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Study on Effect of Welding Speed on Micro Structure and Mechanical Properties of Pulsed Current Micro Plasma Arc Welded Inconel 625 Sheets

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ABSTRACT

Nickel alloys had gathered wide acceptance in the fabrication of components which require high temperature resistance and corrosion resistance, such as metallic bellows used in expansion joints used in aircraft, aerospace and petroleum industry. Micro Plasma Arc Welding (MPAW) is one of the important arc welding processes commonly using in fabrication of Nickel alloys. In the present paper welding of Inconel 625 sheets using pulsed current micro plasma arc welding was discussed. The paper mainly focuses on studying the weld quality characteristics like weld pool geometry parameters, microstructure, grain size, hardness and tensile properties of Pulsed Current Micro Plasma Arc Welded Inconel 625 sheets at different welding speeds. Results reveals that at a welding speed of 260 mm/minute better weld quality characteristics can be obtained.

Keywords: Pulsed Current Micro Plasma Arc Welding; Inconel 625; Grain Size; Hardness; Tensile Properties

1. Introduction

The plasma welding process was introduced to the welding industry in 1964 as a method of bringing better control to the arc welding process in lower current ranges. Today, plasma retains the original advantages it brought to the industry by providing an advanced level of control and accuracy to produce high quality welds in both miniature and pre precision applications and to provide long electrode life for high production requirements at all levels of amperage. Plasma welding is equally suited to manual and automatic applications. It is used in a variety of joining operations ranging from welding of miniature components to seam welding to high volume production welding and many others.

During welding of thin sheets by conventional arc welding processes, which offer high heat input has various problems such as burn through or melt trough, distortion, porosity, buckling warping & twisting of welded sheets, grain coarsening, evaporation of useful elements present in coating of the sheets, joint gap variation during welding, fume generation form coated sheets etc. Micro Plasma arc Welding (MPAW) is a good process for joining thin sheet, but it suffers high equipment cost compared to Gas Tungsten Arc Welding (GTAW). However it is more economical when compare with Laser Beam welding and Electron Beam Welding processes.

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.

From the earlier works reported on Inconel 625 [3-5] it is understood that selection of welding process parameters play a vital role in obtaining the desired weld quality. Hence, an attempt is made to study the welding quality characteristics. The present paper focuses on studying the weld quality characteristics like weld pool geometry parameters, microstructure, grain size, hardness and tensile properties of Pulsed Current Micro Plasma Arc Welded

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Inconel 625 sheets.

2. Experimental Procedure

Inconel 625 sheets of 100 × 150 × 0.25 mm are welded autogenously with square butt joint without edge preparation. The chemical composition of Inconel 625 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 [6-9] 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 [3-5]. Hence peak current, back current, pulse rate and pulse width are chosen and their values are presented in **Table 3**.

Table 1. Chemical composition of INCONEL 625 (weight %).

C	Mn	P	S	Si	Cr	Ni	
0.0300	0.0800	0.0050	0.0004	0.1200	20.8900	61.6000	
Al	Mo	Cb	Ta	Ti	N	Co	Fe
0.1700	8.4900	3.4400	0.0050	0.1800	0.0100	0.1300	4.6700

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	1 mm
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	1 mm
Nozzle to plate distance	1 mm
Welding speed	260 mm/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, aqua regia 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 4**.

Figures 2(a)-(d) indicate the back surface of the welded joint at welding speeds of 150, 200, 260 & 300 mm/minute respectively.

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. Aqua Regia was used as an etchant. For revealing the Microstructure, Electrolytic Etching was done. The Microstructure was measured using Metallurgical Microscope at a magnification of 100×. **Figures 3(a)-(d)** indicates the microstructures at welding speeds of 150, 200, 260 & 300 mm/minute respectively. The left portion in the **Figures 3(a)-(d)** indicates weld fusion zone ad right portion indicates Heat Affected Zone (HAZ).

