Optimization of Tungsten Inert Gas Welding Process Parameters on Stainless Steels 316L Alloy Using Taguchi Technique

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Abstract

Tungsten inert gas (TIG) welding is a semi - automatic or automatic arc welding process which produces weld with non consumable tungsten electrode and shielding gas supplied through a welding torch to protect weld from atmosphere contamination. TIG welding is one such welding process which is used extensively in the manufacturing field due to its simplicity, versatility and capability to produce neat and strong joint. With the rise in the economy recent research on welding is focused on the techniques to get the optimum results for maximum production with minimum investment. The most important factors which affect the quality, strength, productivity and cost of manufacturing are the welding parameters.

In present work TIG welding is performed by varying welding parameters such as welding current, speed, gas flow rate, gap between base metals, electrode gap, and plate thickness. The performance measures like hardness and ultimate tensile strength of welded Stainless Steel 316l plates are assessed. Experiment is performed according to L29 orthogonal array and optimized values are obtained from Taguchi technique.

Keywords: *TIG Welding, Welding parameters, Hardness, Strength, Taguchi, ANOVA.*

1. Introduction

Welding is one of metal joining process, which is used to connect metal parts permanently at their touching surfaces by the applying heat and/or pressure, with/without using filler metal depending on type of welding process used. Weld pool produced between electrode and base metal is protected from atmosphere by coated flux, shielding gases or other means. Gas Tungsten Arc Welding is also called as tungsten inert gas welding (TIG welding). When compared to GMAW, in GTAW a non-consumable electrode is used and hence no weld spool is required. Shielding gas provided in this case is same as in the GMAW process. Generally argon, carbon dioxide, helium or their combination is used. Filler material is provided separately if required. Generally in GTAW reverse polarity is used.

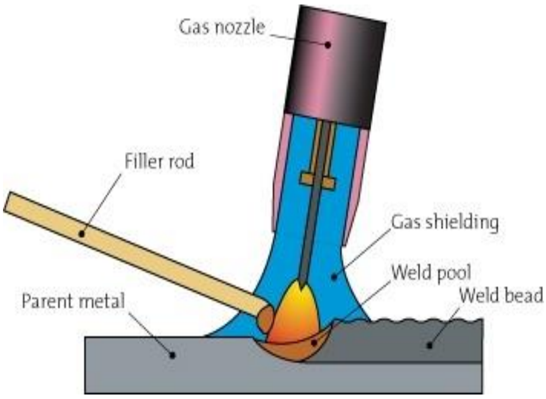

Figure.1 Gas-Tungsten Arc Welding

The objective of this project is to analyze the effect process parameters such as current, speed, gap between base metals, electrode gap, gas flow rate, and plate thickness on welding characteristics (hardness & ultimate tensile strength). Optimization of the welding parameters of tungsten inert gas welding to achieve optimized value using Taguchi robust design methodology and also effect of each parameter on hardness and strength of welded joint is analyzed.

2. Literature review:

Vikas Kumar et al. [1] have studied the Taguchi's design method for optimization of GTAW of Stainless Steel. The input parameters considered here are welding voltage, welding current& gas flow. In this work, L_9orthogonal array is used and total nine experiments were performed. Afterwards, using the ANOVA software effect of each parameter on Hardness & tensile strength were calculated. S.R. Meshram and N.S. Pohokar et al [2] studied the influence of process parameters TIGW like voltage, gas flow, welding speed, electrode gap and feed rate by using ANOVA methodology. Penetration value and UTS are taken as observed parameters. From result, it was concluded that increasing the welding current, UTS and depth of penetration increases. On the other hand, welding speed and arc voltage is another parameter that influenced the value of UTS. Bhargav Patel, Jaivesh Gandhi et al. [3] researched the effect of process parameters of TIGW like welding speed, arc voltage, gas flow and welding current are taken as input parameters and Tensile strength is taken as output parameter. ANOVA software is used to analyses effect of each parameter on it. It was observed that increasing current results in increased the UTS value. Moreover, voltage is another parameter which increases the value of UTS. However, its effect is not as much as current. Salawadagi Sushant S., Kumbhar S et al. [4] have optimized the process parameters of TIGW for SS-304 and low carbon steel using Taguchi technique. Three TIG welding parameters viz. voltage, current and weld speed were selected for optimization. The analysis for signal-to-noise ratio was done for higher-the-better quality characteristics. The effect of each selected parameter was investigated by using the ANOVA. Lastly the confirmation tests were conducted to compare the concluded values with the experimental values. Vikas Chauhan et al. [5] researched the influence process parameters of TIG welding viz welding speed, weld current and weld plate angle. The ANOVA and GRA method is used by considering residual stress as output parameter.

