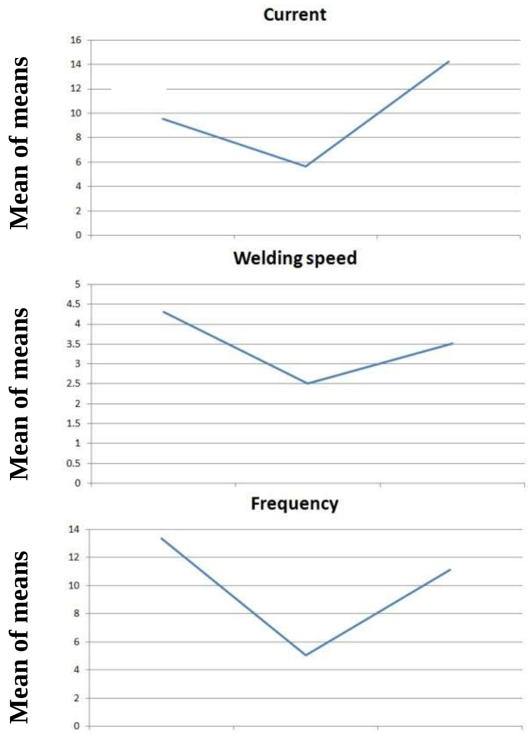

Figure 1: Graphical representation of SN ratio

6. ANOVA (Analysis of Variance)

The purpose of the analysis of variance (ANOVA) is to investigate which design parameters significantly affect the quality characteristic. This is accomplished by separating the total variability of the S/N ratios, which is measured by the sum of the squared deviations from the total mean S/N ratio, into contributions by each of the design parameters and the error. First, the total sum of squared deviations SST from the total mean S/N ratio nm can be calculated as,

$$SST = \sum(n_i - n_m)^2$$

Table 4: SN Ratio for ranking

Mean SN Ratio			
Level	Welding Current	Welding Speed	Welding Distance
	A	B	C
1.00	9.55	14.78	13.32
2.00	5.67	10.45	5.02
3.00	14.23	4.21	11.11
Delta(Δ)	8.56	10.57	8.3
Mean	9.14		
Rank	2	1	3

Table 5: Result of ANOVA

Para meter	***SS***	***dof***	***var***	***F***	***Result***	***Confi dence***	***Signifi cance***
I	47.6	2	23.8	22.3	0.99	99.0	*Yes*
V	72.2	2	36.1	33.9	0.96	96.3	*Yes*
H	76.6	2	38.3	35.9	0.98	98.6	*Yes*
Error	6.39	6	1.06				
Total	203	12	***At least 95% confidence***				

7. Percentage contribution of welding parameters

Table 6: Percentage contribution of welding parameters

Factor	*Welding Parameter*	*SS*	*dof*	*Var*	*F*	*%*
I	*Current*	47.65	2	23.825	22.37	23.47
S	*Speed*	72.29	2	36.145	33.94	35.61
H	*Frequency*	76.66	2	38.33	35.99	37.77
Error		6.39	6	1.065		3.15
Total		202.99	12			100.00

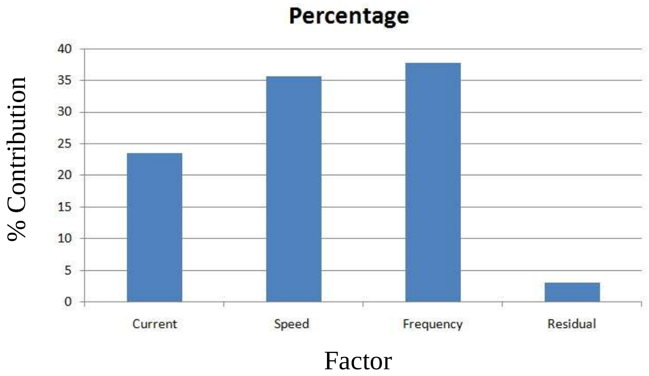

Figure 2: Graphical representation for % of Contribution in Parameters

It is evident from the calculation and graphical representation, that frequency has the highest contribution to the tensile strength of the joint. Speed and current has equally contributed to the tensile strength of the joint.

8. Conformation Test

Once the optimal level of design parameters has been selected, the final step is to predict and verify the improvement of the quality characteristic using the optimal level of design parameters. The estimated S/N ratio using the optimal level of the design parameters can be calculated as

$$\acute{\eta} = \eta_m + \sum_{i=1} (\eta_i - \eta_m)$$

where η_m is total mean of S/N ratio, η_i is the mean of S/N ratio at the optimal level, and n is the number of main welding parameters that significantly affect the performance. The comparison of the predicted strength with actual strength using the optimal parameters is shown in table 6. Good agreement between the predicted and actual penetration being observed.

Table 6: Result of the conformation test

Process Factor	Initial Process Parameters	Optimum Process Parameter (MPa)	
		Prediction	Experiment
Composition	A1B2C2	A2B3C3	A2B3C3
Strength	66.06	93.47	99.01
S/N Ratio	26.63	37.68	39.91

9. Conclusion

Taguchi optimization method was applied to find the optimal process parameters for strength. A Taguchi orthogonal array, the signal-to-noise (S/N) ratio and analysis of variance were used for the optimization of welding parameters. A conformation experiment was also conducted and verified for the effectiveness of the Taguchi optimization method. The experiment value that is observed from optimal welding parameters, the strength is 99.01MPa. & S/N ratio is 39.91.

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