Optimization of Process Parameters in TIG Welded Joints for Austenitic Stainless Steel

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Abstract— The Joining of the Austenitic Stainless Steels is often used in the pressure vessel industries. In the fabrication of the pressure vessel, the successful bending operation, after welding demands higher tensile strength and bending strength. The other mechanical properties at the weld bead should also be at the optimum level for favourable gauge length. Several process parameters interact in the complex manner resulting in direct or indirect influence on the mechanical properties. It is necessary to find out the optimum process condition capable of producing desired weld quality. Therefore to achieve the typical tensile strength and bending strength in TIG welding is the primary objective of this paper. X Ray radiographic test of all the samples are performed to check for any defects before going for the mechanical tests. The optimum values for the tensile and bending strength are found out and analyzed.

Key words: Welding, Stainless steel, Optimization, ANOVA

I. Introduction

In most of the Industries materials are fabricated into the desired shape mainly by one of the following methods viz. casting, forming, machining and welding. The selection of a particular technique depends upon different factors which may include shape and size of the component, precision required, material and its availability. Sometimes one specific process may be used to achieve the desired object. However, more frequently it is possible to have a choice between the processes available for making the end product. Among the available options economy plays the decisive role in making the final decision[1].

Welding is type of fabrication process which is used for joining several metal parts by causing them to coalesce locally with each other into desired structure for the purpose of fabricating. This is done often by melting the workpieces and adding filler material to form a weld pool with or without application of pressure. Cooling of the joint so formed makes a permanent strong bond between both workpieces. Permanent joint so formed cannot be separated easily unless broken. This process is found to be most efficient and economical means of making permanent joints, finds applications even in space and underwater. The source of heat may be an electric arc, friction, chemical reaction, electric resistance or radiation of high intensity but in this case we would be using electric Arc as the heat source for welding operation.

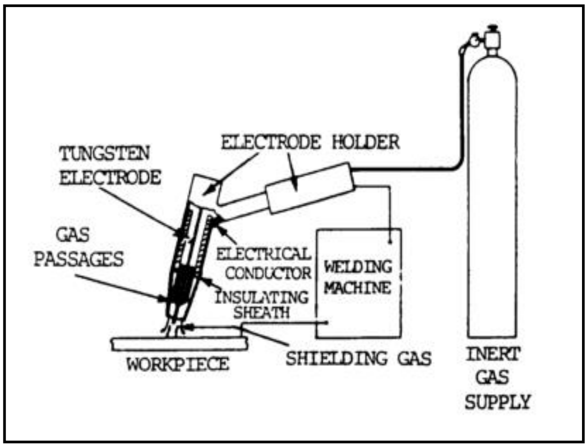

Fig. 1: GTAW Setup

Fig 1 shows the typical GTAW setup actually used in the industry. In TIG welding the tungsten electrode is non-consumable whereas shielding gas and filler wires are major consumables, along with this the energy consumption also is a major consumable for the arc welding process[2].

A. *TIG welding operation:*

Manual gas tungsten arc welding is often considered the most difficult amongst all the welding processes commonly used in industry thus Great care and skill are required to prevent contact between the electrode and the work piece during process and the welder must maintain a short arc length. GTAW normally requires two hands, since most applications require that the welder manually feed a filler metal into the weld area with one hand while manipulating the welding torch in the other, thus in this case also the welder used his both hands for welding operation.

Welders often develop a technique of rapidly alternating between adding filler metal and moving the torch forward (to advance the weld pool). The filler rod is withdrawn from the weld pool when the electrode advances, and it is never removed from the gas shield to prevent oxidation of its surface and contamination of the weld. Filler rods composed of metals with low melting temperature (such as aluminium) require that the operator maintain some distance from the arc while staying inside the gas shield. The filler rod can melt before it makes contact with the weld puddle and held too close to the arc. As the weld nears completion, the arc current is often gradually reduced to allow the weld crater to solidify and prevent the formation of crater and cracks at the end of the weld[4].

P. Bharatha et al. [8] Studied Optimization of 316 Stainless Steel Weld Joint Characteristics using Taguchi Technique. He studied parameters as welding speed (50-65-80), current(60-80-100), electrode(316-309L-347), root gap(1-1.5-2.0), operator(1,2,3). In the same work optimization of tensile strength and bending strength was performed. The result shows that Current is most influencing factor to have highest bend strength and Speed that is to be used while welding is the most influencing factor to get higher tensile strength.

