A Study on Comparison of Weld Quality Characteristics of Various Austenitic Stainless Steels

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Abstract: **Austenitic stainless steels have gathered wide acceptance in the fabrication of corrosion resistance components like metal bellows, diaphragms. The use of pulsed current has been found to improve the mechanical properties of the welds compared to continuous current. The present work discusses about the effect of pulsed current micro plasma arc welding process parameters on weld quality characteristics of various austenitic stainless steels namely AISI 304L, AISI 316L, AISI 316Ti, AISI 321. During the study peak current, back current, pulse rate and pulse width are chosen as the main welding process parameters influencing the weld quality characteristics like weld pool geometry, microstructure, grain size, hardness and tensile properties. Results reveal that out of all the materials considered in the study AISI 304L attains better weld quality characteristics.**

Key Words: **Pulsed current micro plasma arc welding, microstructure, grain size, hardness, tensile properties.**

1. INTRODUCTION

1.1 Stainless Steels

Around the turn of the twentieth century it was discovered that by adding at least 12% chromium by weight steels become more corrosion resistant than common carbon steels. The addition of chromium caused the spontaneous formation of a passive protective layer, which reduced the rate of surface dissolution [1]. As the science of metallurgy progressed, it was found that by further alloying steels with elements such as nickel, molybdenum, copper, titanium, aluminum, silicone, niobium, nitrogen, sulfur and selenium, other desirable properties could be selectively created. While stainless steels are generally defined as an iron alloy containing a minimum of 12 wt. % chromium, they may be further categorized into several sub-categories. These categories are martensitic, ferritic, duplex, precipitation hardenable and austenitic.

1.1.1 Austenitic Stainless Steels

Austenitic stainless steels are probably the most commonly used material of all the stainless steels. The most common austenitic family, the 300 series, is an iron-chromenickel system. Austenitic stainless steels are considered to be more resistant to corrosion due to the high wt. % chromium and nickel content (18-20 and 8-12 respectively). They are non magnetic and nonhardenable by heat treatment. However, they can be hardened significantly by cold working.

Austenitic stainless steels are used extensively in petrochemical, nuclear, and corrosive chemical environments [2-4] Austenitic stainless steels are further defined by the carbon content as; “L” grades, straight grades and “H” grades. The L grades contain ≤ 0.03 wt. % C, the straight grades contain 0.03-0.08 wt. % C and the H grades contain anywhere from 0.04-0.10 wt. % C. The higher carbon content of the H grades produces a harder and more wear resistant material. The increased carbon also helps the material hold its strength at high temperatures and is therefore often used in high temperature applications. However, the increase in carbon leads to problems in the Heat Affected Zone (HAZ) of the welds and is discussed in the proceeding section. The lower carbon content of the “L” grades is specifically designed for improved weldability. High carbon grades are often employed where harder, wear resistant, or high temperature applications exist. Low carbon stainless steels such as 304L, 316L are routinely used where intergranular corrosion is of concern.

1.1.2 Welding Austenitic Stainless Steels

Primilarily Arc welding has long been considered as a viable process for joining ferrous materials; austenitic stainless steels are no exception. Inherent in the arc welding process however, are certain problems, which keep it from being an “ideal” process. Typically in all arc welding processes, problems such as chemical inhomogeneites in the weld, microporosity, cold laps, microfissures, and hot cracks reduce the quality of the joint [5]. Austenitic stainless steels are particularly prone to the hot cracking phenomenon. It has been determined however, that hot cracking may be reduced in austenitic stainless steel weldments by using filler materials that contain a small percentage of retained ferrite [1,4,6]. Although appropriate filler materials have been developed, problems still arise especially in the root of weldments, where the filler material may be diluted by the high amount of austenite in the parent material. Furthermore, the slower cooling rate at the root with respect to the rest of the weld nugget reduces the amount of retained ferrite and increases the likelihood of hot cracking [4,6].

