Optimization of P-GMAW Welding Parameters using Taguchi Technique for SS304L Pipes

Rudreshi Addamani [1], H V Ravindra[2], Darshan C S [3]

[1,2] Department of Mechanical Engineering, P.E.S college of Engineering, Mandya, India.
[3] Department of Mechanical Engineering Bangalore Technological Intitute, Bangalore, India
rudreshaddamnai@gmail.com

Abstract. The Pulsed Gas Metal Arc Welding (P-GMAW) welding parameters are the most important factors affecting the quality, productivity and cost of welding. This paper presents the influence of welding parameters like welding current, Gas flow rate, wire feed rate, etc. on weld strength and hardness of SS304L pipes during welding. By using DOE method, the parameters can be optimize and having the best parameters combination for target quality. The analysis from Taguchi technique method can give the significance of the parameters as it give effect to change of the quality and strength of product or does not. A plan of experiments based on Taguchi technique has been used to acquire the data. An Orthogonal array of L_{27} and analysis of variance (ANOVA) are employed to investigate the welding characteristics of SS304L pipes and optimize the welding parameters. Finally the conformations tests have been carried out to compare the predicated values with the experimental values confirm its effectiveness in the analysis of weld strength and hardness.

Keywords: Pulsed Gas, SS304L, Taguchi Technique, ANOVA.

1 Introduction

Pulsed Gas Metal Arc Welding is widely used process, especially in pipe welding. It offers an improvement in quality and productivity over regular Gas Metal Arc Welding (GMAW). The process enables stable spray transfer with low mean current and low net heat input. It applies waveform control logic to produce a very precise control of the arc through a broad wire feed speed range. With precise control of arc dynamics, Pulsed Gas Metal Arc Welding (P-GMAW) can be used as a fast-follow process at high travel speeds, or it can be run as a high deposition rate, fast-fill process. A variation of the spray transfer mode, pulse-spray is based on the principles of spray transfer but uses a pulsing current to melt the filler wire and allow one small molten droplet to fall with each pulse. The pulses allow the average current to be lower, decreasing the overall heat input and thereby decreasing the size of the weld pool and heat-affected zone while making it possible to weld thin work pieces. The pulse provides a stable arc and no spatter, since no short-circuiting takes place. This also makes the process suitable for nearly all metals, and thicker electrode wire can be used as well. The smaller weld pool gives the variation greater versatility, making it possible to weld in all positions. In comparison with short arc Gas Metal Arc Welding (GMAW), this method has a somewhat slower maximum speed (85 mm/s or 200 in/min) and the process also requires that the shielding gas be primarily argon with a low carbon dioxide concentration. Additionally, it requires a special power source capable of providing current pulses with a frequency between 30 and 400 pulses per second. However, the method has gained popularity, since it requires lower heat input and can be used to weld thin work pieces, as well as nonferrous materials.

2 Literature Review

S.V Sapakal et al. **[1]** presented a research on the optimization of MIG welding parameters using Taguchi design method. In their research they considered welding current, welding voltage and welding speed as input variables and penetration depth as output variable. MS C20 was selected as work piece material. 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) were employed to investigate the welding characteristics of MS C20 material and optimize the welding parameters. Their experimentation results that the lower current.

L. Suresh Kumar et al. **[2]** have investigated for welding aspects of AISI 304 & 316 by Taguchi technique for the process of TIG & MIG welding. Mechanical properties of austenitic stainless steel for the process of TIG and MIG welding have discussed here. The voltage has taken constant and various characteristics such as strength, hardness, ductility, grain structure, tensile strength breaking point, HAZ have observed in these two processes.

S.R. Meshram et al. **[3]** have done a research on optimization of process parameters of gas metal arc welding to improve the quality of weld bead geometry. In their work, a grey-based Taguchi method was adopted to optimize the gas metal arc welding process parameters. Many quality characteristic parameters were combined into one integrated quality parameter by using grey relational grade or rank. The welding parameters considered in their research were arc voltage, wire feed rate, welding speed, nozzle to plate distance and gas flow. The quality characteristics consider were penetration, reinforcement and bead width. Analysis of variance has performed to find the effect of individual process parameter on quality parameters. The Taguchi L_{25} array was adopted to conduct the experiments. The stainless steel (AISI410) was used as welding specimen.

