Optimization of PC-GTAW Orbital Welding Parameters of AISI 304L Stainless Steel Pipe Using ANOVA and Taguchi Method

A S Baskoro, G Kiswanto and A Widyianto

1 Mechanical Engineering Department, Faculty of Engineering Universitas Indonesia, Kampus Baru UI Depok, 16424, Indonesia

* E-mail: ario@eng.ui.ac.id

Abstract. In the present study, the PC-GTAW orbital welding parameters of AISI 304L stainless steel pipe have been optimized by using ANOVA and Taguchi method. The welding method uses Pulsatile Current-GTAW without added material (autogenous). Peak currents were varied in this study and had the same average current of 100 ± 0.5 amperes. The Taguchi method was applied to search for OBW, DoP and UTS that are optimal and L16 Taguchi’s orthogonal array with two factors, four levels and two replications. S/N ratio with a quality character of larger is better (LB) was used to find the maximum value. The results show that raising the peak current would widen the OBW and deepen the DoP but reduce UTS. The 35 parameter was the optimal parameter to produce OBW and DoP while the 100-C parameter was the optimal parameter to produce maximum UTS.

Keyword: Orbital welding, PC-GTAW, Taguchi, AISI 304L

1. Introduction

The pipe is one of the most functional materials as an effective means of transportation such as water, gas, oil, etc. One type of material commonly used is stainless steel. Stainless steel has the characteristics of corrosion resistance at high temperatures and pressures [1]. One of the welding methods used is orbital pipe welding. This welding has disadvantages in the bead width and depth of penetration of welding results due to the influence of the gravitational force. To minimize the effects of gravitational forces can use the pulsating current welding method [2, 3]. Optimization of welding parameters is needed for orbital pipe welding to get the best weld results.

The previous researcher examined that orbital pipe welding is affected by the welding position and welding current [3]. Joseph [4] reported the results of his research on the optimization of GTAW welding parameters pulsating current using simulated annealing and genetic algorithm, that the peak current, base current, welding speed and gas flow rate had an influence on tensile strength and elongation. The Taguchi method can be used to find optimal parameters to improve the tensile strength of S30430 steel plate [5] and API 5L X65 pipes [6]. Ragavendran [7] successfully optimizes hybrid laser welding parameters - TIG uses RSM in 316LN material.

Based on studies that have been carried out that optimization of welding parameters is still needed to improve weld quality. Therefore this paper aims to find the optimal parameters to obtain the best tensile strength in orbital pipe welding. The material used in this study is AISI 304L stainless steel
pipe with pulsatile current welding for the welding method. The optimization method used is the Taguchi method with ANOVA analysis.

2. Experimental Methods

2.1 Material

The material used in this study was AISI 304L stainless steel pipe with outer diameter 114.2 mm and thickness of 3 mm. The optical emission spectrometer (OEM) was used to test the chemical composition of AISI 304L stainless steel pipe and the chemical composition was listed in Table 1. Before welding, the surfaces of all specimens were cleaned by 80 until 400 grit flexible sandpapers. After that, it was cleaned with acetone solution to remove surface impurities.

2.2 Experimental design and optimization

The welding method used in this study were without filler metal (autogenous) and using orbital pipe welding. A GeKaMac power TIG 2200 DC pulsatile welding machine was used in this study with 1 phase input voltage, 230 V, 50-60 Hz and current range 5-220 A. The top weld zone was shielded by high purity argon (99.99%) gas with a flow rate of 11 L/min. A tungsten electrode was used EWTh-2 with a red code AWS with diameter 2.4 mm and sharpening angle of 30°. The welding speed was set constant 1.40 mm/s. The welding parameters and the process parameters that were used in this study were shown in Table 2 and Table 3, respectively.