While filler materials are able to compensate for undesired changes in the microstructure of the solidified region, they cannot prevent the microstructural changes in the HAZ. When steel is held at critical temperature range (600-800 ° C) chromium precipitates out of the matrix and forms chrome carbides along the grain boundaries. The formation of chrome carbides produces a chemical inhomogeneity in the surrounding grains; they become depleted in chromium with respect to the base material. When these precipitates cause the surrounding areas to have less than about 13 wt. % chromium, the areas become susceptible to corrosion. Keeping the carbon content low reduces this problem by reducing the amount of chromium being precipitated along the grain boundaries.

The present paper focuses on comparing the of weld quality characteristics of various austenitic stainless steels like AISI 304L, AISI 316L, AISI 316Ti and AISI 321 welded using pulsed current micro plasma arc welding process.

2. EXPEIMENTAL DETAILS

Austenitic stainless steels (AISI 304L, AISI 316L, AISI 316Ti, AISI 321) sheets of 100 x 150 x 0.25mm are welded autogenously with square butt joint without edge preparation. The chemical compositions and tensile properties of AISI 304L, AISI 316L, AISI 316Ti, AISI 321 austenitic stainless steel sheets is given in Table 1. 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 2. There are many influential process parameters which effect the weld quality characteristics of Pulsed Current MPAW process like peak current, back current, pulse rate, pulse width, flow rate of shielding gas, flow rate of purging gas, flow rate of plasma gas, welding speed etc. From the earlier works [7-13] carried out on Pulsed Current MPAW it was understood that the peak current, back current, pulse rate and pulse width are the dominating parameters which effect the weld quality characteristics. The values of process parameters used in this study are the optimal values obtained from our earlier papers [9-13]. Hence peak current, back current, pulse rate and pulse width are chosen and their values are presented in Table.3.

Table 1a Chemical composition of AISI 304L, AISI 316L, AISI 316Ti, AISI 321 (weight %)

Material	C	Si	Mn	P	S	Cr	Ni	Mo	Ti	N
AISI 304L	0.025	0.361	1.319	0.031	0.003	18.13	8.038	--	--	0.067
AISI 316L	0.04	0.52	1.61	0.029	0.007	17.02	12.48	2.04	--	--
AISI 316Ti	0.04	0.43	1.69	.026	0.002	16.5	10.6	2.12	0.41	0.012
AISI 321	0.02	0.35	1.60	0.031	0.014	17.42	9.25	--	0.32	0.02

Table 1bTensile properties of AISI 304L, AISI 316L, AISI 316Ti, AISI 321

Material	Elongation (%)	Yield Strength (MPa)	Ultimate Tensile strength (MPa)
AISI 304L	48.60	349.77	783.52
AISI 316L	43.20	219.94	549.85
AISI 316Ti	47	261	634
AISI 321	56.40	264.55	608.47

Table 2 Welding conditions

Power source	Secheron Micro Plasma Arc Machine (Model: 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 3 Important weld parameters

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

2.1 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. A typical weld bead geometry is shown in Figure 1.The measured values of weld pool geometry are presented in Table 6. Figure's 2a, 2b, 2c,2d indicates welded joint of AISI 304L,AISI 316L, AISI 316Ti, AISI 321 respectively.