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 Aqua Regia 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. **Figures 5(a)-(d)** indicates the fusion zone grain size at welding speeds of 150, 200, 260 & 300 mm/minute respectively. As the grains in some parts of the weld fusion zone are elongated and uneven, an average value was reported by measuring grain size at different locations in the fusion zone of each sample.

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

Elding speed (mm/minute)	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
150	260.7	258.4	229.3	242.0	241.9	248.8	250.8	249.3	255.2
200	242.4	255.6	254.6	238.2	231.9	240.0	255.0	240.1	234.2
260	247.8	255.5	242.3	248.1	262.4	249.5	260.6	256.6	244.0
300	232.2	238.5	250.1	239.9	253.9	236.3	255.0	238.4	226.5

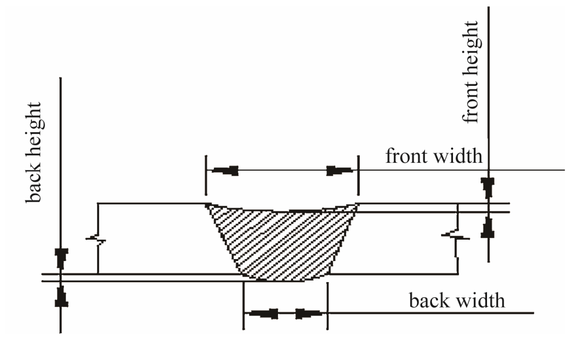


Figure 1. Typical weld bead geometry.

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

In the **Table 4** points 1, 2, 8, 9 indicates at Heat Affected Zone (HAZ) and the points 3, 4, 5, 6, 7 indicate 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**.

From **Table 4** and **Figure 8** it understood that hardness at centre of FZ is less and it keeps on increasing 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 **Figure 9** and **10**. Tensile tests are carried out in 100 kN computer controlled Universal Testing Machine (ZENON, Model No: WDW-100) as shown in **Figure 11**. The specimen is loaded at a rate of 1.5 kN/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 5**.

3. Results & Discussions

3.1. Weld Pool Geometry

From **Table 5** and from **Figures 2(a)-(d)** it is noticed that at the welding speed of 150 mm/minute over melting of base metal was noticed and when the welding speed of 300 mm/minute there is improper fusion of the base metal. At the welding speed of around 260 mm/min optimum weld pool geometry parameters are obtained.

3.2. Fusion Zone Grain Size

The variation of fusion zone grain size with respect to welding speed was presented in **Figure 12**. It is noticed that the grain size decreased up to a welding speed of 260 mm/minute and there after increased. This is due to improper fusion of base metal.

3.3. Fusion Zone Hardness

The variation of fusion zone hardness with respect to welding speed was presented in **Figure 13**. It is noticed that the hardness increases gradually up to 252.58 VHN at welding speed of 260 mm/minute and there after decreases to 247.04 VHN, when the welding speed is 300 mm/minute.

3.4. Ultimate Tensile Strength

The variation of ultimate tensile strength with respect to welding speed was presented in **Figure 14**. It is noticed that the ultimate tensile strength increases gradually up to 857 MPa at welding speed of 260 mm/minute and there after decreases to 837 MPa, when the welding speed is 300 mm/minute.

4. Conclusion

Inconel 625 sheets are successfully welded using pulsed current MPAW process at different welding speeds. From the experiments performed, it is revealed that sound weld pool geometry is obtained at the welding speed of 260 mm/minute. Fusion zone grain size decreased from welding speed of 150 mm/minute to 300