Pawan Kumar et al. **[4]** have obtained the use of Taguchi's parameter design methodology for parametric study of Gas Metal Arc Welding of Stainless Steel & Low Carbon Steel. The input process variables considered here include welding current, welding voltage and gas flow rate. A total no. of 9 experimental runs were conducted using an L9 orthogonal array, and calculate the signal-to-noise ratio. Subsequently, using Analysis Of Variance (ANOVA) the significant coefficients for each input parameter on tensile strength & Hardness (PM, WZ & HAZ) were determined

A.K. Panday, Moeed et al. **[5]** performed their analysis on optimization of resistance spot welding parameters using Taguchi method. The experiments were conducted under varying pressure, welding current and welding time. The output characteristic considered was tensile strength of the welded joint. The material used was low carbon steel sheets of 0.9mm. Their conclusion leads that the contribution of welding current holding time and pressure towards tensile strength is 61%, 28.7% and 4 % respectively as determined by the ANOVA method.

S.R Patil et al. **[6]** presented their work on optimization of MIG welding parameters for improving welding strength. They presents the influence of welding parameters welding current, welding voltage, welding speed on ultimate strength of welded joints of AISI mild steel materials. A plan of experiments using Taguchi has decided. Experiments were performed and result was confirmed. From this study they concluded that the welding current and welding speed are the major factors affecting tensile strength of welded joints

Ajit hooda et al. **[7]** has done their research on optimization of MIG welding parameters in order to improve yield strength of AISI 1040 mild steel. The process parameters welding current, voltage, gas flow rate and wire speed were studied. The experiments were conducted based on four factors, three level orthogonal arrays.

In the present work, it is planned to analyze the different input parameters in Pulsed Gas Metal Arc Welding to improve both Ultimate Tensile Strength and Hardness of the welding joint using Taguchi's technique.

3 Experimental Details

The experiments have been conducted using a Pulsed Current Lorch welding machine having 400 Amperes maximum current with air type cooling and automated welding set up. In this welding machine automated Metal Inert Gas torches as well as automatic feeler wire feeding units have provided.

3.1 Material Selection

The present study has been carried out SS304L pipes. Most common uses are in refineries and plants when gasses or fluids are transported at high temperatures and pressures.

Table 1: Chemical Composition of SS304L Pipe Material

Element	C	Mn	P	S	Si	Cr	Ni	N	Fe
%	0.21	1.27	0.030	0.001	0.35	18.10	8.02	0.053	Balance

3.2 Taguchi Technique

The Taguchi method developed by Genuchi Taguchi is a statistical method used to improve the product quality. Optimization of process parameters is the key step in the Taguchi method for achieving high quality without increasing cost. This is because optimization of process parameters can improve quality characteristics and the optimal process parameters obtained from the Taguchi method are insensitive to the variation of environmental conditions and other noise factors. Basically, classical process parameter design is complex and not easy to use. A large number of experiments have to be carried out when the number of process parameters increases. To solve this task, the Taguchi method uses a special design of orthogonal arrays to study the entire process parameter space with a small number of experiments only. A loss function is then defined to calculate the deviation between the experimental value and the desired value. Taguchi recommends the use of the loss function to measure the deviation of the quality characteristic from the desired value. The value of the loss function is further transformed into signal-to-noise (S/N) ratio.

3.3 S/N Ratio

The signal to noise ratios (S/N), which are log functions of desired output, serve as the objective functions for optimization, help in data analysis and the prediction of the optimum results. There are 2 Signal-to-Noise ratios of common interest for optimization of Static Problems.

1. Smaller the better is given by $\boldsymbol{\eta = -10 \log [(\Sigma Y_i^2/n]}$
2. Larger the better is given by $\boldsymbol{\eta = -10 \log [(\Sigma\ 1/Y_i^2)/ n]}$

Where, η = Signal to Noise ratio
Y_i= i^{th} observed value of response
n = no. of observations in a trial
y = average of observed response.