Table 1. Chemical composition (wt %) of AISI 304L pipe

| AISI 304L | C    | Si   | Mn   | P     | S     | Cr   | Mo   |
|-----------|------|------|------|-------|-------|------|------|
|           | 0.026| 0.400| 1.44 | 0.037 | 0.011 | 19.5 | 0.118|

| Ni       | Al   | Cu   | Nb   | Ti    | V    | Fe   |
|----------|------|------|------|-------|------|------|
| 8.26     | 0.006| 0.096| 0.018| 0.002 | 0.078| bal. |

Table 2. Pulsatile current GTAW parameters

| No | Code | Peak current (A) | Base current (A) | Peak time (ms) | Base time (ms) | Frequency (Hz) | Duty cycle (%) | Mean current (A) | Welding speed (mm/s) |
|----|------|------------------|------------------|----------------|----------------|----------------|----------------|-------------------|---------------------|
| 1  | 35-C | 212              | 40               | 70             | 130            | 5              | 35             | 100.2             | 1.4                 |
| 2  | 50-C | 160              | 40               | 100            | 100            | 5              | 50             | 100               | 1.4                 |
| 3  | 65-C | 133              | 40               | 130            | 70             | 5              | 65             | 100.45            | 1.4                 |
| 4  | 100-C| 100              | 100              | 100            | 100            | 5              | 100            | 100               | 1.4                 |

Table 3. Process parameters at four level

| No | Parameters       | Level 1 | Level 2 | Level 3 | Level 4 |
|----|------------------|---------|---------|---------|---------|
| 1  | Welding current | 35-C    | 50-C    | 65-C    | 100-C   |
| 2  | Welding position| 0       | 90      | 180     | 270     |

A pulsatile current GTAW (PC-GTAW) method was adopted, with variations of peak currents, base currents and duty cycles. In pulsatile currents GTAW has the same mean current of 100 ± 0.5 Amperes and the average excitation voltage during the welding process was between 12–13 volts. Furthermore, the heat input calculation was received by the material in pulsatile current welding. Heat input in the pulsatile current GTAW can be calculated from the mean current. Control of heat input can be made with adjustments peak current, base current and duty cycle [8]. Figure 1 shows the
welding results on the welded pipe surface using one of the pulsed welding parameters. The pipe was cut into four parts then OBW was seen visually after that measurements were made using a digital microscope. For DoP measurements, it has been prepared macrostructure previously. While for tensile testing carried out by ASTM E-8M standard.

![Figure 1. The weld surface profile of pipe](image)

The Taguchi technique was applied to conduct the optimization of PC-GTAW parameters. The experimental procedure included the design of experiment, materials, and welding parameters. The Taguchi method can study data with minimum experimental runs. Based on the Taguchi method, \((L_{16})\) orthogonal arrays with four levels, two factors, and two replications were employed as presented in Table 4.

| Experiment number | Process parameters | OBW (mm) | DoP (mm) | UTS (MPa) |
|-------------------|--------------------|----------|----------|-----------|
|                   | Welding current    | Welding position | Rep. I | Rep. II | Rep. I | Rep. II | Rep. I | Rep. II |
| 1                 | 35-C               | 0         | 7.76     | 7.46     | 0.91   | 1.25    | 613.24  | 647.86  |
| 2                 | 35-C               | 90        | 7.44     | 8.01     | 1.15   | 1.18    | 678.41  | 648.32  |
| 3                 | 35-C               | 180       | 7.63     | 8.20     | 0.56   | 0.85    | 684.34  | 667.43  |
| 4                 | 35-C               | 270       | 7.42     | 7.93     | 0.84   | 0.54    | 496.83  | 545.34  |
| 5                 | 50-C               | 0         | 6.44     | 6.64     | 0.31   | 0.17    | 653.61  | 620.47  |
| 6                 | 50-C               | 90        | 6.79     | 7.56     | 1.28   | 0.57    | 593.88  | 604.56  |
| 7                 | 50-C               | 180       | 7.11     | 7.42     | 0.59   | 0.79    | 613.51  | 647.24  |
| 8                 | 50-C               | 270       | 8.32     | 7.23     | 0.07   | 0.05    | 626.80  | 640.89  |
| 9                 | 65-C               | 0         | 7.24     | 7.39     | 0.37   | 0.24    | 611.66  | 645.67  |
| 10                | 65-C               | 90        | 6.97     | 5.92     | 0.11   | 0.19    | 602.33  | 656.24  |
| 11                | 65-C               | 180       | 6.53     | 6.55     | 0.07   | 0.19    | 664.78  | 638.57  |
| 12                | 65-C               | 270       | 6.49     | 6.87     | 0.11   | 0.23    | 670.67  | 659.86  |
| 13                | 100-C              | 0         | 6.65     | 7.32     | 0.38   | 0.10    | 637.27  | 715.22  |
| 14                | 100-C              | 90        | 8.15     | 6.91     | 0.28   | 0.15    | 683.08  | 655.55  |
| 15                | 100-C              | 180       | 6.02     | 6.32     | 0.04   | 0.08    | 636.35  | 649.43  |
| 16                | 100-C              | 270       | 6.89     | 6.59     | 0.17   | 0.10    | 659.81  | 663.50  |
Taguchi uses a signal-to-noise (S/N) ratio to find the optimal value (maximum and minimum) of several factors used. The S/N ratio depends on several types of quality characteristics, it consists of 4 types defined as smaller is better (SB), nominal is best (NB), larger is better (LB), and fraction defective (FD) [9, 10]. In this study, to search the maximum value of OBW, DoP and UTS using the larger is better method. The S/N ration for LB can be calculated using the following Equation [6].

