Study on Weld Quality Characteristics of Micro Plasma Arc Welded Austenitic Stainless Steels

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Abstract

Micro Plasma Arc Welding (MPAW) is one of the important arc welding process commonly using in sheet metal industry for manufacturing metal bellows, metal diaphragms etc. The paper focuses on weld quality characteristics like weld bead geometry, grain size, hardness and ultimate tensile strength of MPAW welded joints of various austenitic stainless steels namely AISI 316L, AISI 316Ti, and AISI 321. From the analysis carried out it is noticed that for the same thickness of work piece material and same welding conditions, AISI 304L has achieved sound weld bead geometry, highest tensile strength and hardness. However it is noticed that AISI 316L has attained lowest tensile strength, AISI 321 has lowest hardness and grain size.

Keywords: Micro Plasma Arc Welding,;Austenitic Stainless steel; Weld bead geometry; grain size; hardness; tensile strength

1. Introduction

Austenitic stainless steels have excellent strength and good ductility at high temperature. Typical applications include aero-engine hot section components, miscellaneous hardware, tooling and liquid rocket components involving cryogenic temperature. They can be joined using variety of welding methods, including Gas Tungsten Arc Welding (GTAW), Plasma Arc Welding (PAW), Laser Beam Welding (LBW) and Electron Beam Welding (EBW). Of these methods, low current PAW (Micro PAW) has attracted particular attention and has been used extensively for the fabrication of metal bellows, diaphragms which require high strength and toughness. PAW welding...
is conveniently carried out using one of two different current modes, namely a Continuous Current (CC) mode or a Pulsed Current (PC) mode.

Pulsed current MPAW involves cycling the welding current at selected regular frequency. The maximum current is selected to give adequate penetration and bead contour, while the minimum is set at a level sufficient to maintain a stable arc [1,2]. This permits arc energy to be used effectively to fuse a spot of controlled dimensions in a short time producing the weld as a series of overlapping nuggets. By contrast, in constant current welding, the heat required to melt the base material is supplied only during the peak current pulses allowing the heat to dissipate into the base material leading to narrower Heat Affected Zone (HAZ). Advantages include improved bead contours, greater tolerance to heat sink variations, lower heat input requirements, reduced residual stresses and distortion, refinement of fusion zone microstructure and reduced width of HAZ. Based on the worked published [3-8], four independent parameters that influence the process are peak current, back current, pulse rate and pulse width.

| Nomenclature                        |
|-------------------------------------|
| AISI                                | American Iron and Steel Institute |
| DCEN                                | Direct Current Electrode Negative |
| ASTM                                | American Standard of Testing of Metals |
| MPAW                                | Micro Plasma Arc Welding           |
| VHN                                 | Vickers Hardness Number            |

2. Experimental Procedure

Austenitic stainless steel sheets (AISI 304L, AISI 316L, AISI 316Ti, AISI 321) of 100 x 150 x 0.25 mm are welded autogenously with square butt joint without edge preparation. High purity argon gas (99.99%) is used as a shielding gas and a trailing gas right after welding to prevent absorption of oxygen and nitrogen from the atmosphere. The welding has been carried out under the welding conditions presented in Table 1. From the literature four important factors of pulsed current MPAW as presented in Table 2 are chosen.

Welding was carried out on AISI 304L, AISI 316L, AISI 316Ti, AISI 321 sheets. The values of process parameters used in this study are the optimal values obtained from our earlier papers [5]. Hence peak current, base current, pulse rate and pulse width are chosen and their values are presented in Table 2.

| Table 1 Welding conditions          |
|-------------------------------------|
| Power source                        | Secheron Micro Plasma Arc Machine |
| Model Number                        | PLASMAFIX 50E                     |
| Polarity                            | DCEN                              |
| Mode of operation                   | Pulse mode                        |
| Electrode                           | 2% thoriated tungsten electrode    |
| Electrode Diameter                  | 1mm                               |
| Plasma gas                          | Argon & Hydrogen                  |
| Plasma flow rate                    | 6 Lpm                             |
| Shielding gas                       | Argon                             |
| Shielding flow rate                 | 0.4 Lpm                           |
| Purging gas                         | Argon                             |
| Purging flow rate                   | 0.4 Lpm                           |
| Copper Nozzle diameter              | 1mm                               |
| Nozzle to plate distance            | Vertical                          |
| Welding speed                       | 260mm/min                         |
| Torch Position                      | Automatic                         |
| Operation type                      |                                   |
Table 2  Important weld parameters for welding stainless steels

| Serial No. | Input Factor  | Units         | Value |
|------------|---------------|---------------|-------|
| 1          | Peak Current  | Amperes       | 7     |
| 2          | Base Current  | Amperes       | 4     |
| 3          | Pulse rate    | Pulses/second | 40    |
| 4          | Pulse width   | %             | 50    |

3. Measurement of Weld Quality Characteristics

3.1 Measurement of Weld Bead Geometry

Sample preparation and mounting was done as per ASTM E 3-1 standard. The samples were cut from the welded specimens and mounting using Bakelite powder. After standard metallurgical polishing process, Oxalic acid is used as the etchant to reveal weld bead geometry. The weld pool geometries were measured using Metallurgical Microscope, Make: Dewinter Technologie, Model No. DMI-CROWN-II. The measured values of weld bead geometry at 100X magnification are presented in Table 4. Figures 1a, 1b, 1c, 1d indicate welded joint of AISI 304L, AISI 316L, AISI 316Ti, AISI 321 respectively.