3.4 Experimental parameter

Input parameters: Welding Current, Gas Flow Rate and Wire Feed Rate.

Output parameters: Ultimate Tensile Strength (UTS) and Hardness

Table 2: Control factors and their level

Sl.No	Symbol	Factors	Unit	Level 1	Level 2	Level 3
1	A	Welding Current	Ampere	55	60	65
2	B	Gas Flow Rate	l/min	12	13	14
3	C	Wire Feed Rate	mm/min	110	115	120

3.5 Experimental Work

Experiments were conducted using Pulsed current Lorch welding machine by DC electrode positive power supply. Test pieces of size outer diameter of 25 mm, length of 300 mm with wall thickness of 3mm were cut in to length of each 150 mm initially with an edge preparation of 45 degree and tack welded as shown in Fig. 1. Copper coated Mild steel electrode of 1.2 mm diameter was used for welding. Argon (85%) and CO_2 (15%) gas mixture was used for shielding. The experimental setup used consists of a rotating disk in to which work sample was attached as shown in Fig. 2. Welding speed (157 mm/min) has been kept constant for all twenty trails. Single pass welding was performed on pipes by varying the parameters as shown in Table 2. The working ranges for the process parameters were selected from the American Welding Society handbook. Based on the designed L_{27} orthogonal array combination a series of joining processes was performed in welding machine. Ultimate Tensile Strength and hardness are considered as objectives. For the calculation of the responses of welded specimens, tensile test were performed using Advanced Universal Testing Machine model number; UTM US-1000 kN and make; Akash Industries Hardness test was performed using Vickers hardness testing machine.

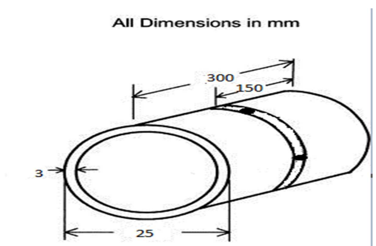

Fig.1: Sample specimen with dimension

Fig.2: Experimental Set up

Table 3: Welding performances using L_{27} orthogonal array

Runs	Current (Amps)	Gas flow rate (l/min)	Wire feed rate (mm/min)	Ultimate tensile strength (N/mm^2)	Hardness (VHN)
1	55	12	110	313	102.83
2	55	12	115	311	103.83
3	55	12	120	315	111.91
4	55	13	110	321	106.30
5	55	13	115	318	102.56
6	55	13	120	324	112.90
7	55	14	110	326	108.34
8	55	14	115	323	112.07
9	55	14	120	325	118.23
10	60	12	110	341	102.71
11	60	12	115	344	104.44
12	60	12	120	345	113.18
13	60	13	110	347	104.40
14	60	13	115	346	114.35
15	60	13	120	348	117.90
16	60	14	110	350	110.30
17	60	14	115	354	112.07
18	60	14	120	352	118.23
19	65	12	110	356	107.35
20	65	12	115	355	108.89
21	65	12	120	359	111.69
22	65	13	110	363	114.87

24	65	13	120	362	113.56
25	65	14	110	367	108.91
26	65	14	115	365	114.44
27	65	14	120	368	127.20

4. ANOVA table and response calculation

The purpose of the Analysis of Variance (ANOVA) is to examine 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 parameters and the error. The ANOVA table for both Ultimate Tensile Strength and hardness are shown in table 4 and 5. The response table for both UTS and hardness are shown in table 6 and 7.

Table 4*:* ANOVA Table for Ultimate Tensile Strength

Source	DOF	SS	MS	F	P (%)
A	2	5.44629	2.72315	1339.4	93.8***
B	2	0.30195	0.15098	74.27	5.2**
C	2	0.017070	0.00583	4.20	0.29*
Error	2	0.04066	0.00203		
Total	8	5.80597			

SS, sum of squares;
DOF, degree of freedom;
% P, percentage contribution;
*, level of significance at 95% confidence level

Table 5: ANOVA Table for hardness

Source	DOF	SS	MS	F	P (%)
A	2	0.54393	0.2719	5.06	10.44*
B	2	1.3296	0.6644	12.37	25.53**
C	2	2.2596	1.1297	21.02	43.38***
Error	2	1.0749	0.5375		
Total	8	5.20801			

