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# OPTIMIZATION OF P-GMAW WELDING PARAMETERS USING TAGUCHI TECHNIQUE FOR SS304L PIPES

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## 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 $L_9$ and analysis of variance (ANOVA) are employed to investigate the welding characteristics of SS304L material 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:** P-GMAW, SS304L, Taguchi Technique, ANOVA

## INTRODUCTION

Welding is a process of joining two materials, which is extensively used in any manufacturing industry. Generally, all welding processes are used with the aim of obtaining a welded joint with the desired weld-bead parameters, excellent mechanical properties with minimum distortion. Pulsed Current Metal Inert Gas welding is widely used process, especially in sheet metal industries. 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 Current Metal Inert Gas Welding 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. 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. 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.

## 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

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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]

In the present work, it is planned to analyze the different input parameters in Pulsed Gas Metal Arc Welding to improve the ultimate tensile strength and Hardness of the welding joint using Taguchi's orthogonal array.

## EXPERIMENTAL DETAILS

The experiments have been conducted using a Pulsed Current Lorch welding machine having 400Amperes 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.

### 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**.**

***Table1.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 |

### 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.

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***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.

***Table2. Control factors and their level***

| Sl. No. | Welding Parameters | Symbol | Units | Levels | | |
|---|---|---|---|---|---|---|
| | | | | **1** | **2** | **3** |
| 1 | Current | A | Ampere | 55 | 60 | 65 |
| 2 | Gas Flow Rate | B | LPM | 12 | 13 | 14 |
| 3 | Wire Feed Rate | C | mm/min | 110 | 115 | 120 |

**Proposed Design of Experiment**

For performing the experiments Taguchi $L_9$ 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 $L_9$ Orthogonal Array***

| A | B | C |
|---|---|---|
| 1 | 1 | 1 |
| 1 | 2 | 2 |
| 1 | 3 | 3 |
| 2 | 1 | 2 |
| 2 | 2 | 3 |
| 2 | 3 | 1 |
| 3 | 1 | 3 |
| 3 | 2 | 1 |
| 3 | 3 | 2 |

**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 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. The working ranges for the process parameters were selected from the American Welding Society handbook. Based on the designed $L_9$ 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 i.e. Ultimate Tensile Strength and hardness of welded specimens, tensile test were performed using Advanced Universal Testing Machine as shown in Fig.1

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model number; AI UTS-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 table 4.

*Figure.1. Advanced Universal testing machine*

*Figure.2. Failure of the specimens*

*Table4. Experimental design matrix and results*

| Current (Ampere) | Gas Flow Rate (LPM) | Wire Feed Rate (mm/min) | UTS ($N/mm^2$) | Hardness (VHN) |
|---|---|---|---|---|
| 55 | 12 | 110 | 551 | 227.4 |
| 55 | 13 | 115 | 520 | 261.2 |
| 55 | 14 | 120 | 560 | 266.2 |
| 60 | 12 | 115 | 560 | 268.9 |
| 60 | 13 | 120 | 538 | 270.2 |
| 60 | 14 | 110 | 559 | 269.7 |
| 65 | 12 | 120 | 554 | 277.4 |
| 65 | 13 | 110 | 542 | 261.2 |
| 65 | 14 | 115 | 549 | 259.8 |

**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 5 and 6. The response table for both Ultimate Tensile Strength and Hardness are shown in table 7 and 8.

*Table5. ANOVA Table for Ultimate Tensile Strength*

| Source | DOF | SS | MS | F | % Contribution |
|---|---|---|---|---|---|
| A | 2 | 0.158839 | 0.079420 | 52.50 | 87.5 |
| B | 2 | 0.018468 | 0.009234 | 6.10 | 10.17 |
| C | 2 | 0.001192 | 0.01564 | 3.25 | 0.65 |
| Error | 2 | 0.003025 | 0.000596 | - | 1.66 |
| Total | 8 | 0.181526 | - | - | 100 |

*Table6. ANOVA Table for Hardness*

| Source | DOF | SS | MS | F | % Contribution |
|---|---|---|---|---|---|
| A | 2 | 0.02058 | 0.01029 | 2.68 | 5.6 |
| B | 2 | 0.20333 | 0.10167 | 6.70 | 55.8 |
| C | 2 | 0.10988 | 0.05494 | 3.62 | 30.17 |
| Error | 2 | 0.03033 | 0.01516 | - | 8.32 |
| Total | 8 | 0.36412 | - | - | 100 |

*Table7. Response Table for Ultimate Tensile Strength*

| Levels | A | B | C |
|---|---|---|---|
| 1 | 49.91 | 50.10 | 50.10 |
| 2 | 50.13 | 50.03 | 50.07 |
| 3 | 50.23 | 50.14 | 50.09 |
| Delta | 0.32 | 0.11 | 0.03 |
| Rank | 1 | 2 | 3 |

*Table8. Response Table for Hardness*

| Levels | A | B | C |
|---|---|---|---|
| 1 | 48.57 | 48.77 | 48.61 |
| 2 | 48.61 | 48.44 | 48.41 |
| 3 | 48.50 | 48.47 | 48.67 |
| Delta | 0.12 | 0.33 | 0.26 |
| Rank | 3 | 1 | 2 |

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## RESULT AND DISCUSSION

**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 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 first level of wire feed rate (A3B3C1).