3. Welding Process Parameters

In manual welding operation, the welder has to control welding variables, which influence the weld penetration and the weld quality. Proper welding parameters selection produces satisfactory weld quality. These parameters are completely dependent and changing any of the parameter requires the changing of others to achieve desired result. In selecting of welding parameters we have to consider base metal and filler rod used and type of joint design.

3.1 Welding Current

As increasing the current will increase the width and depth of penetration and the size of weld bead increases. As the welding current increases wire feed rate also increases which results in higher rate of deposition. Lower the welding current for any given size of electrode produces poor penetration and also lower the strength of joint. For too high welding current the weld bead size is high and the deep penetration produces. Hence the filler metal wasted results in burn- weld metal.

3.2 Travel Speed

It is defined as speed at which the TIG torch travels along with the work. In semi-automatic welding, travel speed is handled by welder and by machine in automatic welding process. The arc travel speed effects on welding same way as the arc voltage. The weld penetration first increases and is maximum at a given travel speed and then decreases with increasing it. For any given current, lower travel speeds provide larger beads & higher heat input because longer heating time. The high heat supply increases the penetration and the metal deposit rate per unit length. The lower travel speed causes lower penetration, slag inclusions, poor fusion and porosity.

3.3 Gas Flow Rate

In TIG welding Shielding gas are used to protect melted weld pool from atmospheric conditions. Helium, argon, carbon dioxide and sometimes mixture of them can be used. Appropriate gas flow rate should use in order to get good welding. Increasing gas flow rate weld quality also increases and after reaching maximum value it starts decreasing. High gas flow rate leads to excessive weld spatter, uneven weld deposition, porosity, and mechanical properties also decreases.

3.4 Electrode gap

The electrode gap is the distance between the tips of the electrode to base metal surface. An increase in the electrode gap results in an increase in its electrical resistance. As increase in electrical resistance causes the electrode temperature to rise, and results in a small increase in electrode melting rate. Overall, the increased electrical resistance produces a greater voltage drop from the contact tube to the work. This is sensed by the power source, which compensates by decreasing the current.

- Increasing gap between base plates results in increasing weld strength up to certain limit, the after starts decreasing in strength. We should select optimum gap of plate which depends on type of weld, type of base metal etc.

4. Experiment Procedure

Total 27 experiments were conducted to investigate effect of welding parameters on TIG welding. These analyses have been under taken to inspect the effect of as current, welding speed, gap between base metals, electrode gap, gas flow rate, and plate thickness on the ultimate strength and hardness presented in Table 2. Stainless steel

316l plates of different thickness are TIG welded according to L27 orthogonal array presented in table3.