Ugur Esme [9] worked on Optimization of weld bead geometry in TIG welding process using grey relation analysis and taguchi method. The following weld parameters were taken welding speed (1.06-1.99-2.31-3.55), Current (40-55-70-85), Gas flow rate (8-10-12-14 lit/min), Gap distance (1.5-2-2.5-3). It was also mentioned that TIG welding is a multi input and multi response process. He performed the optimization on bead width, bead height, Penetration, area of penetration as well as width of heat affected zone and tensile load and found that welding speed (52.41 % contribution) is the most effective parameter on the responses under the multi criteria optimization. The percent contributions of other parameters are gap distance (20.12 %), current (15.40 %) and shielding gas flow rate (9.09 %). He also identified that the Taguchi based grey relational analysis can be used for optimization of the TIG welding bead geometry parameters successfully.

Shekhar Rajendra Gulwande [10] worked on Parameter Optimization of Tig Welding using Austenitic Stainless Steel. The process parameters used for the optimization of Hardness were welding Current (100-150-200), Welding Voltage(23-25-30) , Gas Flow Rate(20-23-25). He found that the experiment value that is observed from optimal welding parameters of the Hardness is 188.70 BHN. It has been also observed that Welding current and welding voltage has the highest impact.

II. Stainless steel

Gas tungsten arc welding is most commonly used to weld nonferrous materials, such as aluminum and magnesium and stainless steel and it can be applied to nearly all metals, with exceptions being lead and zinc. Its applications involving carbon steels are limited because of the existence of more economical steel welding techniques, such as gas metal arc welding and shielded metal arc welding and not because of process restrictions. Furthermore, GTAW can be performed in a variety of positions, depending on the skill of the welder and the materials being welded.

A. *Difficulty in welding of stainless steel*

1) Low thermal conductivity and high electrical resistance: It is a big problem as overheating of SS may result in diffusion of metal. It may be overcome by using low values of current and using electrode of shorter lengths.
2) Carbide Precipitation: The austenitic grades are non-hardening type and welding normally does not affect the strength and ductility of the deposit. However, one detrimental effect of heating of a Cr-Ni steel is carbide precipitation at the grain boundaries which results in reduced corrosion resistance. A fine film of rich in chromium carbides containing as much as 90 % Cr, taken from the layer of metal next to the grain boundary will get precipitated along the grain boundary. Using stabilized steels by adding columbium and titanium which have greater affinity for carbon than chromium.[12]
   – Limiting the carbon content to a maximum of 0.03 % can help avoiding the harmful carbide precipitation.
   – Post weld solution annealing: It puts carbide back into solution and restores corrosion resistance. Austenitic stainless steel stabilized with niobium plus tantalum or titanium and welded with stabilized filler metal gives good strength and corrosion properties.[14]

III. Experimental details

A. *Material Preparation*

The raw material includes all those consumables or non-consumable used in the tungsten welding process. The TIG welding for SS 304 grade is performed most often in the pressure vessel industry. Hence stainless steel plates of the dimensions 100*50*6 mm are made as shown in the fig. 2

Fig. 2: Raw Material of Stainless Steel

According to the design of experiments we need 18 such plates to perform the L9 orthogonal array design.

Stainless steel are also known as corrosion resistant steels. Their principal alloying element is chromium while some other elements like nickel, manganese etc. can also be present in different amounts. For gas tungsten arc welding of stainless steels, the selection of a filler material is necessary to prevent excessive porosity. Before welding in order to prevent contamination oxides on the filler material and workpieces must be removed, and immediately prior to welding, alcohol or acetone should be used to clean the surface. The following table 1 shows the chemical constituents present in the stainless steel grade SS 304.

BASE METAL	Chemical Composition								
	% C	% Mn	% Cr	% Ni	% Mo	% S	% P	% Si	%Fe
	0.068	1.06	18.58	8.32	0.27	0.014	0.018	0.45	Remaining

Table 1:Chemical Composition Of Base Material

The Checked parameters of the given sample confirms to SS 304 grade as per SAE 1970. The chemical composition test was performed at SN Metallurgical Services, Aurangabad.

