PARAMETRIC OPTIMISATION OF PULSED – TIG WELDING PROCESS IN BUTT JOINING OF 304L AUSTENITIC STAINLESS STEEL SHEETS

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Abstract

Stainless steels are widely used in thermal power plant, pressure vessels and automobiles components due to their superior fracture toughness, good inter granular corrosion resistance and non-requirement of post process annealing. Heat affected zone decreases the strength of the weld hence Pulsed TIG welding process is carried out to reduce the heat affected zone. This inherent property of the material reduces crack growth at high pressure which leads to the increase in efficiency of the pressure vessels and automobile components, when operated at high pressure. This paper describes the optimization of process parameters like current, voltage, stand-off distance, pulse on time, pulse off time and weld speed, gas flow to improve weld quality. In this work Taguchi method is used to get the optimal parameters. In Taguchi method, L27 orthogonal array is used for experimentation. Further, the experimental values and the various settings of the process parameters are fed as input to Taguchi and hence the S/N ratio values are obtained. Weld speed and input current are found to be the most significant parameters. Finally, the strength of the weld is validated by tensile and bending test.

Keywords: *Stainless Steel, Pulsed TIG welding, Inter-granular corrosion resistance, Fracture toughness, strength testing, Taguchi method.*

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1. INTRODUCTION

In today's scenario welding of thin sheets is being the challenging task in the field of Engineering. The major reason behind this is perfection, which is being the nominal factor considered during the joining process of sheets because, in such joining of plate, two pass and three pass welding cannot be carried out in thin sheets below 4mm, as under welding results in predominant reduction in strength and over weld results in formation of hole. Hence optimization of weld parameter plays a predominant role in joining of thin sheets. This research is to make the thin sheet welding easy and compatible by optimizing the process parameters. And in this paper, we have explained about the suitable parameters for butt joining on 304L Stainless Steel material of thickness 1.6mm which has good inter-granular corrosion resistance which increase the life span pressure vessels and automobile components. Superior fracture toughness reduces the crack initiation and crack growth under high pressure. These two factors enhances the maximum pressure withstandability , apart from this Pulsed-TIG welding process is used for welding which reduces the heat affected zone by welding the material by alternate melting and cooling which forms a good grain boundary layered by chromium with maximum strength. And this material does not require post process annealing for hardening which is used to increase the strength of the material. Quality of weld is based on the protrusion of weld from face to root and good quality weld can be obtained by optimizing the process parameters like current, voltage, stand-off distance, pulse on time, pulse off time, weld speed to improve weld quality. In this paper, experimental investigation detail of various process parameters to obtain good quality weld is discussed. The Taguchi design of experiments is a powerful method used to achieve high quality in lesser no of experiments. It provides better settings as compared to traditional experimental designs which are time consuming due to a large number of experiments and most of the time not feasible. The Taguchi method reduces the sensitivity of quality characteristics to various unknown noise factors.

2. LITERATURE SURVEY

Balasubramaniyan et al.,[1] discussed about the Effect of microstructure on impact toughness of pulsed current GTA welded α–β titanium alloy, the pulsed current has been found to be beneficial primarily due to its advantages over the conventional continuous current process. Aniruth et al.,[2] discussed about the study on laser cleaning and pulsed gas tungsten arc welding of Ti–3Al–2.5V alloy tubes, Welding of laser-cleaned samples show excellent weld quality. G.Lothongkum et al[4] discussed the Study on the effects of pulsed TIG welding parameters on delta-ferrite content, shape factor and bead quality in orbital welding of AISI 316L stainless steel plate, because of the high nitrogen content of the cover gas and lowest pulse currents compared to all other welding positions. Radiography showed acceptable weld beads free of porosity. Juang et al.[8] discussed about Process parameter selection for optimizing the weld pool geometry in the tungsten inert gas welding of stainless steel the selection of process parameters for obtaining an optimal weld pool geometry in the tungsten inert gas (TIG) welding of stainless steel the front height, front width, back height and back width of the weld pool. Karafi et al.[12] discussed about Study on automatic control of arc gap in robotic TIG welding. This paper presents a method for automatic control of arc length in tungsten inert gas (TIG) welding process using the arc voltage. Zhang et al. [16] discussed about the Laser cladding of Colmonoy powder on AISI316L austenitic stainless steel in which he proves that austenitic stainless steel has good inter-granular corrosion resistance.