Figure.2 Stainless Steel 316L Plates

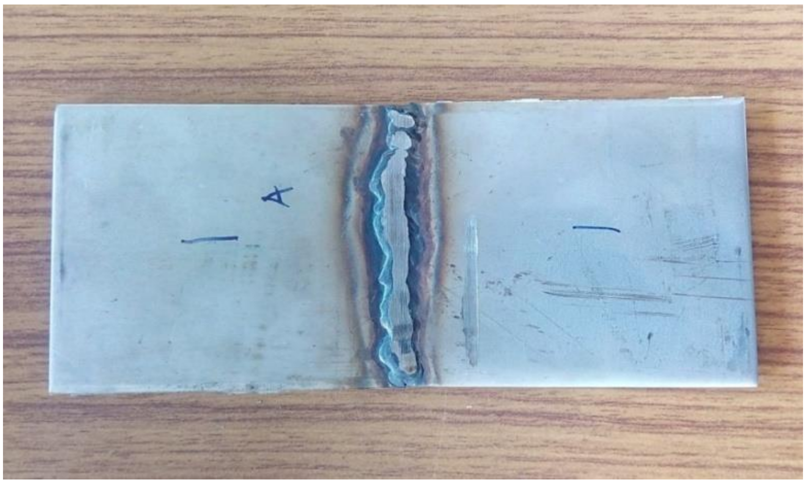

Figure.3 Stainless Steel 316L plates after welding

Table .1 Stainless Steel 316l Alloy Composition

Element	C	Mn	Si	P	Cr	Ni	Mo	Cu	Al	S	T
Base metal composition (%)	0.03	1.47	0.58	0.025	18.33	8.33	0.2	0.19	0.01	0.01	....
Filler metal composition (%)	0.02	1.68	0.53	0.012	19.45	9.22	0.11	0.08	0.01	0.03	...

Table.2 Representation of L27 Array

Factor	Name	Level values	column	level
A	Current (amp)	120, 130, 140	1	3
B	Speed (mm/s)	2, 3, 4	2	3
C	Gas flow rate (mm3/s)	8, 10,12	3	3
D	Gap between base metals (mm)	0, 1, 2	4	3
E	Electrode gap (mm)	8, 12, 16	5	3
F	Plate thickness (mm)	2.5, 3, 3.5	6	3

Table.3 Influence of Design Parameters on Strength and Hardness

SN	Current	Speed	Gas flow rate	Gap between base metals	Electrode gap	Plate thickness	Ultimate strength (Mpa)	Hardness
1	120	2	8	0	8	2.5	246	66
2	120	2	8	0	12	3.0	265	68
3	120	2	8	0	16	3.5	275	68
4	120	3	10	1	8	2.5	294	69
5	120	3	10	1	12	3.0	302	70
6	120	3	10	1	16	3.5	308	71
7	120	4	12	2	8	2.5	174	73
8	120	4	12	2	12	3.0	195	73
9	120	4	12	2	16	3.5	227	72
10	130	2	10	2	8	3.0	319	80
11	130	2	10	2	12	3.5	323	80
12	130	2	10	2	16	2.5	320	80
13	130	3	12	0	8	3.0	361	82

14	130	3	12	0	12	3.5	386	83
15	130	3	12	0	16	2.5	372	84
16	130	4	8	1	8	3.0	333	74
17	130	4	8	1	12	3.5	347	76
18	130	4	8	1	16	2.5	339	78
19	140	2	12	1	8	3.5	511	96
20	140	2	12	1	12	2.5	494	97
21	140	2	12	1	16	3.0	520	98
22	140	3	8	2	8	3.5	417	86
23	140	3	8	2	12	2.5	393	89
24	140	3	8	2	16	3.0	433	89
25	140	4	10	0	8	3.5	467	90
26	140	4	10	0	12	2.5	446	95
27	140	4	10	0	16	3.0	477	94

Figure.4 Vickers Hardness Tester

Figure.5 Universal Testing Machine

After welding work pieces are surface grinded and tested for hardness on Vickers hardness tester as shown in Figure 4. Testing is done at three places on welded portion on work piece. Three hardness results obtained are noted and average of three is taken as final hardness value. Ultimate tensile strength obtained from universal testing machine which shown in figure 5.