Composition	C%	Cr%	Mn%	Si%	S%	P%
308 L	0.03	19.3	1.0	0.7	0.01	0.09

Table 2: Chemical Composition Of Filler 308l

The Electrode is suitable for use on brewing equipment, vacuum pump parts, dairy equipment, chemical handling equipment, textile drying equipment and food processing. Table 2 shows the chemical composition of the filler wire.

B. *Test Procedure*

In common welding practices, the welding surface needs to be prepared to ensure the strongest weld possible.

Preparation is needed for all forms of welding and all types of joints. Filler metal, in the form of welding rod, is almost always used in making square butt welds. It is seldom possible to make a satisfactory, full-strength weld by merely butting the pieces tight together, without spacing, and then melting the edges together. When welding, contact is established only at a few points in the surface therefore the strength attained will be only a fraction of the full strength. Also, the irregular surface may not be very clean, being contaminated with adsorbed moisture, oxide film, grease layer etc. The orthogonal array used for the experimentation is as shown bellow in table 3

Sr. No.	Current	Gas Flow Rate	Root Gap
1	100	8	0
2	100	12	1
3	100	16	2
4	125	8	1
5	125	12	2
6	125	16	0
7	150	8	2
8	150	12	0
9	150	16	1

Table 3: Orthogonal Array L9

Groove angles were made on the welding plates of 60 degrees and measured with the help of star protractor. Root face of 1 mm was also made on the each side of the plate. Welding was performed taking the above orthogonal array as input parameters. fig 3.shows operator making a grove angle of 60 degrees on the weld plates.

Fig. 3: Welded Samples of Stainless Steel

After welding process as per orthogonal array, the weld bead was cleaned thoroughly with clean cloth and acetone as shown in the fig. 3.

C. Machining of Welded Specimens for Various Testing:

After the samples were welded they were machined according to the ASTM standard and the outer positions were cut out to remove any discontinuities in the weld.

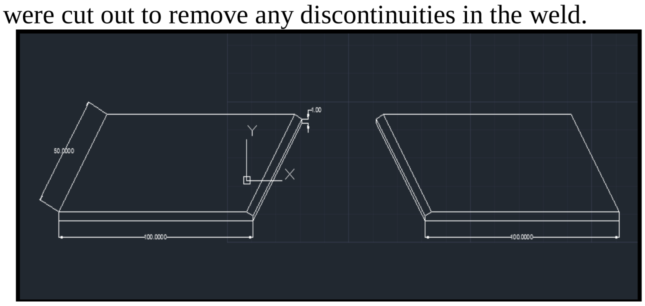

Fig. 4: AUTOCAD model of samples before weld

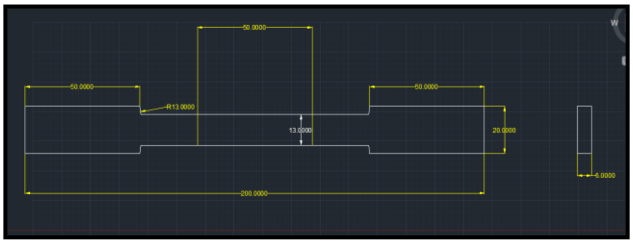

Fig. 5: AUTOCAD model of samples to be prepared for Tensile Test

Different samples were prepared for the tensile and bending test with same orthogonal array and process parameters. Fig 4 and fig 5 show AUTOCAD designs of the samples to be welded and then machined as per the ASTM Section IX Standards

The welded flats of 200*50*6 mm are machined to the required standards as per the ASTM. More than two third of the grip section is loaded into the universal testing machine. The actual dimensions used in the testing are as shown in the table 4 and fig. 6 shows the nomenclature of standard specimen.

Gauge Length	50 mm
Width of reduced Section	13mm
Radius of the fillet	13mm
Overall length	200mm
Length of the reduced section	60mm
Length of the grip section	50mm

Table 4: Dimensions of Samples After Machining

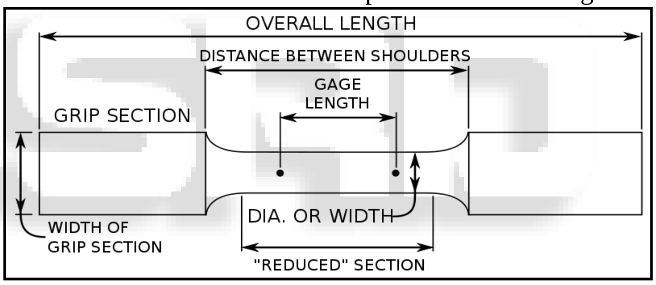

Fig. 6: ASTM Dimension for Tensile Test of Specimens

Level	Current(Amps)	Gas Flow Rate(Lit/min)	Root Gap(mm)
1	100	8	0
2	125	12	1
3	150	16	2