\[
\frac{S}{N} \text{ ratio} = -10\log \left( \frac{1}{n} \sum_{i=1}^{n} \frac{1}{y_i^2} \right)
\]  

(1)

In additional, ANOVA was applied to determine the significance of each input parameters against the response parameters.

3. Results and Discussion

3.1. Analysis of outer bead width (OBW)

The ANOVA analysis for OBW was shown in Table 5. Welding currents have a very high contribution to the formation of OBW by 93.54% while the welding position only contributes of 6.46%. This is confirmed by the result of the response from OBW as shown in Table 6. Increasing the peak current in welding with pulsatile currents can widen the OBW while the welding position has little effect on the OBW.

| Source          | DF | Sum of squares | Mean of squares | F-value | p-value | P.C. |
|-----------------|----|----------------|-----------------|---------|---------|------|
| Welding position| 3  | 0.1626         | 0.05419         | 0.23    | 0.870   | 6.46 |
| Welding current | 3  | 2.3525         | 0.78416         | 3.40    | 0.067   | 93.54|
| Error           | 9  | 2.0758         | 0.23064         |         |         |      |
| Total           | 15 | 4.5908         |                 |         |         |      |

Table 5. ANOVA analysis for outer bead width

3.2. Analysis of depth of penetration (DoP)

The ANOVA analysis for DoP was shown in Table 7. Welding currents have a significant contribution to the formation of DoP by 85.04% while the welding position only contributes of 14.96%. This is confirmed by the result of the response from DoP as shown in Table 6. DoP in orbital pipe welding is strongly influenced by welding current other than the effect of the welding position and the gravitational force.
### Table 7. ANOVA analysis for depth of penetration

| Source            | DF | Sum of squares | Mean of squares | F-value | p-value | P.C. |
|-------------------|----|----------------|-----------------|---------|---------|------|
| Welding position  | 3  | 0.2550         | 0.08501         | 1.72    | 0.232   | 14.96|
| Welding current   | 3  | 1.4497         | 0.48325         | 9.79    | 0.003   | 85.04|
| Error             | 9  | 0.4443         | 0.04937         |         |         |      |
| Total             | 15 | 2.1491         |                 |         |         |      |

#### 3.3. Analysis of ultimate tensile strength (UTS)

The ANOVA analysis for UTS was shown in Table 8. The welding position and welding current have a contribution of 32.05% and 67.95%, respectively to UTS. The welding current still has a higher contribution than the welding position as shown in Table 6. Increasing the peak current in welding with pulsatile currents has little effect on UTS.

