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Optimization of MIG Welding Process Parameters on 316l Stainless Steels Using Taguchi Technique

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Abstract: Metal inert gas (MIG) welding is a semi - automatic or automatic arc welding process in which a continuous and consumable wire electrode and a shielding gas are supplied through a welding torch. MIG 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 MIG welding is performed by varying parameters such as welding current, welding voltage, gas flow rate, feed rate and type of cooling medium. The performance measures like hardness, yield strength and ultimate strength of welded stainless steel 316l plates are assessed. Experiment is performed according to L16 mixed orthogonal array and optimal values are obtained from Taguchi technique.

KEY WORDS: MIG Welding, Welding parameters, Hardness, Strength, Taguchi, ANOVA.

INTRODUCTION

A continuous consumable electrode in the form of wire is supplied through a suitable gun which is used as both an electrode & filler material. Electrical energy converted in to heat energy which melts base metal when we maintain a small gap between electrode and work piece. Due to small air resistance electrons try to jump from negative electrode with high velocity. This kinetic energy is converted into heat and produces high temperature. The shielding gas (usually helium, argon) supplied from separate cylinder preventing the newly produced weld from surrounding atmospheric contamination.

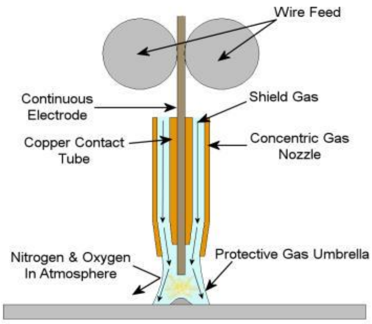

Figure 1 Basic principle of MIG welding

IJARSE
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WELDING PROCESS PARAMETERS

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-through & undercut. Too low as well as too high current affects the tensile strength and ductility of weld metal.

Welding Voltage

Welding voltage controls the arc length, it is the distance from wire electrode tip to the weld pool during welding. When the welding process parameters like electrode size and composition, shielding gas type, and the welding operation held constant, the arc length varies directly with arc voltage. With increasing the voltage the section of weld bead turns into wider and flatter. High as well as low voltages results in an unstable arc. High voltage produces excessive spatter & porosity. Low voltage causes narrower weld beads with high crown.

Travel Speed

It is defined as speed at which the MIG 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.

Gas Flow Rate

In MIG 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.

Cooling Medium

Mechanical properties such as strength, hardness, ductility etc greatly affected by cooling medium provided after welding. Slow cooling rate i.e. air cooling of welded joints removes internal stresses and refine grain structure hence strength of joint increases. Fast cooling like quenching in water or other oil medium results

IJARSE
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in increasing hardness and strength of the joint. For stainless steel 316l alloy water quenching doesn't affect the hardness.

Other parameters like electrode diameter, electrode sickout, type of joint and shielding gas type etc also affect weld quality.

The objective of the present work is to analyse the effect of current, voltage, feed rate, gas flow rate, and type of cooling on welding characteristics (hardness, yield strength, & ultimate tensile strength) and optimization of the welding parameters of metal 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 analysed. Many researchers worked on effect of welding parameters and attempted on optimization of parameters and characteristics.

Vikas Chauhan et al. [1]have optimized the process parameters of MIGW for SS-304 and low carbon steel using Taguchi technique. Three MIG 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. Salawadagi Sushant S., Kumbhar S et al. [2] researched the influence process parameters of MIG welding viz. welding speed, weld current and weld plate angle. The ANOVA and GRA method is used by considering residual stress as output parameter. R Raman Mishra et al. [3] have analysed on dissimilar metal joint as a structural material used in various applications which provided good combined mechanical properties i.e. corrosion resistance, strength with low cost. In this study, stainless steel grades 316, 310, 304 and 202 were welded with mild steel by TIG and MIG welding processes. The percentage of dilutions of weld and tensile strength ware investigated. The comparison of results is done for different joints welded by TIG &MIG welding technique. It was concluded that TIG welded joints have better mechanical properties than MIG welded joints. S.R. Meshram and N.S. Pohokar et al [4]studied the influence of process parameters MIGW 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. [5]researched the effect of process parameters of MIGW 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 analyse 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. Pawan Kumar et al. [6] have studied the Taguchi's design method for optimization of GMAW 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.