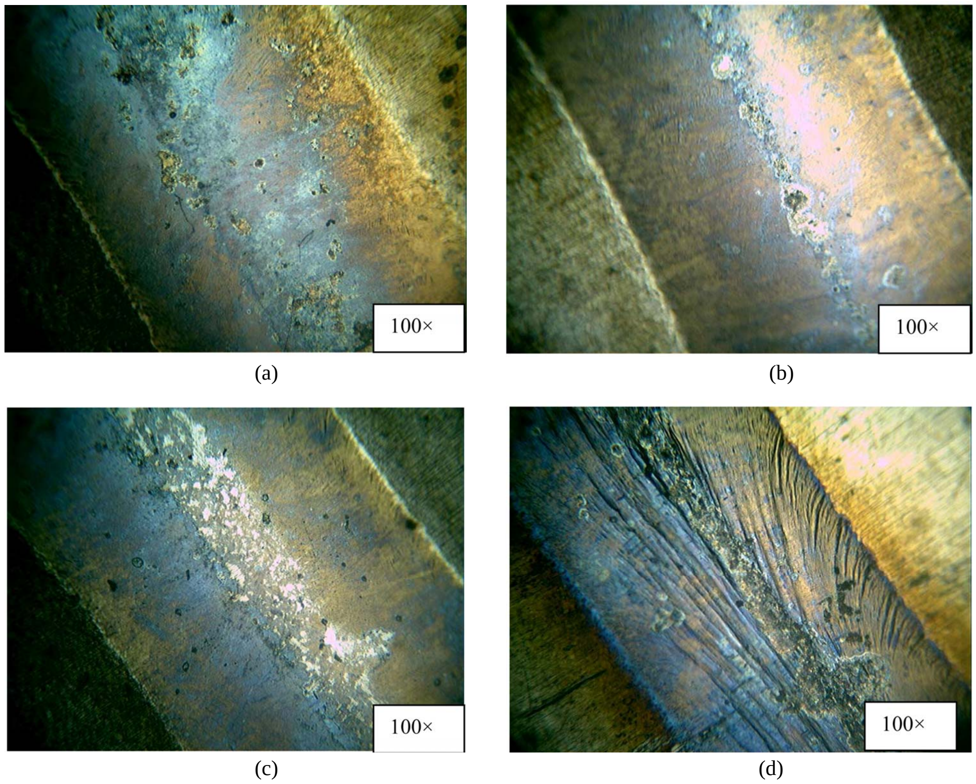


Figure 2. (a) welding speed of 150 mm/minute; (b) welding speed of 200 mm/minute; (c) welding speed of 260 mm/minute; (d) welding speed of 300 mm/minute.