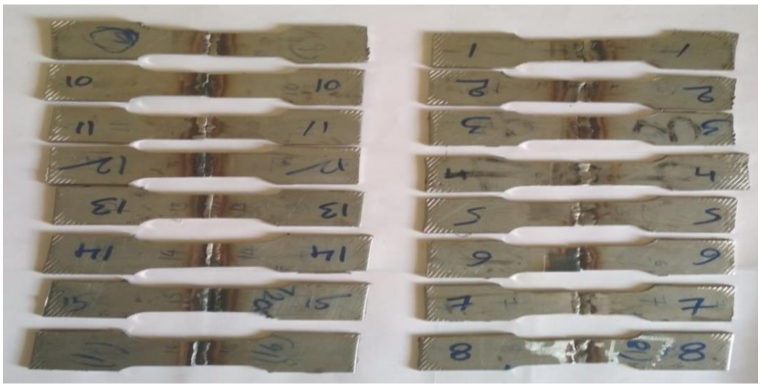

Figure.6 Welded Pieces after UTM Test

In this experimental work L27 orthogonal array was used. This experiment consists of six parameters and three levels as illustrated in table 2. In this Taguchi technique, all the experimental values are determined based on “larger is the better”. Thus in this work, the observed values of hardness & ultimate strength were set to maximum. Then, the optimum observed values were calculated by comparing the standard analysis & analysis of variance which was based on the Taguchi method.

Table.4 Response Table for Signal to Noise Ratio for Ultimate strength

level	current	speed	gas flow rate	base metals gap	electrode gap	plate thickness
1	47.95	50.87	50.44	51.03	50.40	50.32
2	50.72	51.12	51.00	51.44	50.59	50.68
3	53.26	49.95	50.49	49.46	50.94	50.93
Delta	5.31	1.17	0.57	1.98	0.53	0.61
Rank	1	3	5	2	6	4

Table.5 Analysis of Variance for Ultimate Tensile Strength

source	DF	Adj SS	Adj MS	F-Value	P-Value
current	2	195791	97895.3	1963.31	0.000
speed	2	5185	2592.5	51.99	0.478
gas flow	2	2977	1488.6	29.85	0.110

rate					
Base metals gap	2	25409	12704.7	254.80	0.023
electrode gap	2	1387	693.4	13.91	0.670
thickness	2	1954	976.9	19.59	0.587
error	14	698	49.9		
total	26	233401			

Results obtained from ANOVA software, the delta value indicate difference between highest & lowest average value for each parameter. Rank 1 is given to maximum delta value that is welding current & rank 2 is given to the second maximum i.e. base metals gap, and so on, to indicate the relative effect of each factor on response. Hence current, base metals gap, and speed are mostly effect on ultimate tensile strength hence is given by first three ranks. Plate thickness, gas flow rate, electrode gap are least effect on strength and hence given fourth, fifth and sixth ranks respectively. From table 5 F value in ANOVA is used to find out if means between two populations are significantly different. Hence F value for current is maximum and for electrode gap it is minimum.

Figure.7 Main Effective Plots for SN Ratio for Ultimate Strength

From above graphs we can conclude that ultimate tensile strength varies proportionally with current which increases with increase in current and is maximum when current value taken as 140 amp and minimum at 120 amp. When we take base metal gap 1mm gives maximum strength. Electrode gap didn't affect much on strength.

4.1 Regression Equation

ULTIMATE TENSILE STRENGTH = 353.48-99.48 CURRET_120-9.04 CURRENT__130+108.52 CURRENT_10.19 SPEED_2 + 9.41 SPEED_3-19.59 SPEED_14.81 GAS FLOW RATE _8+8.30 GAS

FLOW RATE_10+ 6.52 GAS FLOW RATE_12+12.63 GAP BETWEEN BASE METAL_0+29.63 GAP BETWEEN BASE METAL_1-42.26 GAP BETWEEN BASE METALS-2-6.59 ELECTRODEGAP_8+ 3.37 ELECTRODE GAP_12+9.96 ELECTRODE GAP_16+11.48 PLATE THICKNESS_2.5+ 2.33 PLATE THICKNESS_3.0- 8.85 PLATE THICKNESS_3.5.