From the above literature reviews, it has been observed that there is need for improving quality of the thin sheet welding for various applications like pressure vessels, automobile etc. These literatures provide that the thermal conductivity of stainless steel is very less and normal welding process increases heat affected zone hence Pulsed-TIG welding process is used to Increase the strength of pressure vessel by reducing the heat affected zone. Quality of weld depend on the protrusion of weld from face to root hence Optimizing the process parameters like current, voltage, pulse on time, pulse off time, weld speed is required to improve weld quality an opportunity to do the work on Pulsed TIG to develop the strength and quality of the weldment and this work on stainless steel 304L was not reviewed in most of the literatures available till now.

3. EXPERIMENTAL PROCEDURE:

3.1 Welding Parameter Selection

In this paper FRONIUS welding machine (Magic Wave/Trans TIG) is used for experimentation. The bead on trials are made in 2mm Stainless Steel plate . The machining parameters were selected on the basis of various trial runs by checking their effect on depth of penetration. Initially the parameters considered for experimentation were speed, current, stand-off distance, frequency and gas flow. And after conducting few trials it was found that the frequency and gas flow does not influence the depth of penetration, width of weld bead and area of the weld profile hence both the parameters are maintained constant. The trials were taken for the current range of 75 A to 125 A , speed ranging from 125 mm/min to 375 mm/min and standoff distance / Arc length ranging from 2mm to 4mm. The initial machining parameters used for Welding 304L Stainless Steel were as follows: current-75 A, Speed 125 mm/min, Standoff Distance 2mm, were frequency and gas flow were maintained constant as 3Hz and 10 liter/min. The welding parameters and levels are shown in Table 1.

3.1.1 Welding Performance Evaluation

The Welding performances considered in this paper is Depth of Penetration. Struers Welding Expert System is used for measuring depth of penetration, width of weld bead and Shape/Area of the weld.

Depth of Penetration= $nAlfg$ (1)

Where n is weld speed in mm/min, A is the Current in Ampere (A), l is stand-off distance in mm, f is the frequency in Hz and g is the gas flow in litre/minute (l/m).

Constant Parameters:
Frequency: 3 Hz
Gas flow : 10 litre/minute

Table: 1 Welding parameters and levels

Symbol	Parameters	Level1	Level2	Level3
A	Speed (mm/min)	125	250	375
B	Stand-off Distance (mm)	2	3	4
C	Current (Amps)	75	100	125

3.1.2 Material Specification

A thin sheet of 304L Stainless Steel was used for experimentation with length 150 mm, width 40mm and thickness 1.6 mm. The chemical composition and mechanical properties of the material are shown in the Table 2 and Table 3.

Table: 2 Chemical Composition of 304L Stainless Steel

Chemicals	% of Composition
Carbon	0.03
Manganese	2.00
Phosphorus	0.045
Sulphur	0.03
Silica	0.75
Chromium	18-20
Nickel	8-12
Nitrogen	0.10
Iron	67-71

Table: 3 Mechanical properties of 304L Stainless Steel

Tensile Strength	564 MPa
Yield Strength	241 MPa
Hardness	B80 HBN
Melting Point	1400-1450 °C
Density	8 g/cm^3

3.1.3 Experimental Process

Experiment is carried out FRONIUS (Magic Wave/Trans TIG) welding machine which has the different modules for TIG, Pulsed TIG and Plasma Arc and this project is carried out with Pulsed-TIG welding module in Stainless steel specimens with dimensions 150*30*1.6 mm^3 were cut and milled and edge preparation is made by using wire EDM.