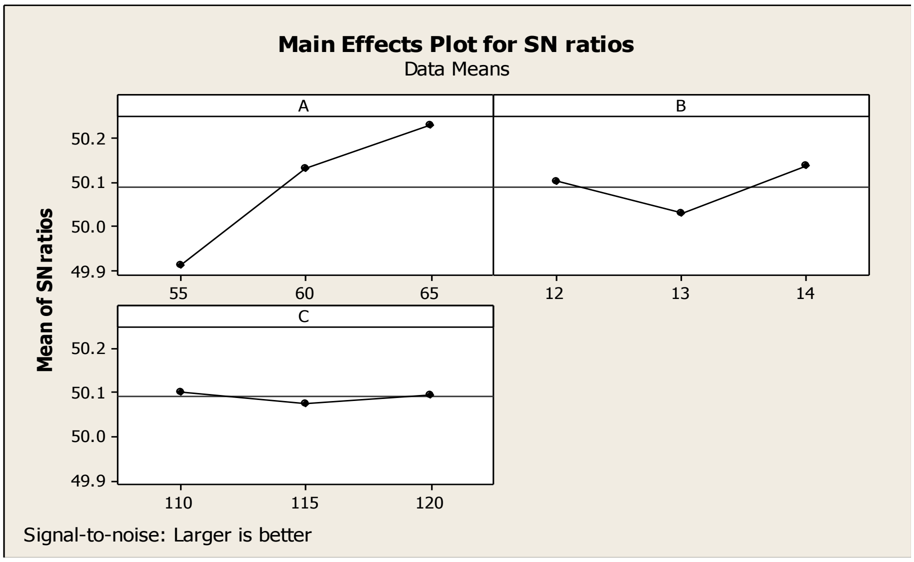


*Figure4. Main Effects Plot for Ultimate Tensile Strength*

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

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 Ultimate Tensile Strength of joint.

**Optimum parameter selection from S/N ratio for Hardness**

Percentage of elongation 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 second level of welding current, first level of gas flow rate and third level of wire feed rate (A2B1C3).

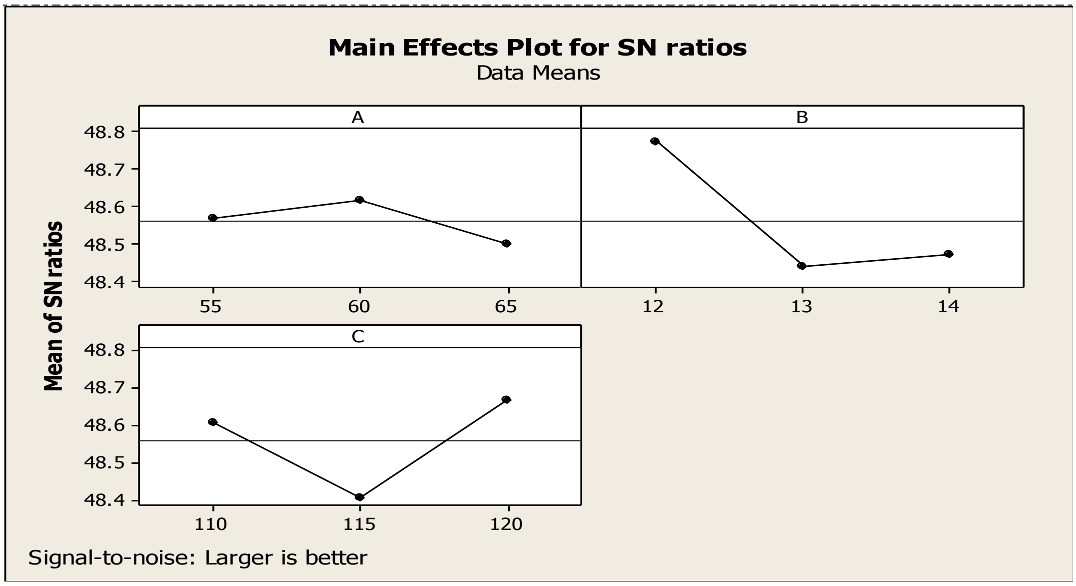


***Figure.5. Main Effects Plot for Hardness***

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

The calculated values of Analysis of variance for hardness 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 gas flow rate is the most contribution factor and the current is the least contribution factor for hardness of the joint.

## VERIFICATION EXPERIMENT

The confirmation run was conducted using same experimental setup by taking optimized parameters for the SS304L pipes considered in this present work. The results obtained from the confirmation runs are tabulated in the below Table 9.

***Table9. Results of Verification Experiment***

| Condition Description | Initial set of parameters | | Optimized welding parameters | |
|---|---|---|---|---|
| | UTS ($N/mm^2$) | Hardness (VHN) | UTS ($N/mm^2$) | Hardness (VHN) |
| Level | A3B1C1 | A2B1C1 | A3B3C1 | A2B1C3 |
| Response obtained | 520 | 268.9 | 564 | 280.6 |

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 SS304L pipes. Ultimate Tensile Strength (UTS) was at 520 $N/mm^2$ for initial settings of parameters and the value has been increased to 564 $N/mm^2$ after setting parameters to optimized values. Similarly, the hardness has been increased from 268.9 VHN to 280.6 VHN.

## 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 UTS is (A3B3C1) i.e. current = 65 Ampere, gas flow rate = 14 LPM and wire feed rate = 110 mm/min ii) optimum condition for maximum hardness is (A2B1C3) i.e. current = 60 Ampere gas flow rate = 12 LPM 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 gas flow rate influences most significantly, followed by current. Conformation experiment was also conducted and verified the effectiveness of the Taguchi optimization method.

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