Table 6: Response Table for Ultimate Tensile Strength

Levels	A	B	C
1	50.09	50.56	50.69
2	50.82	50.70	50.66
3	51.17	50.81	50.73

Delta	1.08	0.26	0.06
Rank	1	2	3

Table 7: Response Table for hardness

Levels	A	B	C
1	40.72	40.62	40.61
2	40.88	40.90	40.77
3	41.07	41.16	41.29
Delta	0.35	0.54	0.68
Rank	3	2	1

5. Result and Discussion

1) **Optimum parameter selection from S/N ratio for UTS**

Ultimate Tensile Strength is larger-the-better type quality characteristic higher values of Ultimate Tensile Strength are considered to be optimal. It is clear from Fig. 4, that Ultimate Tensile Strength is highest at third level of welding current, third level of gas flow rate and third level of wire feed rate.

2) **Optimum parameter selection from S/N ratio for hardness**

Hardness is larger-the-better type quality characteristic higher values of hardness are considered to be optimal. It is clear from Fig. 5, that hardness highest at third level of welding current, third level of gas flow rate and third level of wire feed rate.

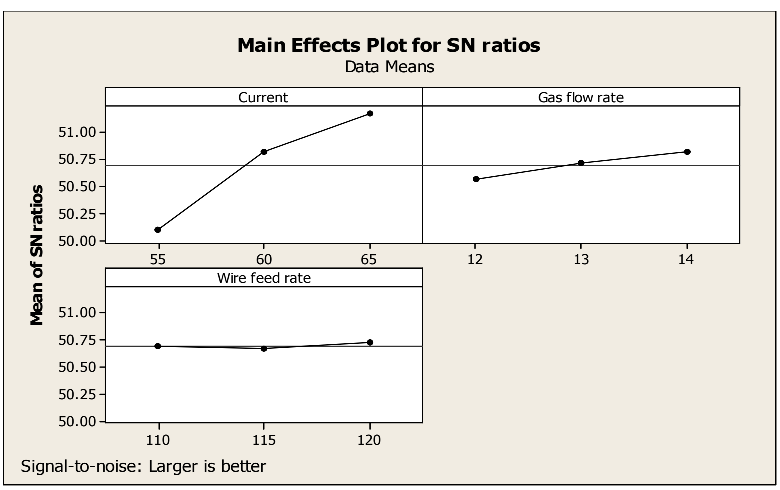

Fig.4 : Main Effects Plot for Ultimate Tensile Strength

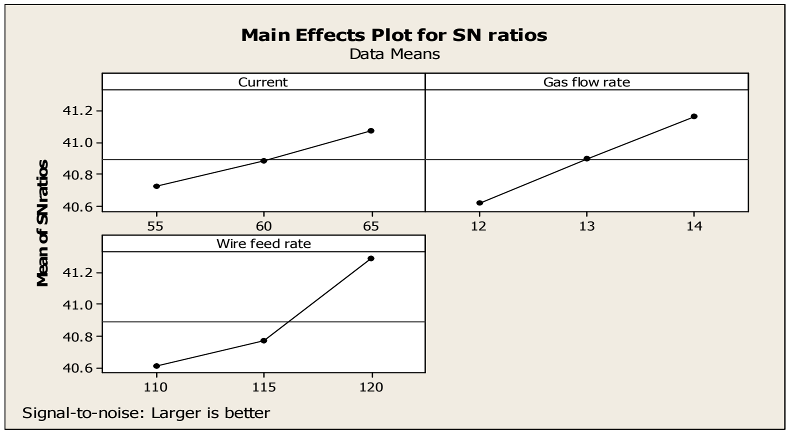

Fig.5 : Main Effects Plot for Hardness

3) **Analysis of Variance (ANOVA) for Ultimate Tensile Strength**

The calculated values of Analysis of Variance for Ultimate Tensile Strength of welding joint are listed in table 4. The calculated values of ANOVA present the percentage effect of each parameter on Ultimate Tensile Strength of the joint. From the analysis, it is seen that current is the most contribution factor and the wire feed rate is the least contribution factor for Ultimate Tensile Strength of joint.