Fig: 1 Pulsed TIG Welding Experimental Setup

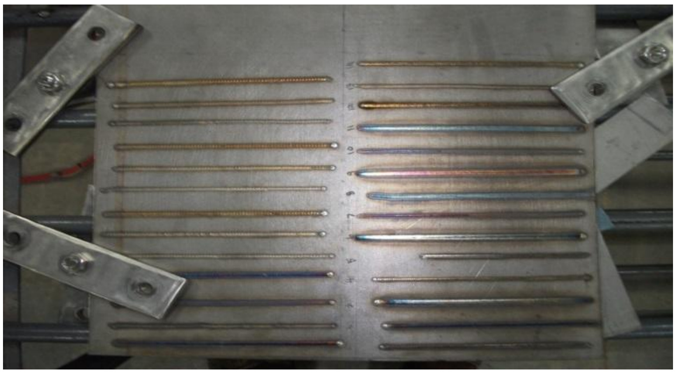

Fig: 2 Trials based on L27 Orthogonal Array

Figure 2 represents the bead on trials based on the orthogonal array. Before conducting trials surfaces of the samples were cleaned using acetone and were placed on the stainless steel fixture and bead on plate trials were carried out in order to optimize the depth of penetration suitable for 1.6mm plate based on the Taguchi model integrated for obtaining L27 Orthogonal array with the parameters mentioned below and with that trials are carried out in 2mm plate and cross sectional profile is cut using wire EDM.

Then followed by Polishing process which includes emery polishing, aluminium powder polishing and diamond paste polishing in Metco Polishing Machine. After polishing the work piece etching process is carried out for macro structure and micro structural analysis by means of combination of Etchents like Aquagiria and Nital for 10 seconds and 30 seconds respectively for good weld bead profile and the parameters like depth of penetration , width of the weld bead and area of the weld bead geometry are measured using Strues Welding Expert System. Then for validation of strength of weld the optimized parameter is used for welding of 1.6mm sheets then tensile test is carried out by cutting the weld profile in Dog bone shape with dimension as mentioned on ASTM standard E8, and bend test is carried out by cutting the weld profile with the dimension as mentioned on ASTM standard E190, both the testing is carried out in Tinius olsen UTM machine.

4. RESULTS AND DISCUSSIONS

The trials are made on the 2mm plate designed by Taguchi model L27 Orthogonal array with 3 factor 3 level design and corresponding depth of penetration for each trial is calculated by means of Welding Expert system. The results of L27 array is as shown in the table 4:

Table: 4 Experimental layout using L27 array and responses

S No	Speed (mm/min)	Stand Off Distance (mm)	Current (amps)	Voltage (volts)	Depth of Penetration (mm)	Width of Weld (mm)
1	125	2	75	8.6	1.159	2.29
2	125	2	100	8.4	1.393	3.366
3	125	2	125	8.3	1.612	4. 152
4	125	3	75	10.8	0.7879	2.2686
5	125	3	100	10.5	1.0512	2.1096
6	125	3	125	9.7	1.573	4.017
7	125	4	75	10.8	0.8036	2.3726
8	125	4	100	11.7	0.978	2.4523
9	125	4	125	11.7	1.4173	3.7795
10	250	2	75	8.4	1.063	2.104
11	250	2	100	10.7	1.325	2.415
12	250	2	125	10.1	1.4906	3.0094
13	250	3	75	11	0.6387	1.4313
14	250	3	100	10.2	1.073	2.181
15	250	3	125	10	1.2922	3.0025
16	250	4	75	11.3	0.6059	1.5154
17	250	4	100	11.3	0.6705	1.7629
18	250	4	125	11.9	0.9172	2.5612
19	375	2	75	11	1.163	2.104
20	375	2	100	10.8	0.6532	1.3357
21	375	2	125	10.6	0.9735	2.0774
22	375	3	75	10.9	0.649	1.1601
23	375	3	100	10.4	0.7441	1.9709
24	375	3	125	11.3	1.188	2.2937
25	375	4	75	11	0.6518	1.2823
26	375	4	100	10.7	0.6931	1.8245

