

Available online at www.sciencedirect.com**ScienceDirect**

Procedia Engineering 97 (2014) 752 – 757

**Procedia
Engineering**www.elsevier.com/locate/procedia

12th GLOBAL CONGRESS ON MANUFACTURING AND MANAGEMENT, GCMM 2014

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

Kondapalli Siva Prasad^{a*}, Chalamalasetti Srinivasa Rao^b, Damera Nageswara Rao^c^{a*}*Anil Neerukonda Institute of Technology & Sciences, Visakhapatnam, INDIA*^b*U College of Engineering, Andhra University, Visakhapatnam, INDIA*^c*Centurion University of Technology & Management, Odisha, INDIA*

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.

© 2014 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/3.0/>).

Selection and peer-review under responsibility of the Organizing Committee of GCMM 2014

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

* Corresponding author. Tel.: 91-9849212391

E-mail address: kspanits@gmail.com

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

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 Insitutute
DCEN	Direct Current Electrode Negative
ASTM	American Standrad 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 gas flow rate	6 Lpm
Shielding gas	Argon
Shielding gas flow rate	0.4 Lpm
Purging gas	Argon
Purging gas flow rate	0.4 Lpm
Copper Nozzle diameter	1mm
Nozzle to plate distance	1mm
Welding speed	260mm/min
Torch Position	Vertical
Operation type	Automatic

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.

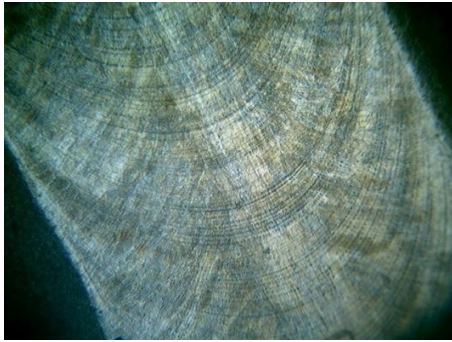


Figure 1a. Weld bead of AISI 304L.

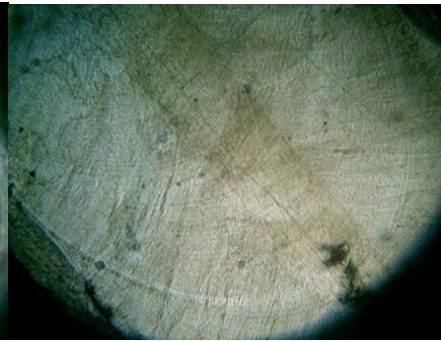


Figure 1b. Weld bead of AISI 316L.



Figure 1c. Weld bead of AISI 316Ti.

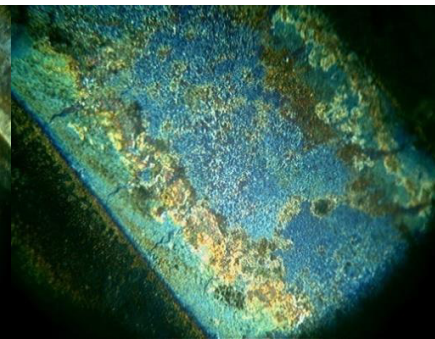


Figure 1d. Weld bead of AISI 321.

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.

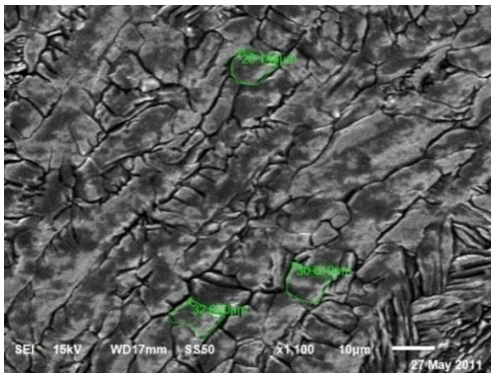


Figure 2a. Grain size of AISI 304L.

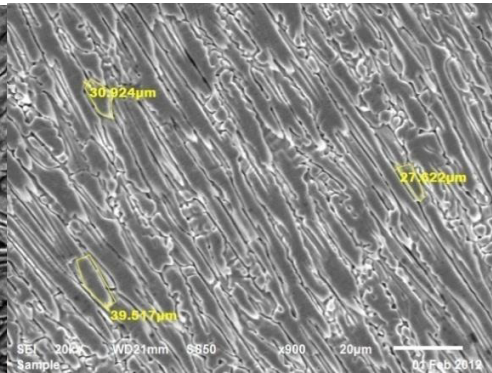


Figure 2b. Grain size of AISI 316L.