IJARSE
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ISSN (P) 2319 - 8346

EXPERIMENT PROCEDURE

Total 16 experiments were run to investigate effect of welding parameters on MIG welding. These analyses have been under taken to inspect the effect of voltage, welding current, feed rate, gas flow rate, & type of cooling on the hardness and yield strength and ultimate strength and presented in Table 4 . The stainless steel 316l is welded by MIG welding machine using SS 316l as electrode wire. Specifications of MIG welding machine, description of work piece material and tool material are presented in the following tables. MIG welding is carried out and after grinding work pieces are tested for hardness on Vickers hardness tester as shown in Figure 2. 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. Yield strength & ultimate tensile strength obtained from universal testing machine.

Table 1**.** Description of work piece material and tool material

Base metal	stainless steel 316l alloy
Dimension of base metal	60 ×60 ×3 mm (32 pieces)
Electrode material	SS 316L
Dimension of Electrode	Ø 0.8 mm

Table 2. MIG400IJ2 Specifications

Description	Parameter
Model	MIG 400IJ
Frequency	50/60 (Hz)
Input Voltage	AC 390V±15%
Output Current Range	50-350
Rated Input Current	21.1
Rated Output Voltage	15.5 - 30.5
Power Facto	0.93
Duty Cycle	60%
Wire Feeder type	Separate
Wire feed	4-7.8 (m/min)
Efficiency	80%
Dimension	510x 250 x 455 mm
Weight	28 kg

Table 3 Representation of L16 orthogonal array

Factor	**Name**	**Level values**	**column**	**level**
A	Current	95, 105, 115, 125	1	4
B	voltage	18, 19, 20, 21	2	4
C	Gas flow rate	8, 12	3	2
D	Feed rate	4, 6	4	2
E	medium	Air, Water	5	2

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Table 4 Influence of design parameters on strength and hardness

s.n	Current (A) amp	Voltage (V) volt	Gas flow rate(Q) mm^3/s	feed rate (F) mm/s	type of medium (X)	Hardness (HRC)			avg hardness	Yield strength (Mpa)	Ultimate strength (Mpa)
						H1	H2	H3	H	F_y	F_u
1	95	18	8	4	air	75	72	76	74	255.625	302.287
2	95	19	8	4	air	71	74	79	75	258.080	308.209
3	95	20	12	6	water	82	78	80	80	158.207	174.164
4	95	21	12	6	water	81	85	82	83	204.955	227.541
5	105	18	8	6	water	79	80	82	80	216.109	246.991
6	105	19	8	6	water	76	79	80	78	225.362	265.451
7	105	20	12	4	air	81	77	83	80	291.590	333.554
8	105	21	12	4	air	78	80	79	79	282.439	323.213
9	115	18	12	4	water	84	88	87	87	235.562	275.240
10	115	19	12	4	water	83	87	85	85	236.174	294.318
11	115	20	8	6	air	90	86	85	87	296.136	339.773
12	115	21	8	6	air	89	87	90	88	311.704	347.462
13	125	18	12	6	air	90	93	94	92	333.275	372.976
14	125	19	12	6	air	93	94	95	94	349.527	467.532
15	125	20	8	4	water	91	89	84	88	264.410	319.792
16	125	21	8	4	water	84	82	88	85	267.929	320.984