27	375	4	125	10.8	0.9344	2.109 1

4.1 Signal to Noise Ratio

The S/N ratio is the ratio of size of signal factor effect to the size of error factor effect . The S/N ratio consolidates several repeated output responses into a single value which reflects the amount of variation present . The S/N ratio measures the sensitivity of quality characteristic to external noise factor which is not under control. The highest S/N ratio implies the least sensitivity of output response to noise factors. On the basis of characteristic three S/N ratios are available namely lower the better, higher the better and nominal the better. In this paper higher-the-better is used for maximizing both depth of penetration and width of the weld bead.

The higher-the-better performance characteristic is expressed

$$S/N_{HB} = -10 \log\{(1/y_1^2+1/y_2^2 \ldots 1/y_n^2)/n\} \quad (1)$$

Where n is the number of repetition of output response in the same trial and y is the response.

Table: 5 S/N ratios of responses

S.No	Depth of Penetration (mm)	S/N Ratio
1	1.159	1.281668719
2	1.393	2.879022328
3	**1.612**	**4.147300749**
4	0.7879	-2.07057799
5	1.0512	0.433707044
6	1.573	3.934574452
7	0.8036	-1.899201438
8	0.978	-0.193222904
9	1.4173	3.029235742
10	1.063	0.53066529
11	1.325	2.444317565
12	1.4906	3.467222338
13	0.6387	-3.894061677
14	1.073	0.611994439
15	1.2922	2.226594734
16	0.6059	-4.35198095
17	0.6705	-3.472024356
18	0.9172	-0.750719079
19	1.163	1.311594295
20	0.6532	-3.699076479
21	0.9735	-0.233280883
22	0.649	-3.755106064
23	0.7441	-2.567373909
24	1.188	1.496328813
25	0.6518	-3.717712877
26	0.6931	-3.184082023
27	0.9344	-0.589343405

This table 5 shows the result obtained from the orthogonal array and signal-to-noise ratio. Here there is a need to increase the depth of penetration, hence the maximum is the best is selected and the main effects for the Signal to noise ratio is plotted in the following graph.

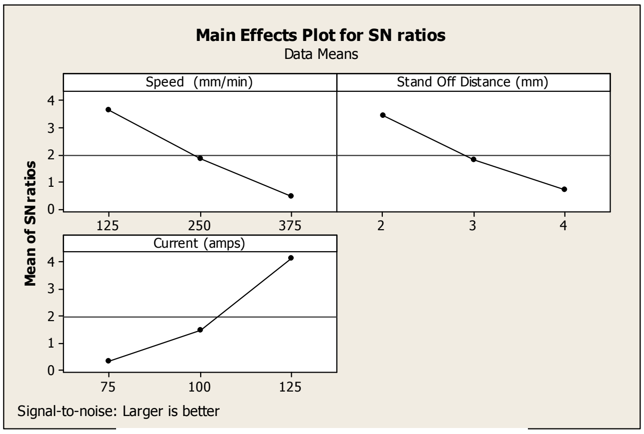

Fig: 4 Main Effect Plot for S/N Ratios

4.2 Confirmation Test

Further confirmation is required as weld quality changes based on the environmental change so by making standoff distance constant further proceed with experimentation by using L9 Orthogonal array.

Table: 6 Parameter for L9 Orthogonal array

Symbol	Parameters	Level1	Level2	Level3
A	Speed (mm/min)	100	125	150
B	Current (A)	100	125	150

From optimization technique we found that maximum current with minimum speed increases the depth of penetration hence we modified our input accordingly and made 9 more confirmation runs.