3.2 Measurement of Fusion Zone Grain Size

In order to reveal the grains, polishing was done according to standard Metallurgical procedure and Etching was done as per ASTM E407. Electrolytic was done using Nitric Acid for about 1 minute. Scanning Electron Microscope, Make: INCA Penta FETx3, Model: 7573 is used to measure the fusion zone grain size and parent...
metal. Figures 2a, 2b, 2c, 2d indicate the fusion zone grain size at welding speeds of AISI 304L, AISI 316L, AISI 316Ti, AISI 321 respectively. As the grains in some parts of the weld fusion zone are elongated, an average value was reported by measuring grain size at different locations in the fusion zone of each sample.

![Figure 2a. Grain size of AISI 304L.](image)

![Figure 2b. Grain size of AISI 316L.](image)

![Figure 2c. Grain size of AISI 316Ti.](image)

![Figure 2d. Grain size of AISI 321.](image)

3.3 Measurement of Hardness

Vickers Micro hardness was done as per ASTM E384. The samples were cut from the welded specimens and Vickers Micro Hardness values across the weld joint at an interval of 0.3 mm using Digital Micro Hardness testing Machine, make METSUZAWA CO LTD, JAPAN, Model No: MMT-X7 and the values obtained are presented in Table 3. The variation of hardness values across the weld joint is shown in Figure 3.

| Material  | Hardness values at different locations on the weld joint in VHN | HAZ zone |
|-----------|---------------------------------------------------------------|----------|
|           | HAZ zone | Fusion zone | HAZ zone |
| AISI 304L |          |             |          |
| AISI 316L | 203.9 | 216.9 | 216 | 200.6 | 202.5 | 206.8 | 213.4 | 206.3 | 193.9 |
| AISI 316Ti | 174.2 | 169.1 | 191.4 | 175.4 | 191.7 | 188.2 | 179.2 | 169.6 | 158.6 |
| AISI 321  | 174.9 | 186.7 | 176 | 180.5 | 179.5 | 195.4 | 182 | 184.2 | 182.4 |

Table 3 Variation of hardness values across the weld for various steels
From Table 3 and Figure 3, it is understood that hardness at the center of the fusion zone is lower and it keeps on increasing away from the center and decreases towards HAZ.

3.4 Measurement of ultimate tensile strength

Three transverse tensile specimens are prepared as per ASTM E8M-04 guidelines and the specimens after wire cut Electro Discharge Machining. Tensile tests are carried out in a 100kN computer controlled Universal Testing Machine (ZENON, Model No: WDW-100). The specimen is loaded at a rate of 1.5kN/min as per ASTM specifications, so that the tensile specimens undergo deformation. From the stress-strain curve, the yield and ultimate tensile strength of the weld joints is evaluated and the average of three results is presented in Table 4.

The results of all the weld quality characteristics discussed in sections 3.1 to 3.4 on the welded samples of AISI 304L, AISI 316L, AISI 316Ti, AISI 321 are summarized and presented in Table 4.

| Material   | Weld bead Geometry | Fusion Zone grain size (Microns) | Fusion Zone hardness (VHN) | Ultimate Strength (MPa) |
|------------|--------------------|----------------------------------|-----------------------------|-------------------------|
|            | Front Width (mm)   |                                  |                             |                         |
|            | Back Width (mm)    |                                  |                             |                         |
|            | Front Height (mm)  |                                  |                             |                         |
|            | Back Height (mm)   |                                  |                             |                         |
| AISI 304L  | 1.509              | 0.060                            | 30.861                      | 207.86                  | 657                     |
| AISI 316L  | 1.408              | 0.052                            | 32.687                      | 185.18                  | 526                     |
| AISI 316Ti | 1.225              | 0.048                            | 27.862                      | 182.68                  | 594                     |
| AISI 321   | 1.134              | 0.046                            | 23.862                      | 170.98                  | 582                     |

From Table 4, it is understood that AISI 304L has good strength and hardness compared to other steel like AISI 316L, AISI 316Ti, and AISI 321. The variation of grain size, hardness and tensile strength is shown in Figure 4. AISI 304L has the highest hardness and tensile strength; however, the grain size of AISI 321 is the smallest among the other samples.
5 Conclusions

Pulsed current MPAW was carried out successfully on various austenitic stainless steels like AISI 304L, AISI 316L, AISI 316Ti, and AISI 321. From the analysis of the weld quality characteristics, it is revealed that for the same thickness and same welding parameters, AISI 304L has achieved sound weld bead geometry, highest tensile strength and hardness. However it is noticed that AISI 316L has attained lowest tensile strength, AISI 321 has lowest hardness and grain size.

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