Table 5: Process Parameters with Their Values at Three Levels

Fig. 7: Machined Sample used for Tensile test

Following fig. 8 shows samples used for bending test

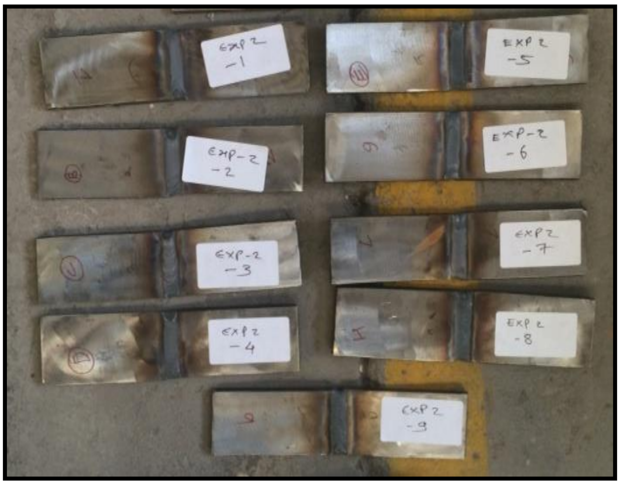

Fig. 8: Samples Prepared for Bending Test

IV. RESULTS AND DISCUSSIONS

A. Results of NDT Testing

All the samples were tested for radiographic tests under these conditions. The results show that the root gap was completely filled during the welding operation and hence the clear picture was shown in the radiographic tests. Fig. 9 shows the radiographic test results of specimen.

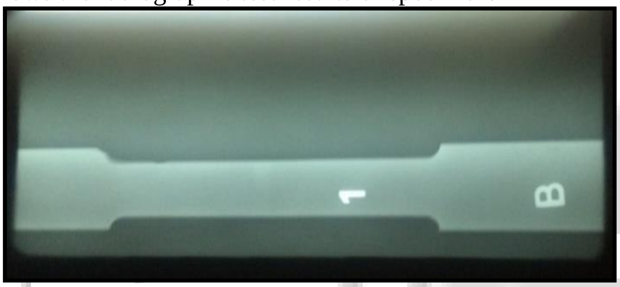
Fig. 9: NDT Testing of specimen

B. Results and Analysis of Tension Test

Sample Number	Calculated UTS (MPa)
1	570.154
2	563.077
3	590.966
4	616.666
5	621.153
6	538.461
7	648.846
8	615.256
9	600.77

Table 6: Calculated Uts From Load Observed On Utm

For the evaluation of the optimum results software MINITAB 17 was used in this experimentation work. Table 6 represents calculated tensile strength from the observed load. In this software the means plot is plotted with the calculations of the S/N ratio. The following are results obtained from MINITAB 17. The broken samples are shown in the fig. 10.


Fig. 10: Weld Samples after Tensile Test

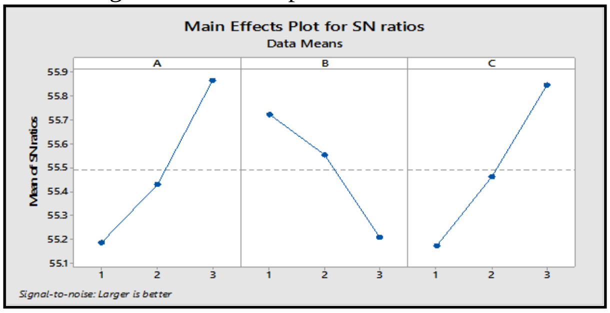

Fig. 11: Means Plot for Tensile Test from MINITAB 17

C. ANOVA calculations for ultimate tensile strength

The Anova Calculation of the ultimate tensile strength was performed in Excel Software and the results are as shown in the table 7.. Sum of Squares and mean square readings are calculated. From these readings the F ratio and % Contribution of F are observed.