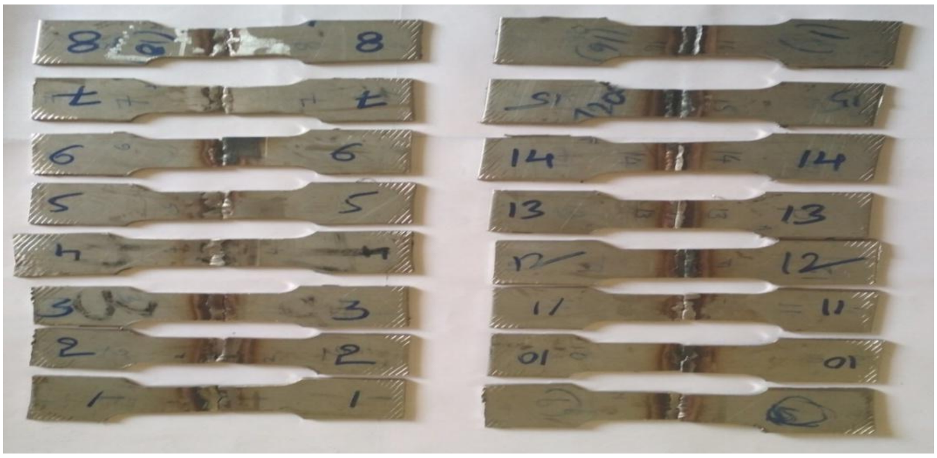

Figure 2 Welded pieces after UTM test

IJARSE
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In this experimental work L16 mixed orthogonal array was used. This array consists of five parameters and four levels for two parameters (current, voltage) and two levels for three parameters (gas flow rate, feed rate, type of medium) as illustrated in table 6.2. 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, yield strength & 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

In this study, Taguchi's DOE software (Quality- 4) is used to calculate the effects of the process parameters, to perform the analysis of variance (ANOVA) and to evaluate the optimum conditions.

Table 5 Response table for signal to noise ratio for hardness

LEVEL	CURRENT	VOLTAGE	GAS FLOW RATE	FEED RATE	TYPE OF MEDIUM
1	37.83	38.38	38.24	38.22	38.41
2	37.98	38.35	38.57	38.60	38.40
3	38.76	38.45	-	-	-
4	39.05	38.45	-	-	-
DELTA	1.22	0.10	0.33	0.38	0.01
RANK	1	4	3	2	5

Table 6 Analysis of variance test for hardness

SOURCE	DF	Adj SS	Adj MS	F-Value	P-Value
CURRENT	3	391.688	130.563	47.84	0.000
VOLTAGE	3	1.688	0.563	0.21	0.889
GAS FLOW RATE	1	39.063	39.063	14.31	0.009
FEED RATE	1	52.563	52.563	19.26	0.005
TYPE OF MEDIUM	1	0.562	0.562	0.21	0.666
Error	6	16.375	2.729		
Total	15	501.938			

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 given to the second maximum i.e feed rate, and so on, to indicate the relative effect of each factor on response. Hence current, feed rate, and gas flow rate are mostly effect on hardness hence is given by first three ranks. Voltage and type of medium are least effect on hardness and hence given fourth and fifth rank respectively.

From table 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 type of medium it is minimum. P value in table indicates that which parameters significantly effects response value.

IJARSE
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ISSN (P) 2319 - 8346

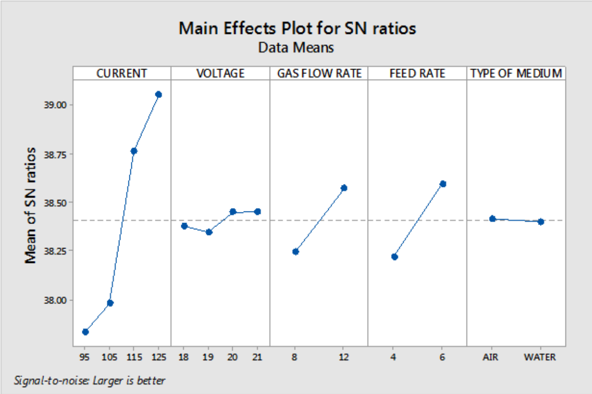

Figure 3 Main effective plots for SN ratio for hardness

From above graphs we can conclude that hardness varies with current which increases with increase in current and is maximum when current value taken as 125 amp and minimum at 95 amp. For voltage when we take 21 volts gives maximum hardness. Hardness increases with raise in both gas flow rate & feed rate and is maximum for 12 mm^3 /sec and 6 mm/sec respectively. Type of medium didn't affect much on hardness.