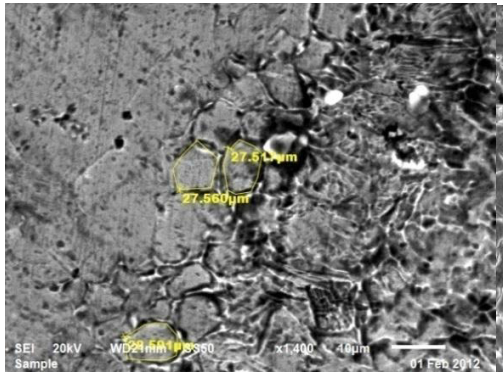


Figure 2c. Grain size of AISI 316Ti.

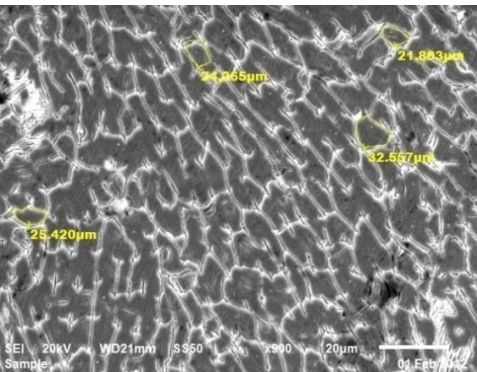


Figure 2d. Grain size of AISI 321.

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.

Table 3 Variation of hardness values across the weld for various steels

Material	Hardness values at different locations on the weld joint in VHN								
	HAZ zone		Fusion zone					HAZ zone	
	1	2	3	4	5	6	7	8	9
AISI 304L	203.9	216.9	216	200.6	202.5	206.8	213.4	206.3	193.9
AISI 316L	174.2	169.1	191.4	175.4	191.7	188.2	179.2	169.6	158.6
AISI 316Ti	174.9	186.7	176	180.5	179.5	195.4	182	184.2	182.4
AISI 321	171.3	178.8	171.7	172.1	165.5	176.5	169.1	174.5	167.8

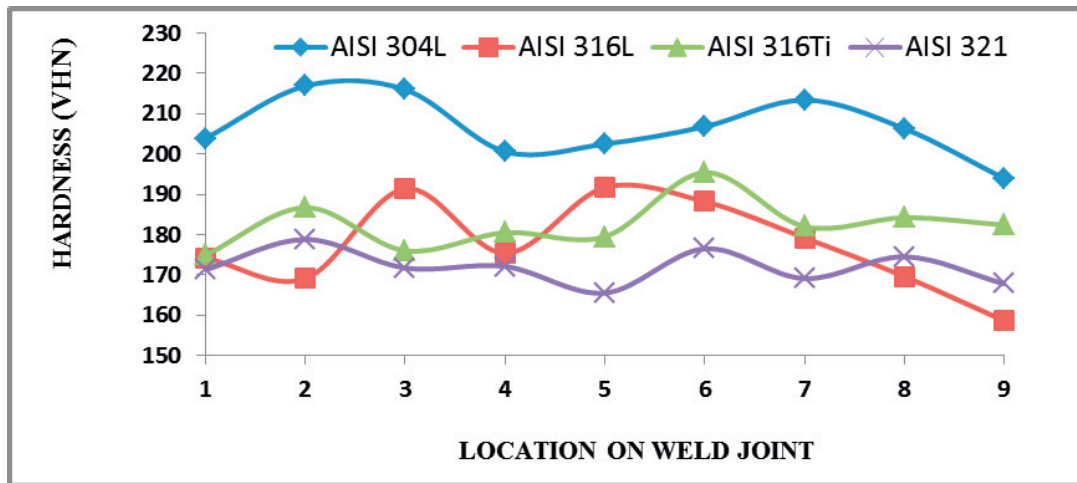


Figure 3. Variation of hardness across the weld for various steels.

From Table 3 and Figure 3, it is understood that hardness at the centre of the fusion zone is less and it increases away from the centre and decreases towards the HAZ.

3.4 Measurement of ultimate tensile strength

Three transverse tensile specimens are prepared as per ASTM E8M-04 guidelines and the specimens are wire cut Electro Discharge Machined. 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.