### Table 8. ANOVA analysis for ultimate tensile strength

| Source            | DF | Sum of squares | Mean of squares | F-value | p-value | P.C. |
|-------------------|----|----------------|-----------------|---------|---------|------|
| Welding position  | 3  | 1948           | 649.3           | 0.38    | 0.771   | 32.05|
| Welding current   | 3  | 4130           | 1376.7          | 0.80    | 0.523   | 67.95|
| Error             | 9  | 15421          | 1713.5          |         |         |      |
| Total             | 15 | 21499          |                 |         |         |      |

![Main Effect Plot](image1.png)

*Figure 2. Main effect plot for SN ratios of (a) OBW, (b) DoP and (c) UTS*
Main effects SN ratio of OBW, DoP and UTS were plot in Figure 2a-c. Raising the peak current in welding with pulsatile current can increasing the OBW and DoP but decreasing the UTS. In parameter 35-C has the maximum OBW and DoP but produces the smallest UTS. The 35-C parameter produces optimal OBW and DoP with welding positions 270° and 90°, respectively. The optimal parameter for producing maximum UTS was 100-C as welding current and 180° as a welding position with sufficient OBW and DoP.

4. Conclusions

In general, raising the peak current in pulsatile currents welding would increase OBW and DoP for several welding positions, but conversely the resulting UTS would decrease. Indirectly OBW and DoP have a correlation to the UTS produced even though there were other factors that influence it. In parameter 35-C has the maximum OBW and DoP with welding position at 270° and 90°, respectively but produces the smallest UTS. While the 100-C parameter and welding position at 180° produces the most maximum UTS with the appropriate OBW and DoP. The welding current has a large contribution of 65% - 95% while the welding position only contributes 6% - 35% to get the maximum OBW, DoP and UTS.

Acknowledgments

This research is supported by the Master Program to Doctorate for Scholar Excellent (PMDSU) program of the Ministry of Research & Technology and High Education (RISTEK DIKTI) 2019 with contract number NKB-1855/UN2.R3.1/HKP.05.00/2019.

References

[1] J. Xu, J. Chen, Y. Duan, C. Yu, J. Chen, and H. Lu, "Comparison of residual stress induced by TIG and LBW in girth weld of AISI 304 stainless steel pipes," Journal of Materials Processing Technology. 248 pp. 178-184, 2017.
[2] H. Eisazadeh, D. J. Haines, and M. Torabizadeh, "Effects of gravity on mechanical properties of GTA welded joints," Journal of Materials Processing Technology. 214 (5) pp. 1136-1142, 2014.
[3] D. W. Figueirôa, I. O. Figozzo, R. H. G. e. Silva, T. F. d. A. Santos, and S. L. Urtiga Filho, "Influence of welding position and parameters in orbital tig welding applied to low-carbon steel pipes," Welding international. 31 (8) pp. 583-590, 2017.
[4] J. Joseph and S. Muthukumaran, "Optimization of pulsed current GTAW process parameters for sintered hot forged AISI 4135 P/M steel welds by simulated annealing and genetic algorithm," Journal of Mechanical Science and Technology. 30 (1) pp. 145-155, 2016.
[5] A. Ahmad and S. Alam, "Grey Based Taguchi Method for Optimization of TIG Process Parameter in Improving Tensile Strength of S30430 Stainless Steel," in IOP Conference Series: Materials Science and Engineering, 2018, vol. 404, no. 1, p. 012003: IOP Publishing.
[6] H. Ada and C. Çetinkaya, "Optimization of maximum tensile strength of welded joints of API 5L X65 pipes by Taguchi method," Materials Research Express. 6 (3) p. 036526, 2018.
[7] M. Ragavendran, N. Chandrasekhar, R. Ravikumar, R. Saxena, M. Vasudevan, and A. Bhaduri, "Optimization of hybrid laser–TIG welding of 316LN steel using response surface methodology (RSM)," Optics and Lasers in Engineering. 94 pp. 27-36, 2017.
[8] T. S. Kumar, V. Balasubramanian, and M. Sanavullah, "Influences of pulsed current tungsten inert gas welding parameters on the tensile properties of AA 6061 aluminium alloy," Materials & design. 28 (7) pp. 2080-2092, 2007.
[9] S. Pandiarajan, S. S. Kumaran, L. Kumaraswamidhas, and R. Saravanan, "Interfacial microstructure and optimization of friction welding by Taguchi and ANOVA method on SA 213 tube to SA 387 tube plate without backing block using an external tool," Journal of Alloys and Compounds. 654 pp. 534-545, 2016.
[10] K. Krishnaiah and P. Shahabudeen, Applied design of experiments and Taguchi methods. PHI Learning Pvt. Ltd., 2012.