4) **Analysis of Variance (ANOVA) for Hardness**

The calculated values of Analysis of variance for hardness of welding joint are listed in table 5. The calculated values of ANOVA present the percentage effect of each parameter on hardness of the joint. From the analysis, it is seen that wire feed rate is the most contribution factor and the current is the least contribution factor for hardness.

6. Verification Experiment

The confirmation run was conducted using same experimental setup by taking optimized parameters for SS316L pipes considered in this present work. The results obtained from the confirmation runs are tabulated in the below Table 8.

Table 8: Results of Verification Experiment

Condition description	Initial set of parameters	Optimal parameters
Level	A2B3C1	A3B3C3
UTS (N/mm^2)	350	378
Hardness (VHN)	110.30	128.5

Form the table 8; one can observe that, the optimized parameters have considerable effect on the response variables i.e. Ultimate Tensile Strength and hardness of SS304L pipes. Ultimate Tensile Strength was at 350 N/mm^2 for initial settings of parameters and the value has been increased to 378 N/mm^2 after setting parameters to optimized values. Similarly, the hardness has been increased from 110.30 VHN to 128.5 VHN.

7. Conclusion

In this present work the optimization of the process parameters for Pulsed Gas Metal Arc welding of SS304L pipes with larger Ultimate Tensile Strength and hardness has been reported. A Taguchi orthogonal array, the signal-to-noise (S/N) ratio and Analysis of Variance (ANOVA) were used for the optimization of welding parameters and it is found that i) optimum condition for maximum Ultimate Tensile Strength is (A3B3C3) i.e. current = 65 Ampere, gas flow rate = 14 liter/min and wire feed rate = 120 mm/min ii) optimum condition for hardness is (A3B3C3) i.e. current = 65 Ampere gas flow rate = 14 liter/min and wire feed rate = 120 mm/min. ANOVA for UTS shows that current is the most significant factor, followed by gas flow rate. ANOVA for hardness indicates that wire feed rate influences most significantly, followed gas flow rate. Conformation experiment was also conducted and verified the effectiveness of the Taguchi optimization method.

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References

[1] Lin C.L. and Lin. J.L, (2002), The use of orthogonal array with Grey relational analysis to optimize the EDM process with multiple performance characteristics. J Matar Process tacnol, pp. 237-244.

[2] S.V Sapakal, M.T. Telsang,(2012),Parametric optimization of MIG welding using Taguchi design method. International Journal Of advanced Engineering Research and Studies, pp. 28-30.

[3] S.R. Meshram, N.S. pohokar, (2013), Optimization of process parameters of Gas Metal Arc Welding to improve Quality of Weld bead geometry. International journal of Engineering, Business and Enterprise Applications, pp. 46-52.

[4] A.K. Panday, M.I. Khan, K.M. Moeed, (2013), Optimization of resistance welding parameters using Taguchi method. International Journal of Engineering Science and Technology, pp. 243-240.

[5] Nirmalendhu Choudhury, Asish Bandyopadhyay, Ramesh Rudrapati, (2014), Design optimization of process parameters for TIG welding based on Taguchi method. International Journal of Current Engineering and Technology, pp. 12-16.

[6] S.R. Patil, C.A. Waghmare, (2013), Optimization of MIG welding parameters for improving strength of welded joints. International Journal of Advanced Engineering and Studies, pp.14-16.

[7] Ajit Hooda, Ashwani Dhingra and Satpal Sharma, (2012) , Optimization of Welding process parameters to predict maximum yield strength in AISI 1040. International Journal of mechanical Engineering and Robotics Research India, pp. 204-212.

[8] Patel, C. N. and Chaudhary, S. International Journal of Research in Modern Engineering and Emerging Technology, 1 (2013) 48-56.

[9] Lakshminarayanan, A. K., Balasubramanian, V. and Elangovan, K. Int J AdvManufTechnol, 40 (2008) 286–296.

[10] Kumar, P., Roy, B. K. and Nishant, International Journal of Engineering and Management Research, 3 (2013) 18-22.