Table 4 Comparison of weld quality characteristics for various steels

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	1.439	0.060	0.047	30.861	207.86	657
AISI 316L	1.408	1.342	0.052	0.044	32.687	185.18	526
AISI 316 Ti	1.225	1.084	0.048	0.038	27.862	182.68	594
AISI 321	1.134	0.966	0.046	0.036	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.

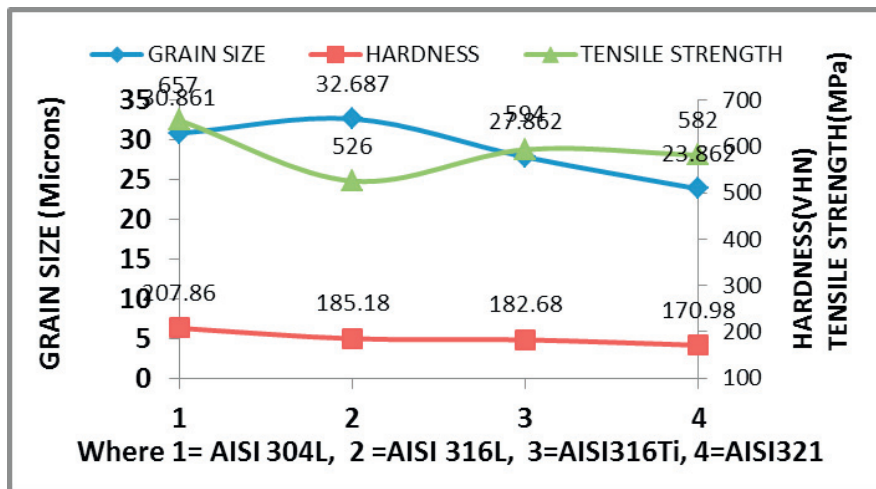


Figure.4. Variation of mechanical properties for various steels.

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.

References

- [1] Balasubramanian.M, Jayabalan.V, Balasubramanian.V, (2010),Effect of process parameters of pulsed current tungsten inert gas welding on weld pool geometry of titanium welds, *ActaMetall.Sin.(Engl. Lett.)*, 23(4), 312-320.
- [2] Balasubramanian.B, Jayabalan.V, Balasubramanian.V,(2006), Optimizing the Pulsed Current Gas Tungsten Arc Welding Parameters, *J Mater SciTechnol*, 22(6), 821-825.
- [3]Kondapalli Siva Prasad , Ch.SrinivasaRao, D.NageswaraRao , (2011),Prediction of Weld Pool Geometry in Pulsed Current Micro Plasma Arc Welding of SS304L Stainless Steel Sheets ,*International Transaction Journal of Engineering, Management & Applied Sciences & Technologies*, 2(3),325-336.
- [4]Kondapalli Siva Prasad, Ch.SrinivasaRao, D.NageswaraRao, (2011), A Study on Weld Quality Characteristics of Pulsed Current Micro Plasma Arc Welding of SS304L Sheets, *International Transaction Journal of Engineering, Management & Applied Sciences & Technologies*, 2(4), 437-446.
- [5]Kondapalli Siva Prasad, Ch.SrinivasaRao, D.NageswaraRao, (2011),Optimizing Pulsed Current Micro Plasma Arc Welding Parameters to Maximize Ultimate Tensile Strength of SS304L Sheets Using Hooke and Jeeves Algorithm, *Journal of Manufacturing Science & Production (DyGuter)*, 11(1-3),39-48.
- [6] Kondapalli Siva Prasad, Ch.SrinivasaRao, D.NageswaraRao, (2012), Effect of Process Parameters of Pulsed Current Micro Plasma Arc Welding on Weld Pool Geometry of AISI 304L Stainless Steel Sheets, *Journal of Materials & Metallurgical Engineering*, 2(1), 37-48.
- [7]Kondapalli Siva Prasad, Ch.SrinivasaRao, D.NageswaraRao,(2012), Establishing Empirical Relations to Predict Grain Size and Hardness of Pulsed Current Micro Plasma Arc Welded SS 304L Sheets, *American Transactions on Engineering & Applied Sciences*, 1(1), 57-74.
- [8]Kondapalli Siva Prasad, Ch.SrinivasaRao, D.NageswaraRao, (2012), Effect of pulsed current micro plasma arc welding process parameters on fusion zone grain size and ultimate tensile strength of SS304L sheets, *International Journal of Lean Thinking*, 3(1), 107-118.