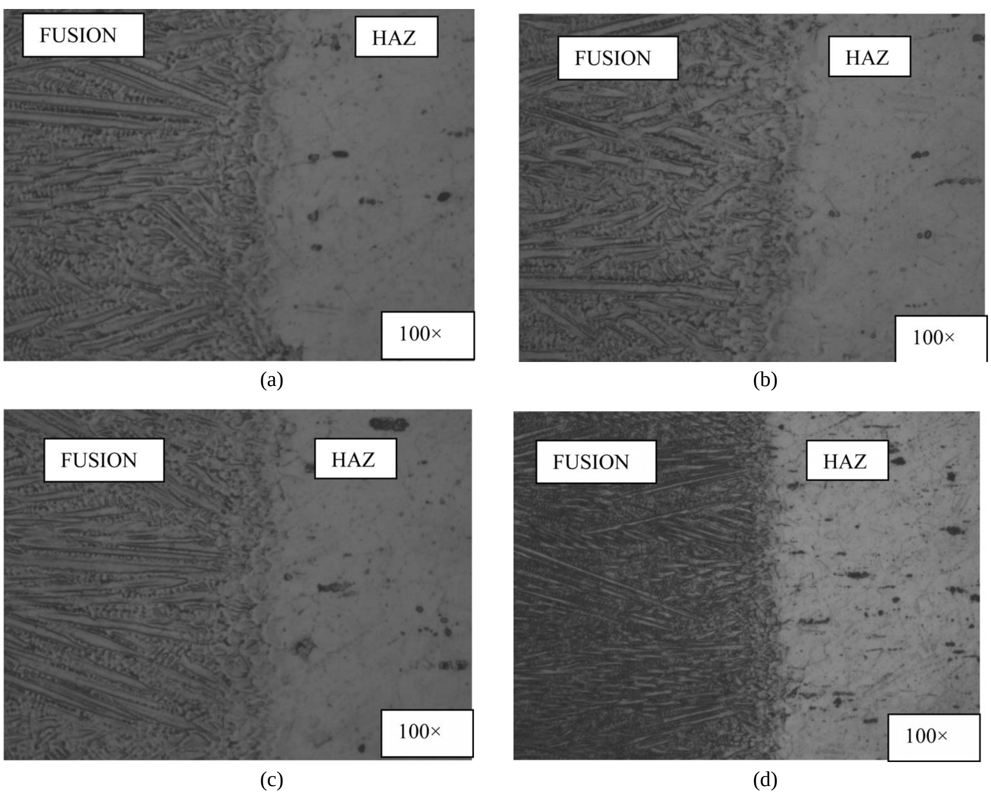


Figure 3. (a) welding speed of 150 mm/minute; (b) welding speed of 200 mm/minute; (c) welding speed of 260 mm/minute; (d) welding speed of 300 mm/minute.

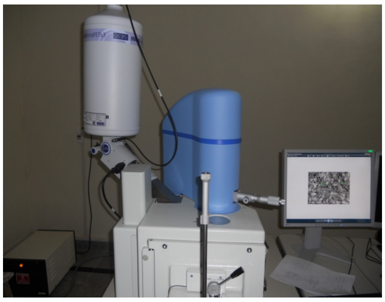
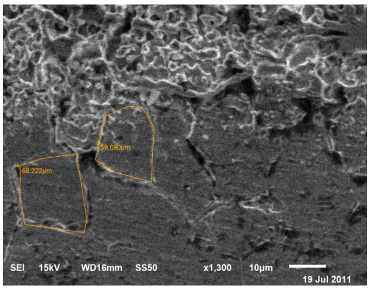
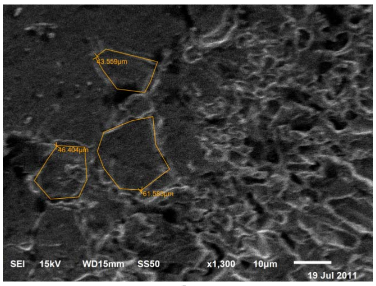


Figure 4. Scanning electron microscope.



(a)



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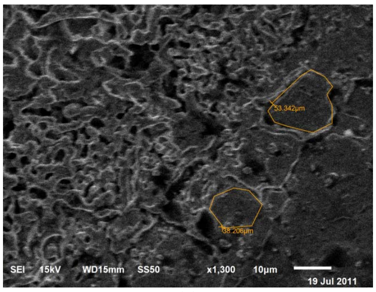
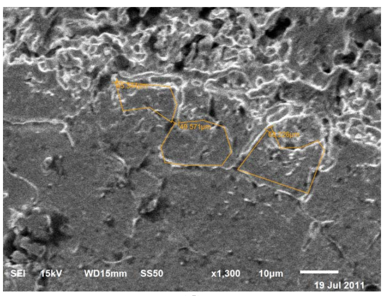


(c)



(d)

Figure 5. (a) Welding Speed of 150 mm/minute; (b) Welding speed of 200 mm/minute; (c) Welding speed of 260 mm/minute; (d) Welding speed of 300 mm/minute.

Figure 6. Vickers micro hardness tester.

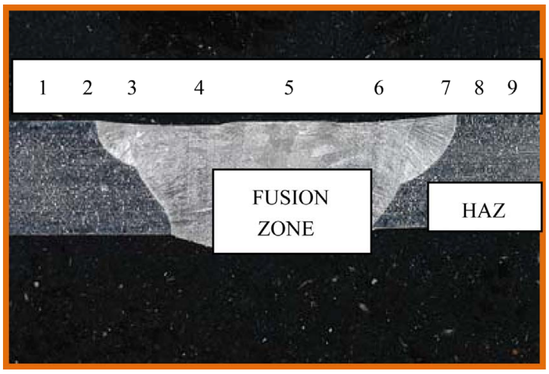


Figure 7. Location of hardness measuring points on the weld joint.

