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Optimization of Pulsed Current MIG Welding Parameters for Ultimate Tensile Strength and Hardness of ASTM A106 Pipes using Taguchi Technique

Darshan C S [1], Praveen Kumar N [2],
Suhas Surya M V [3], Santhosh Prasanna [4]
[1, 2, 3, 4] Students,
Department of Mechanical Engineering,
P.E.S College of Engineering, Mandya, India.

***Abstract*— Parametric optimization of Pulsed Current Metal Inert Gas Welding(PCMIGW) for Ultimate Tensile Strength and Hardness has been performed by using Taguchi method. Welding Current, Gas Flow Rate and Wire Feed Rate were chosen as welding parameters. The material used for this purpose was ASTM A106 pipes having dimensions with outer diameter 25 mm length 300 mm having wall thickness of 3 mm. Argon (85%) and Co_2 (15%) was used as a shielding gas. Mild steel filler wire with copper coated of diameter 1.2 mm was used. An orthogonal array, L_{27} was used to conduct the experiments. Signal to Noise (S/N) ratio and Analysis of Variance (ANOVA) were employed to study the welding characteristics of material. Optimization of parameters was done by Taguchi method using statistical software MINITAB-16. Confirmation tests were carried out with optimal levels of welding parameters to validate the Taguchi's optimization method.**

Keywords—*Pulsed Current, ASTM A106, Taguchi Technique, ANOVA.*

I. INTRODUCTION

Pulsed Current Metal Inert Gas Welding is a variant of Gas Metal Arc welding. Pulsed Current Metal Inert Gas Welding (PCMIGW) 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. It applies waveform control logic (Fig.1) to produce a very precise control of the arc through a broad wire feed speed range. In this process, welding current varies between high and low current levels at regular time interval. This variation in welding current between high and low level is called pulsation of welding current. High current is used for melting of faying surfaces of base metal while low current is used for maintenance of welding arc and allows time for solidification of the weld pool by dissipating of heat to base metal. This feature of current pulsating reduces net heat input to the base metal, so decreases undesirable effects of comparatively high heat input in MIG welding. Selection of the pulse peak current duration depends on the weld pool size and penetration required for welding the work piece a fine grained structure can be achieved using both low and high pulse frequencies.

Pulsed Current Metal Inert Gas Welding is commonly used for root pass welding of tubes and pipe welding.

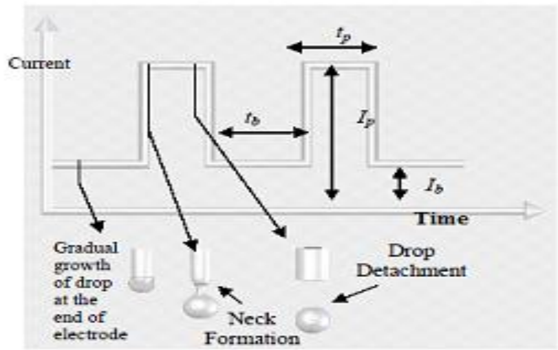

Fig. 1: Pulse metal transfer phenomenon

The main setting parameters which influence weld quality or wire melting are background current "I_b, peak current I_p, background time T_b, and peak time T_p.".

II. LITERATURE REVIEW

S.V. Sapakal & M.T. Telsang 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. [1]

S.R. Meshram & N.S. Pohokar has 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. [2]
A.K. Panday, M.I. khan & K.M. Moeed 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. [3]
Nirmalendu Choudhary, Asish Bandypadhay & Ramesh Rudrapati has presented their work on design optimization of process parameters of TIG welding using Taguchi method. They considered welding current, gas flow rate and filler rod as input process parameters and optimizes their values using Taguchi method to improve the ultimate load on weld materials. Taguchi design of experiment, S/N ratio and ANOVA analysis has performed for optimizing the results. The stainless steel slabs & mild steel slabs were used as work piece material. The optimum welding condition is obtained by the Taguchi method: current= 100A, gas flow rate= 18 l/min, filler rod diameter = 2mm. Confirmation test confirmed the optimum values. [4]
S.R Patil & C.A Waghmare 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. [5]
Ajit hooda, Ashwani dhingra & Satpal sharma 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. The empirical relationship can be used to predict the yield strength of welded material.
[6]
In the present work, it is planned to analyse the different input parameters in MIG welding to improve the ultimate tensile strength and Hardness of the welding joint using Taguchi's orthogonal array.