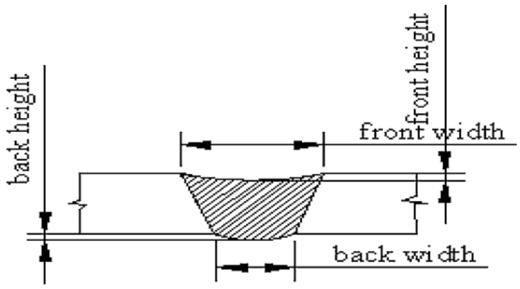

Fig.1 Typical weld bead geometry

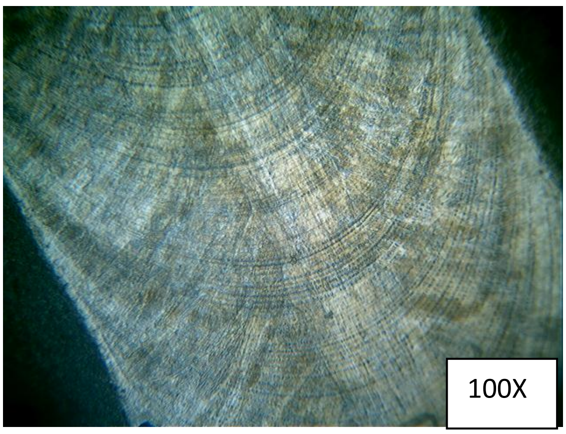

Fig.2aWeld bead of AISI 304L

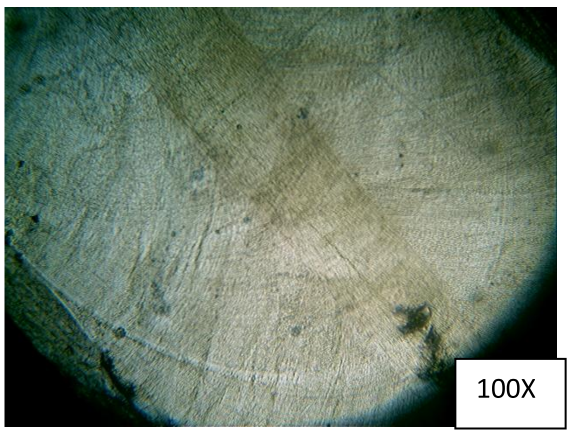

Fig.2b Weld bead of AISI 316L

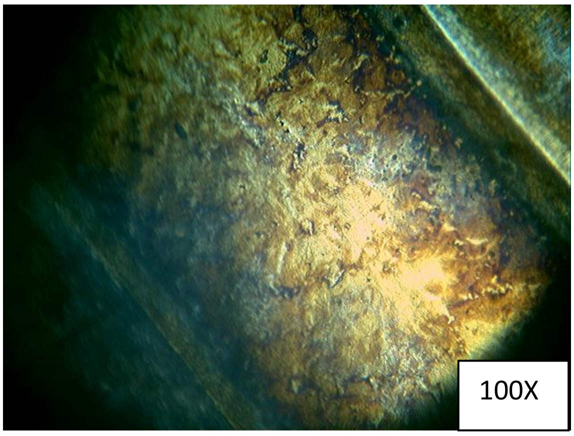

Fig.2c Weld bead of AISI 316Ti

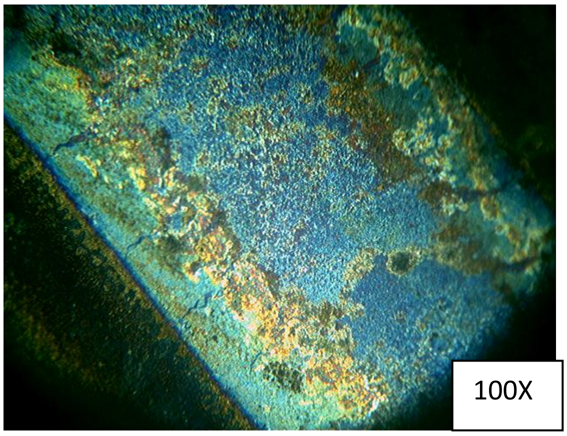

Fig.2d Weld bead of AISI 321

2.2 Microstructure measurement

For Microstructure measurement ASTM E 407 was followed for Etching along with ASM Metal Hand Book, Volume 9. For revealing the Microstructure the weld samples are mounted using Bakelite and polishing was done according to standard Metallurgical procedure. Oxalic Acid was used as an etchant. For revealing the Microstructure, Electrolytic Etching was done. The Microstructure was measured using Metallurgical Microscope at a magnification of 100X. Fig.3a,3b,3c, 3d indicates the microstructures of AISI 304L,AISI 316L, AISI 316Ti, AISI 321 respectively. The left portion in the Fig.3a, 3b indicates weld fusion zone and right portion indicates Heat Affected Zone (HAZ).