Table.6 Response Table for Signal to Noise Ratio for Rardness

level	current	speed	gas flow rate	base metals gap	electrode gap	plate thickness
1	36.90	38.12	37.69	38.10	37.95	38.12
2	38.02	38.06	38.11	38.08	38.13	38.09
3	39.33	38.07	38.45	38.06	38.17	38.03
Delta	2.43	0.06	0.76	0.05	0.21	0.09
Rank	1	5	2	6	3	4

Table.7 Analysis of Variance for Hardness

source	DF	Adj SS	Adj MS	F-Value	P-Value
current	2	2328.67	1164.33	1358.39	0.000
speed	2	6.22	3.11	3.63	0.054
gas flow rate	2	228.22	114.11	133.13	0.000
Base metal gap	2	4.22	2.11	2.46	0.121
electrode gap	2	20.67	10.33	12.06	0.001
thickness	2	4.67	2.33	2.72	0.100
error	14	12.00	0.86		
total	26	2604.67			

From 6 table delta value for both current and gas flow rate is 2.43 and 0.76 and given by rank1 & rank2 respectively. Speed and base metal gap are least effect on hardness and hence is given by rank5 and rank6 respectively.

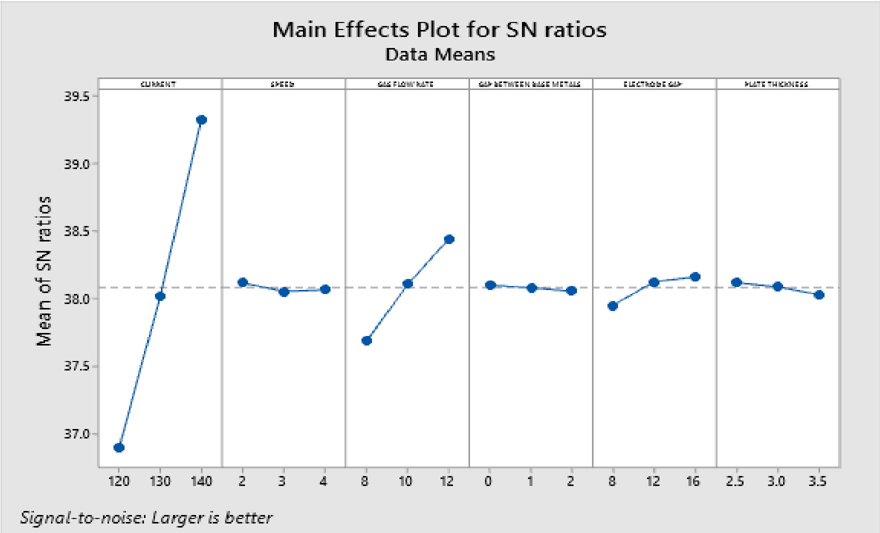

Figure.8 Mean Effective Plots for SN Ration for Hardness

Hardness increases with increase in current and maximum at 140 amps and minimum at 120 amps. Gas flow rate gives maximum hardness at 12 mm3/s. base metal plate gap, speed and plate thickness doesn't effect on hardness. Maximum hardness obtained when electrode gap is 12mm.

4.2 Regression Equation

HARDNESS = 80.778-10.778 CURRET_120-1.111 CURRENT__130+11.889 CURRENT_140+0.667 SPEED_2-0.444 SPEED_3-0.222 SPEED_4-3.667 GAS FLOW RATE _8+0.222 GAS FLOW RATE_10+ 3.444 GAS FLOW RATE_12+0.333 GAP BETWEEN BASE METAL_0+0.222 GAP BETWEEN BASE METAL_1-0.556 GAP BETWEEN BASE METALS-2-1.222 ELECTRODEGAP_8+ 0.444 ELECTRODE GAP_12+0.778 ELECTRODE GAP_16+0.444 PLATE THICKNESS_2.5+ 0.111 PLATE THICKNESS_3.0- 0.556 PLATE THICKNESS_3.5

5. Conclusions

The following conclusions were made out by this project:

- It is concluded that welding current & base metal gap have a significantly influence on ultimate tensile strength of joint and electrode gap is not effect much on strength. Welding current and gas flow rate have effect on ultimate strength of welded plate.
- It is concluded that when current 140 amps, base metal gap 1 mm, speed 2 mm/sec, and plate thickness 3.5 mm at specified values strength of weld is optimum.
- It is concluded that when current 140 amp, gas flow rate 12 mm^3 /sec gives optimised hardness. Plate thickness and gap between base metals does not effect on hardness.
- It is also concluded that with increase current response values hardness & ultimate strength increases.

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