III. 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.

A. Material selection

The present study has been carried out with ASTM A106 pipes is the standard specification for seamless carbon steel pipes for high-temperature service. Most common uses are in refineries and plants when gasses or fluids are transported at high temperatures and pressures.

Table 1: *Chemical compositions of ASTM A106*

Element	C	Mn	P	S	Si	Cr	Ni
%	0.30	0.29	0.035	0.035	0.10	0.40	0.40

B. Taguchi Orthogonal Array Selection

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.

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

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.

D. Experimental parameter

Input parameters: Welding Current, Gas Flow Rate and Wire Feed Rate.
Output parameters: Ultimate Tensile Strength (UTS) and Hardness.

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Table 2: Control factors and their level

Sl.No	Symbol	Factors	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

E. Proposed Design of Experiment

For performing the experiments Taguchi L_{27} orthogonal array was selected for 3-factor and 3-level process parameters and which reduces the number of experiments which is given in table 3.

Table 3: Taguchi L_{27} Orthogonal Array

No. of Runs	A	B	C
1	1	1	1
2	1	1	2
3	1	1	3
4	1	2	1
5	1	2	2
6	1	2	3
7	1	3	1
8	1	3	2
9	1	3	3
10	2	1	1
11	2	1	2
12	2	1	3
13	2	2	1
14	2	2	2
15	2	2	3
16	2	3	1
17	2	3	2
18	2	3	3
19	3	1	1
20	3	1	2
21	3	1	3
22	3	2	1
23	3	2	2
24	3	2	3
25	3	3	1
26	3	3	2
27	3	3	3

F. 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. 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. Welding speed (157 mm/min) has been kept constant for all twenty trails. Single pass welding was performed on pipes by varying the initial parameters as shown in Table 3. 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. The photograph of the pulsed current Lorch welding machine is shown in Fig. 2. Ultimate Tensile Strength and hardness are considered as objectives. For the calculation of the responses (Ultimate Tensile Strength and hardness) 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 .The results of Ultimate Tensile Strength and hardness are shown in table4.

Fig. 2: Lorch MIG Welding Machine

Fig. 3: Welded ASTM A106 Pipes

Table 4: *Experimental design matrix and results*

No. of Runs	Current (Amp)	Gas Flow Rate (l/min)	Wire Feed Rate (mm/min)	UTS (N/mm^2)	Hardness (VHN)
1	55	12	110	303	102.83
2	55	12	115	235	103.83
3	55	12	120	207	111.91
4	55	13	110	215	106.3
5	55	13	115	204	102.56
6	55	13	120	225	112.9
7	55	14	110	195	108.34
8	55	14	115	232	112.07
9	55	14	120	172	118.23
10	60	12	110	258	102.71
11	60	12	115	229	104.44
12	60	12	120	245	113.18
13	60	13	110	210	104.4
14	60	13	115	256	114.35
15	60	13	120	189	117.9
16	60	14	110	250	110.3
17	60	14	115	202	112.07

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18	60	14	120	162	118.23
19	65	12	110	306	107.35
20	65	12	115	375	108.89
21	65	12	120	255	111.69
22	65	13	110	335	114.87
23	65	13	115	276	112.07
24	65	13	120	209	113.56
25	65	14	110	245	108.91
26	65	14	115	251	114.44
27	65	14	120	256	127.2

G. 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 UTS and hardness are shown in table 5 and 6. The response table for both UTS and hardness are shown in table 7 and 8

Table 5: ANOVA Table for UTS

Source	DOF	SS	MS	F	P (%)
A	2	22.863	11.432	10.67	31.75***
B	2	14.226	7.113	6.64	19.76**
C	2	13.472	6.376	6.29	18.71*
Error	2	21.428	1.071		
Total	8	71.989			

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

Table 6: ANOVA Table for Hardness

Source	DOF	SS	MS	F	P (%)
A	2	0.46620	0.23310	38.22	12.65*
B	2	1.15350	0.57675	94.58	31.30**
C	2	1.94251	0.97125	157.27	52.71***
Error	2	0.12197	0.00610		
Total	8	3.68471			

Table 7: Response Table for UTS

Levels	A	B	C
1	220.9	267.8	257.1
2	222.3	235.4	251.1
3	278.3	218.3	213.3
Delta	57.4	49.4	43.8
Rank	1	2	3

Table 8: Response Table for Hardness

Levels	A	B	C
1	109.4	107.7	107.3
2	109.6	110.2	109.4
3	113.0	114.4	115.4
Delta	3.6	6.4	8.1
Rank	3	2	1

The ANOVAs table and response table calculation represents the effect of different parameters on individual responses. Here *** & ** represents most significant and significant parameters and * as less significant for individual response.