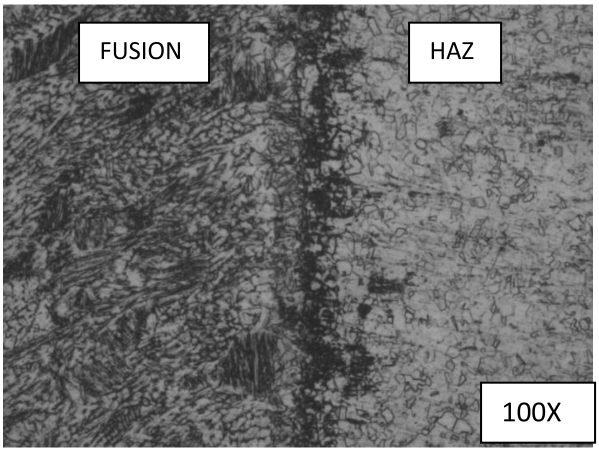

Fig.3a Microstructure of AISI 304L

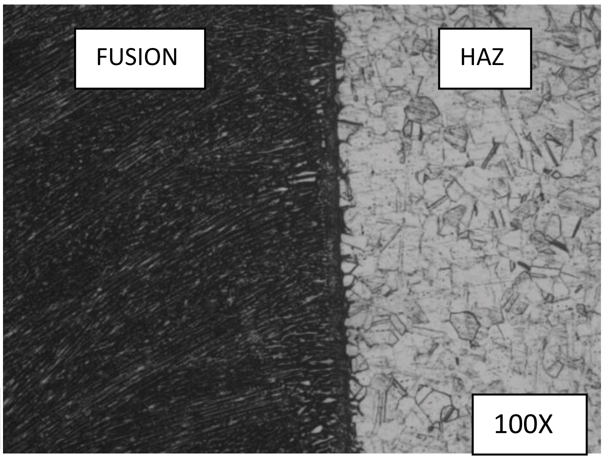

Fig.3b Microstructure of AISI 316L

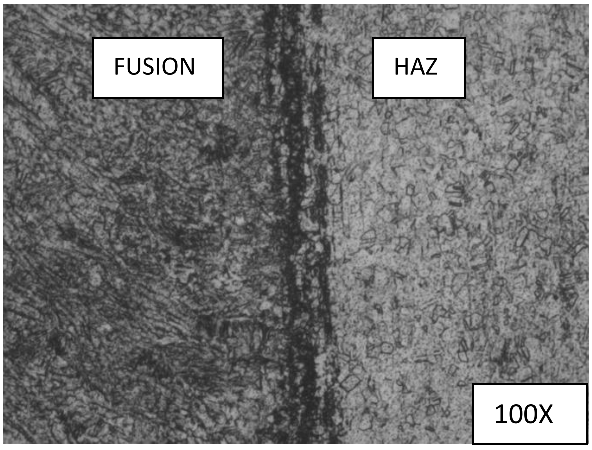

Fig.3c Microstructure of AISI 316Ti

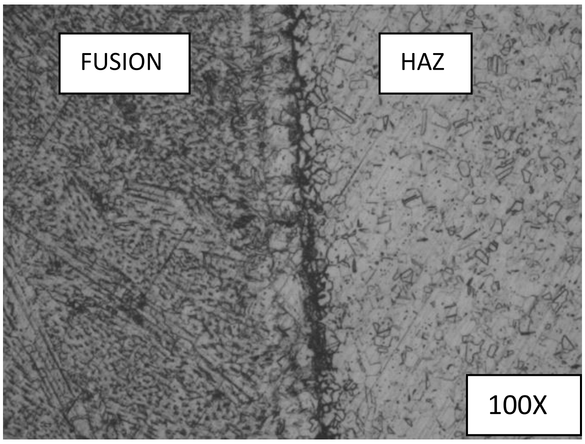

Fig.3c Microstructure of AISI 321

2.3 Grain Size measurement

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 as shown in Figure 4 is used to measure the fusion zone grain size and parent metal. Figure 5a, 5b,5c,5d indicates 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.