Table: 7 Confirmation test:

S No.	Speed (mm/min)	Current (amps)	Voltage (volts)	Depth of Penetration (mm)	Width of Weld (mm)
1	100	100	10	1.523	4.038
2	100	125	10.1	1.654	4.996
3	100	150	10.4	1.959	5.629
4	125	100	9.4	1.412	3.73
5	125	125	9.1	**1.607**	4.667
6	125	150	9.7	1.805	6.392
7	150	100	9.3	1.432	3.719
8	150	125	9.5	1.723	4.557
9	150	150	9.4	1.846	5.417

From the confirmation run it is found that speed 125 mm/min and current 125 A has depth of penetration closer to 1.6mm.

4.3 Validation by Strength Analysis

Hence with optimized parameter butt joining of 1.6mm plate is done then based on ASTM standard weld specimens are cut to standard for tensile and bend test and test is done in Tinson UTM machine to validate the strength of the weld joint.

Fig: 5 Butt Joint of 1.6mm Plate

4.3.1 Tensile Test

Based on ASTM standard E8/E8M tensile specimen is cut using Wire EDM for testing.

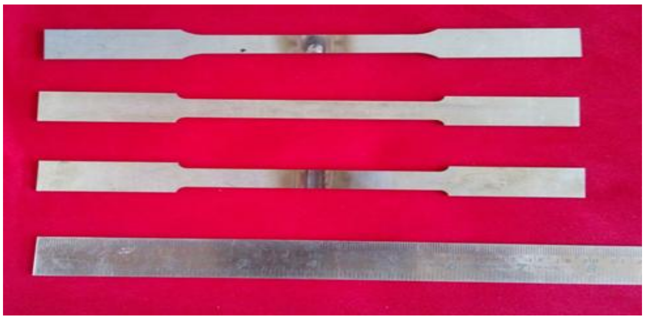

Fig: 6 Tensile Test Specimen before test

Fig: 7 Tensile Test Specimen after test

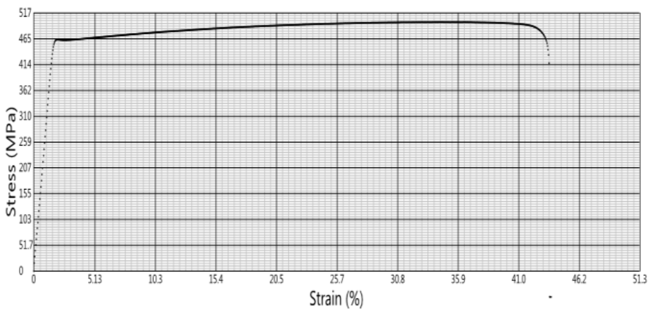

Fig: 8 Parent Metal Tensile test Graph

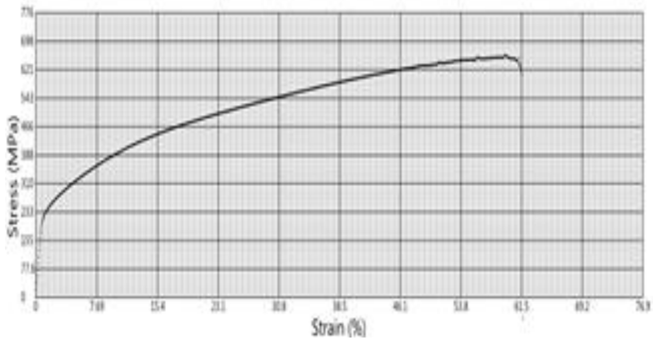

Fig: 9 Weld Joint Tensile test Graph

Table: 9 Tensile test result of Parent metal and Weld Joint

Work Piece	Width mm	Thickness Mm	Ultimate Force N	Ultimate Stress MPa	Break Distance mm	Total Elongation %
Parent Metal	12.5	1.6	9980	499	49.46	49.46
Weld Metal	12.5	1.6	13200	659	61.6	61.6
Result	-	-	+3220	+160	+12.14	+12.14

From table 9 results the weld specimen has 3220 N force with standability , 160 MPa increase in Ultimate stress and 12.14mm extended elongation than the parent metal.