- **Regression Equation**

HARDNESS = 83.438- 5.438 CURRENT_95- 4.187 CURRENT_105+3.313 CURRENT_115+ 6.313 CURRENT_125-0.188 VOLTAGE_18- 0.438 VOLTAGE_19+ 0.312 VOLTAGE_20- 0.313 VOLTAGE_21+ 1.563 GAS FLOW RATE_12+ 1.563 GAS FLOW RATE_8- 1.813 FEED RATE_4+ 1.813 FEED RATE_6+ 0.187 TYPE OF MEDIUM_AIR- 0.187 TYPE OF MEDIUM_WATER.

Table 7 Response table for signal to noise ratio for yield strength

Level	CURRENT	VOLTAGE	GAS FLOW RATE	FEED RATE	TYPE OF MEDIUM
1	46.65	48.19	48.31	48.33	49.42
2	48.02	48.41	48.10	48.07	46.99
3	48.55	47.79			
4	49.58	48.42			
Delta	2.93	0.63	0.21	0.25	2.43
Rank	1	3	5	4	2

Table 8 Analysis of variance test for yield strength

Source	DF	Adj SS	Adj MS	F-Value	P-Value
CURRENT	3	28748.3	9582.8	15.84	0.003
VOLTAGE	3	4059.7	1353.2	2.24	0.185
GAS FLOW RATE	1	19.3	19.3	0.03	0.864
FEED RATE	1	79.7	79.7	0.13	0.729
TYPE OF MEDIUM	1	28100.2	28100.2	46.44	0.000
Error	6	3630.6	605.1		
Total	15	64638.0			

IJARSE
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From table 7 delta value for both current and type of medium is 2.93 and 2.43 and given by Rank 1 & Rank 2 respectively. Gas flow rate & feed rate is least effect on yield strength and hence is given by rank5 and rank4 respectively. From table 8 P value for both type of medium and current is 0.000 & 0.003 are less than 0.005 hence are effects mostly on yield strength.

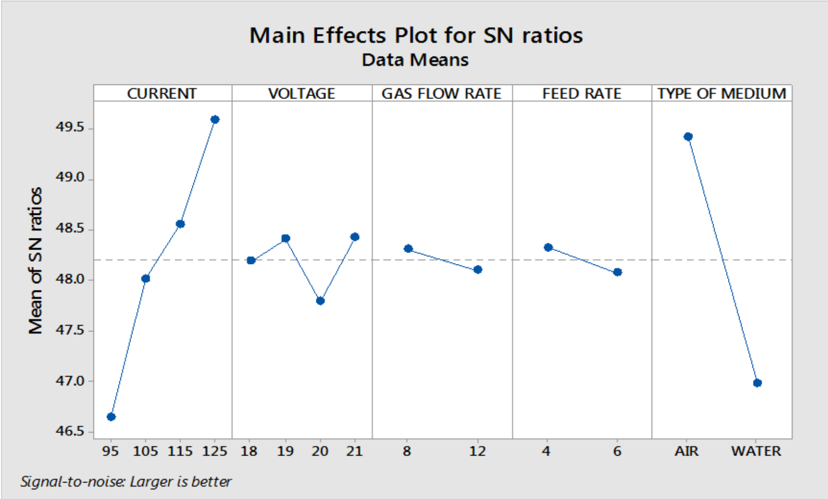

Figure 6.2 Main effects plot for SN ratio for yield strength

Yield strength increases with increase in current and maximum at 125 amps and minimum at 95 amps. Voltage gives maximum yield strength at 21 volts. Gas flow rate and feed rate are not effect on yield strength. Type of medium relatively mostly effect on yield strength and is maximum when cooling is done in air.

- **Regression Equation**

YIELD STRENGTH = 283.26- 51.36 CURRENT_95- 17.7 CURRENT_105+ 5.1 CURRENT_115+ 59.5 CURRENT_125- 9.5 VOLTAGE_18+25.7 VOLTAGE_19-16.4 VOLTAGE_20- 2.7 VOLTAGE_21- 1.26 GAS FLOW RATE_8+ 1.26 GAS FLOW RATE_12+ 2.73FEED RATE_4- FEED RATE_6+ 39.49 TYPE OF MEDIUM_AIR- 39.49 TYPE OF MEDIUM_WATER.