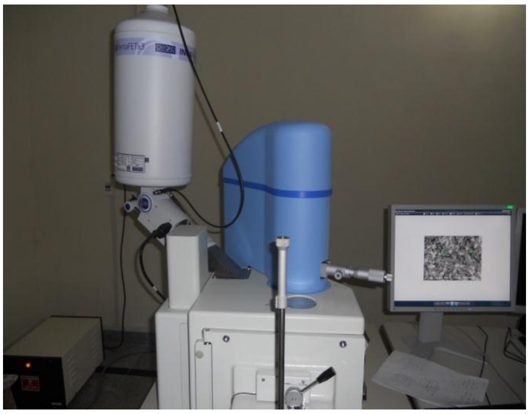

Fig.4 Scanning Electron Microscope

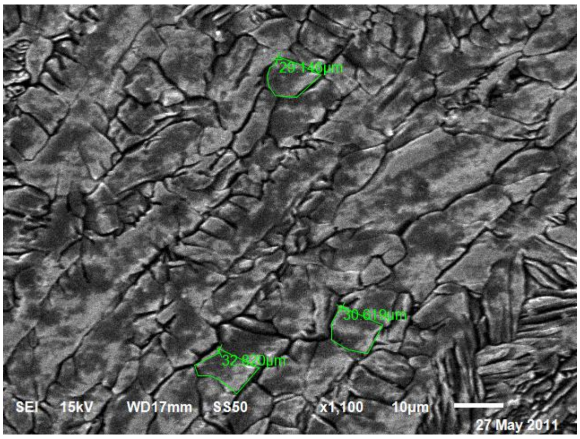

Fig.5a Grain size of AISI 304L

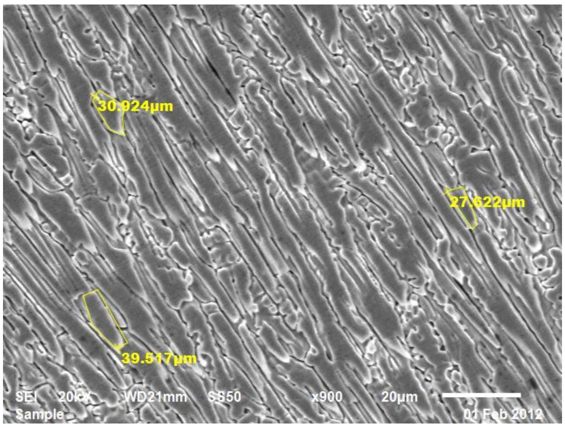

Fig.5b Grain size of AISI 316L

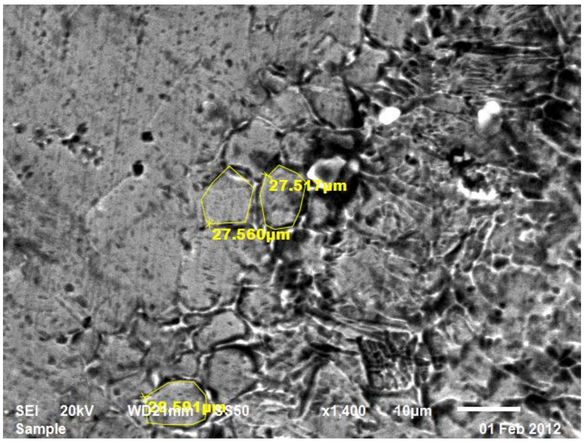

Fig.5c Grain size of AISI 316Ti

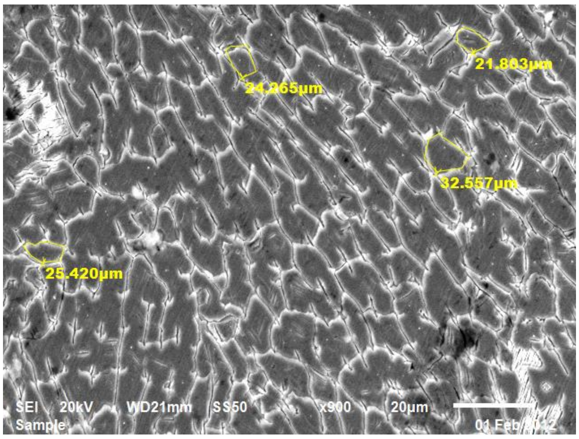

Fig.5d Grain size of AISI 321

2.4 Measurement of Vickers Micro 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 0.3mm using Digital Micro Hardness testing Machine, make METSUZAWA CO LTD, JAPAN, Model No: MMT-X7 as shown in Figure 6 .