4.3.2 Bend Test

Based on ASTM standard E190/E192 bend test specimens are cut using Wire EDM.

Fig: 10 Bend Specimen before testing

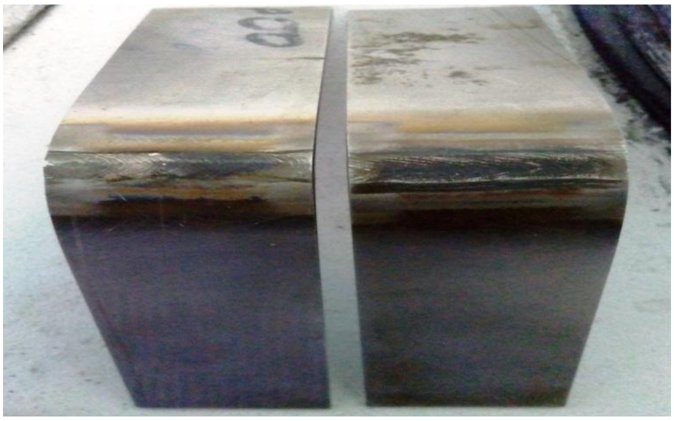

Fig: 11 Bend Specimen after testing

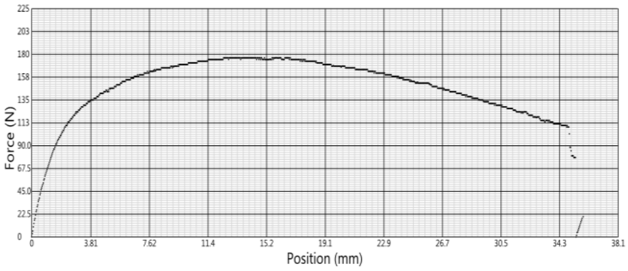

Fig: 14 Bend test Graph on face side of weld

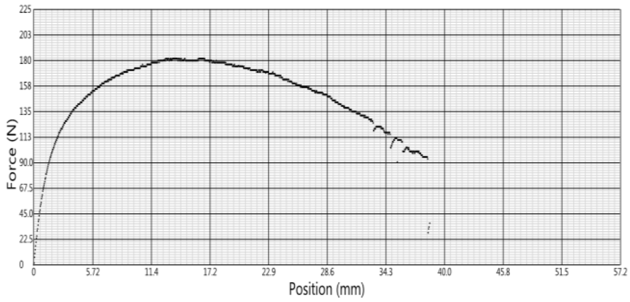

Fig: 15 Bend test Graph on root side of weld

Table: 11 Bend test result on root side of weld

Work Piece	Width mm	Thickness mm	Area mm^2	Ultimate Force N	Ultimate Stress MPa	Observation
Face Side	25.40	1.60	40.6	181.67	385.55	No opening or Crack formation
Root Side	25.40	1.60	40.6	176.67	489.05	No opening or Crack formation

From table 11 results it is clear that both face and root side of weld does not infer any defect which clear that the optimal parameter gives a good quality weld from face to root of the weld joint.

5. CONCLUSIONS

This paper has presented the optimization of process parameters of welding of 1.6mm thin sheets of 304L Stainless Steel material with multiple performance characteristics. . Based on experimental results and confirmation tests the following conclusions can be drawn.

- The optimum values obtained from the selected factors for welding of 1.6mm plate are Speed 125mm/min, Current 125 A, Stand-off 2mm, Frequency 3 Hz, Gas flow 10 litre/min.
- The most important parameters affecting the responses have been identified as speed and current.
- Validation of weld strength is made by tensile and bend test. Also found that there is good improvement in tensile strength after optimizing while comparing with parent metal and bend test result in no opening or crack formation. Hence a good quality weld is obtained from face to root.
- By this study, the optimized process parameters would definitely solve the problems of corrosion and fatigue faced by the material, by improving the weld quality.
- At the same time, it increases the strength of the weld with minimum heat affected zone.

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