Table 9 Response table for signal to noise ratio for ultimate strength

Level	CURRENT	VOLTAGE	GAS FLOW RATE	FEED RATE	TYPE OF MEDIUM
1	47.84	49.42	49.67	49.80	50.79
2	49.25	50.26	49.45	49.32	48.34
3	49.90	49.00			
4	51.26	49.57			
Delta	3.43	1.26	0.22	0.48	2.45
Rank	1	3	5	4	2

IJARSE
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ISSN (P) 2319 - 8346

Table 10 Analysis of variance test for ultimate strength

Source	DF	Adj SS	Adj MS	F-Value	P-Value
CURRENT	3	28748.3	9582.8	15.84	0.003
VOLTAGE	3	4059.7	1353.2	2.24	0.185
GAS FLOW RATE	1	19.3	19.3	0.03	0.864
FEED RATE	1	79.7	79.7	0.13	0.729
TYPE OF MEDIUM	1	28100.2	28100.2	46.44	0.000
Error	6	3630.6	605.1		
Total	15	64638.0			

From table 9 delta value for both current and type of medium is 3.43 and 2.45 and given by rank1 & rank2 respectively. Gas flow rate and feed rate is least effect on ultimate strength and hence is given by rank5 and rank4 respectively. From table 10 P value for both parameters, type of medium and current is 0.000 & 0.003 are less than 0.005 hence are effects mostly on ultimate strength.

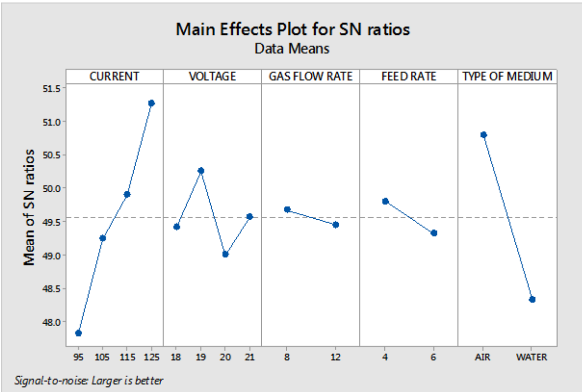

Figure 6.3 Main effects plot for SN ratio for ultimate strength

Ultimate strength increases with increase in current and maximum at 125 amps and minimum at 95 amps. Voltage gives maximum ultimate strength at 19 volts. Gas flow rate doesn't effect on ultimate strength. Maximum ultimate strength obtained when feed rate is 4 mm/sec. Type of medium relatively mostly effect on ultimate strength and is maximum when cooling is done in air.

- **Regression Equation**

ULTIMATE STRENGTH = 307.47- 54.4 CURRENT_95- 15.2 CURRNT_125+ 6.7 CURRENT_115+ 62.9 CURRENT_125- 8.1 VOLTAGE_18+ 26.4 VOLTAGE_19- 15.6 VOLTAGE_20- 2.7 VOLATGE_21- 1.10 GAS FLOW RATE_8+ 1.10 GAS FLOW RATE_12+ 2.23 FEED RATE_4- 2.23 FEED RATE_6+ 41.91 TYPE OF MEDIUM_AIR- 41.91 TYPE OF MEDIUM_WATER.

IJARSE
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CONCLUSIONS

The following conclusions were made out by this project:

- It is concluded that welding current & feed rate have a significantly influence on hardness of joint and type of medium is not effect much on hardness. Welding current and type of medium have effect on both yield strength and ultimate strength of welded plate.
- It is concluded that when current 125 amp, voltage 21 volts, gas flow rate12 mm^3 /sec, and feed rate 6 mm/sec, at specified values hardness is optimum.
- It is concluded that when current 125 amp, voltage 21 volts, gas flow rate 8 mm^ /sec, feed rate 4 mm/sec, and air cooling, gives optimised yield strength.
- It is concluded that when current 125 amp, voltage 19 volts, gas flow rate 8 mm^ /sec, feed rate 4 mm/sec, and air cooling gives optimised ultimate strength.
- It is also concluded that with increase current response values hardness, yield strength & ultimate strength increases.

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