Fig.6 Vickers Micro hardness tester

Table 4 Variation of hardness values across the weld joint at 0.3mm interval

Material	Hardness values in VHN at different locations on the weld joint								
	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

In the Table.6 points 1,2,8,9 indicates at Heat Affected Zone (HAZ) and the points 3, 4,5,6,7 indicates at Fusion Zone (FZ). The location of the hardness measuring points is shown in Figure.7. The variation of hardness across the weld is shown in Figure.8.

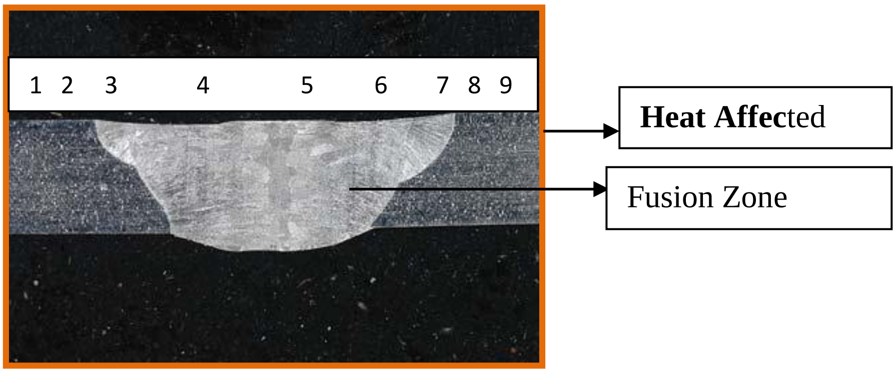

Fig.7 Location of hardness measuring points on the weld joint

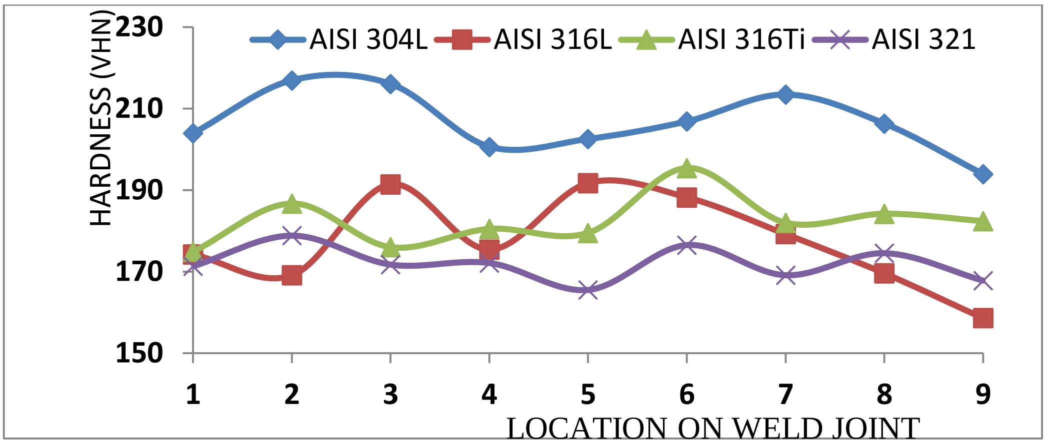

Fig.8 Variation of hardness across the weld

From Table 4 and Figure 8 it understood that hardness at centre of FZ is less and it keeps on increasing away from the centre and decreases towards HAZ.