Source	DF	SS	MS	F	% C
Current	2	0.709	0.354	3.256	35.19
GFR	2	0.407	0.203	1.871	20.22
RG	2	0.68	0.340	3.123	33.76
Residual Error	2	0.21	0.109		
Total	8	2.01			

Table 7: ANOVA Calculations For Tensile Test

It is clear from the ANOVA table 7 that the percentage contribution of current is maximum (About 35 %) for the tensile strength. It was followed by root gap, which had 33.76 % contribution in the tensile strength. Gas flow rate had least effect among the three input parameters.

D. Results and Analysis of Bending Test


Fig. 12: Samples After Bending Test

The results of bending test are calculated as follows,

Moment of Inertia, $I = b * h^3 / 12\ mm^4 = 900\ mm^4$

Maximum Bending Moment = $M = (P * L) / 4$ N-mm

Where,

M = Bending Moment in N-mm

I = Moment of Inertia in mm^4

Y = Distance of the neutral axis from the outermost fiber in mm.
L = 80 mm = Distance between the Rollers in mm.
Bending Stress = [M / I] * Y N/mm^2

$$Y = H / 2 = 3 \text{ mm},$$

We know that the bending Equation,

$$(M / I) = (B / Y)$$

Calculating from the above formulae the bending strength of samples, the following table 8 enlists all the calculated bending strengths of the welded samples on the UTM.

Sample Number	Load in KN	Bending Strength MPa
1	29.68	1978.67
2	33.2	2213.33
3	36.24	2416
4	35.1	2340
5	40.35	2690
6	37.58	2505.33
7	37	2466.67
8	36.45	2430
9	38.55	2570

Table 8: Bending Strength of All the Experiments

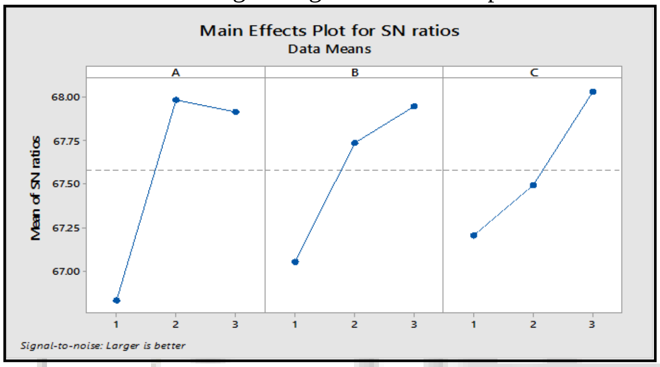

Fig. 13: Means Plot for Bending Strength from MINITAB 17

The maximum effect of the factor A i.e Current was found out at level 2. The maximum effect of factor B i.e. the gas flow rate is found out to be at level 3 and the maximum effect of root gap was observed to be maximum at level 3.

Source	DF	SS	MS	F	%
Current	2	2.522	1.2612	8038.68	51.54
GFR	2	1.313	0.6566	4185.13	26.83
RG	2	1.058	0.529	3371.97	21.61
Residual Error	2	0.0001	0.0001		0.0064
Total	8	4.894			

Table 9: ANOVA Calculations for Bending Strength

V. CONFIRMATION TESTS

The regression model for the tensile strength and bending strength are calculated from software MINITAB 17. These models are as follows

Tensile Strength = 538.7 + 23.45 Current - 17.58 Gas Flow Rate + 22.85 Root Gap.

Bending Strength = 1660 + 143.1 Current + 117.7 Gas Flow Rate + 109.8 Root Gap

Test	Predicted values	Experimental values	Error
Tensile strength	660.02	654.33	0.80%
Bending Strength	2628.7	2694.6	2.47%

Table 10: Confirmation Test for Tensile and Bending Strength

VI. CONCLUSIONS

The successful Tensile and bending strength optimization is performed. The optimum parameters obtained are as follows,

– The results of the NDT testing shows that all the samples are within the acceptable range and the futher mechanical tests could be conducted on the samples.
– The optimum values obtained for tensile strength are obtained as 150 Amps of current, 8 Lit/min of gas flow rate, and 2 mm of root gap.
– The ANOVA contribution for the tensile strength can be noted as, Current as 35%, Gas flow rate of 20%, and root gap as 33%.
– The optimum parameters for bending strength were observed to be current of 125 Amps, 16 Lit/min of gas flow rate and 2 mm of root gap.
– The ANOVA calculations show that current followed by gas flow rate and root gap for bending strength.

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