IV. RESULT AND DISCUSSION

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

Ultimate Tensile Strength is larger-the-better type quality characteristic. Therefore higher values of Ultimate Tensile Strength (UTS) are considered to be optimal. It is clear from Fig. 4, that Ultimate Tensile Strength is highest at third level of welding current, first level of gas flow rate and first level of wire feed rate (A3B1C1).

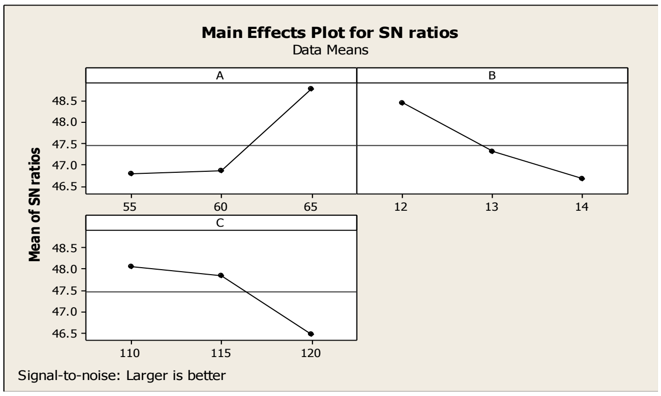

Fig. 4: Main Effects Plot for UTS

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

Hardness is larger-the-better type quality characteristic. Therefore higher values of hardness are considered to be optimal. It is clear from Fig. 5, that hardness of is highest at third level of welding current, third level of gas flow rate and third level of wire feed rate (A3B3C3).

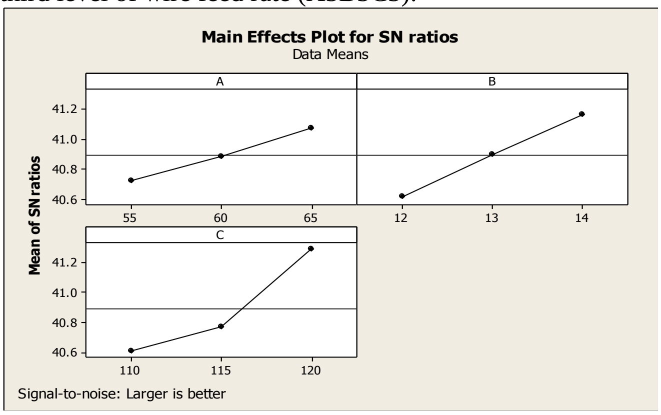

Fig. 5: Main Effects plots for hardness

3) Analysis of Variance (ANOVA) Results for UTS

The calculated values of Analysis of Variance for Ultimate Tensile Strength of welding joint are listed in table 5. 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 UTS of joint.

4) Analysis of Variance (ANOVA) Results for hardness

The calculated values of Analysis of variance for percentage elongation of welding joint are listed in table 6. 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.

V. VERIFICATION EXPERIMENT

The confirmation run was conducted using same experimental setup by taking optimized parameters for the ASTM A106 pipes considered in this present work. The results obtained from the confirmation runs are tabulated in the below Table 9.

Table 9**:** Results of Verification Experiment

	Initial Parameter Readings		Optimized Parameter Readings	
Parameter	UTS (N/mm^2)	Hardness (VHN)	UTS (N/mm^2)	Hardnes s (VHN)
Current (Ampere)	65	65	65	65
Gas Flow Rate (l/min)	12	14	12	14
Wire Feed Rate (mm/min)	115	120	110	120
Response Obtained	375	127.2	383	132.3

Form the table 9; one can observe that, the optimized parameters have considerable effect on the response variables i.e. Ultimate Tensile Strength (UTS) and hardness of ASTM A106 pipes. Ultimate Tensile Strength (UTS) was at 375 N/mm^2 for initial settings of parameters and the value has been increased to 383 N/mm^2 after setting parameters to optimized values. Similarly, the hardness has been increased from 127.2 VHN to 132.3 VHN.

VI. CONCLUSION

In this present work the optimization of the process parameters for Pulsed Current Metal Inert Gas welding of ASTM A106 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 UTS is (A3B1C1) i.e. current = 65 Ampere, gas flow rate = 12 liter/min and wire feed rate = 110 mm/min ii) optimum condition for maximum 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 by gas flow rate. A conformation experiment was also conducted and verified the effectiveness of the Taguchi optimization method.

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