2.5 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 are shown in Fig.9 & 10. Tensile tests are carried out in 100kN computer controlled Universal Testing Machine (ZENON, Model No: WDW-100) as shown in Fig.11. 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 6.

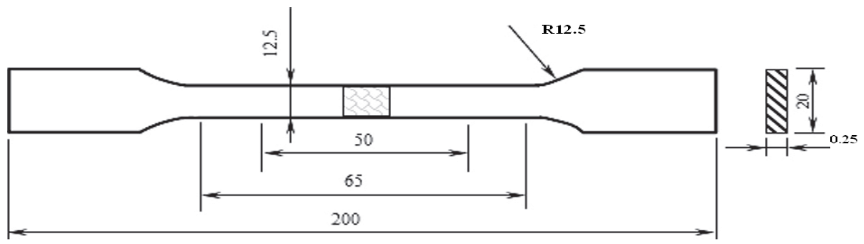

Fig.9 Schematic diagram of tensile specimen as per ASTM E8.

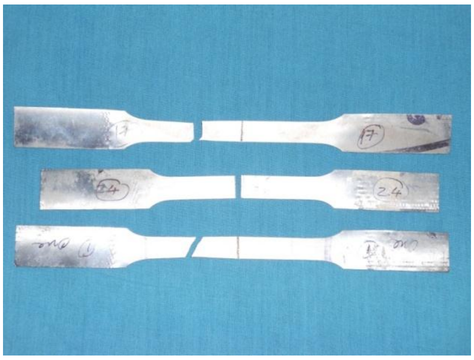

Fig.10 Tensile specimens of welded joints

Fig.11 Universal Testing Machine

3. RESULTS & DISCUSSIONS

The results of all the weld quality characteristics discussed in chapter 2 on the welded samples of AISI 304L, AISI 316L, AISI 316Ti, AISI 321 are summarized and presented in Table 6.

Table 6 Comparison of weld quality characteristics

Material	Weld pool Geometry				Fusion Zone grain size (Microns)	Fusion Zone hardness (VHN)	Yield Strength (MPa)	Ultimate Strength (MPa)
	Front Width	Back Width	Front Height	Back Height				
AISI 304L	1.509	1.439	0.060	0.047	30.861	207.86	256	657
AISI 316L	1.408	1.342	0.052	0.044	32.687	185.18	250	526
AISI 316 Ti	1.225	1.084	0.048	0.038	27.862	182.68	287	594
AISI 321	1.134	0.966	0.046	0.036	23.862	170.98	247	582

From Table 6 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.12. AISI 304L has the highest hardness and tensile strength; however the grain size of AISI 321 is the smallest among the other samples.

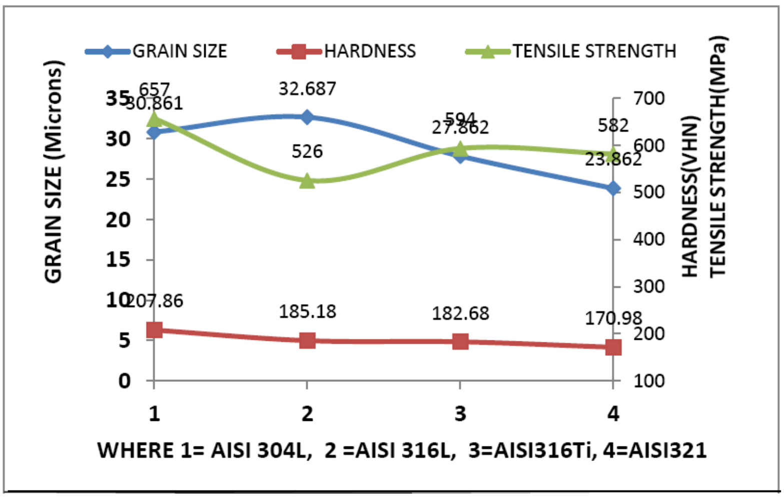

Fig.12 Variation of mechanical properties

4. CONCLUSIONS

Pulse current micro plasma arc welding 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 pool 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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