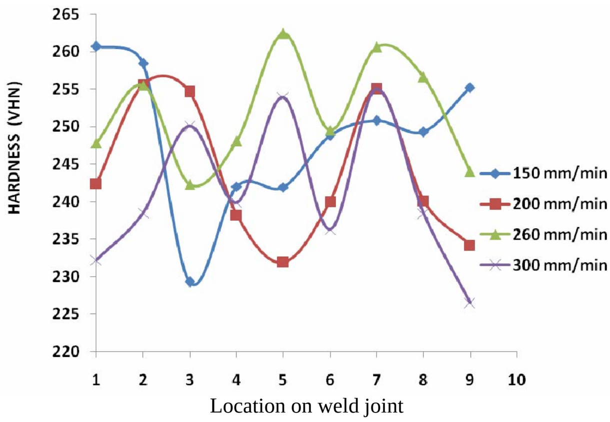


Figure 8. Variation of hardness across the weld.

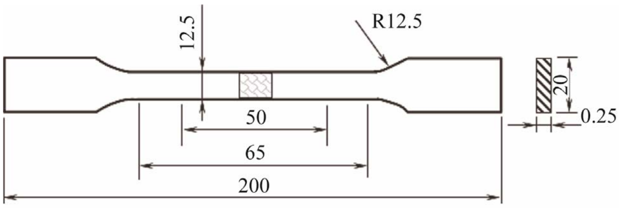


Figure 9. Schematic diagram of tensile specimen as per ASTM E8.

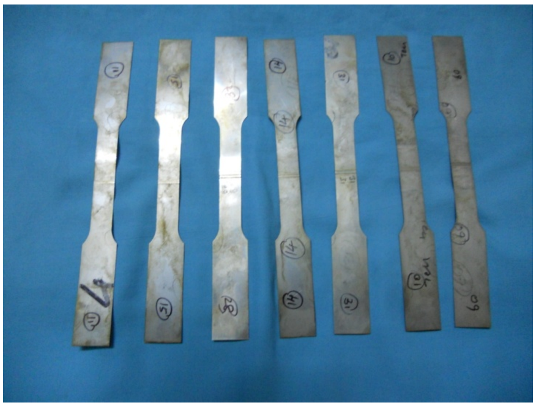


Figure 10. Tensile specimens of inconel 625 welded joints.

Figure 11. Universal testing machine.

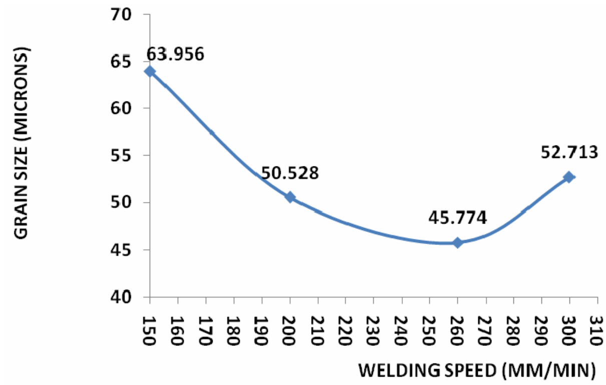


Figure 12. Variation of fusion zone grain size.

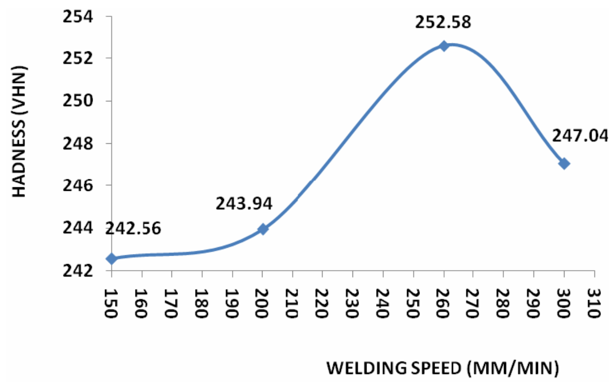


Figure 13. Variation of fusion zone hardness.

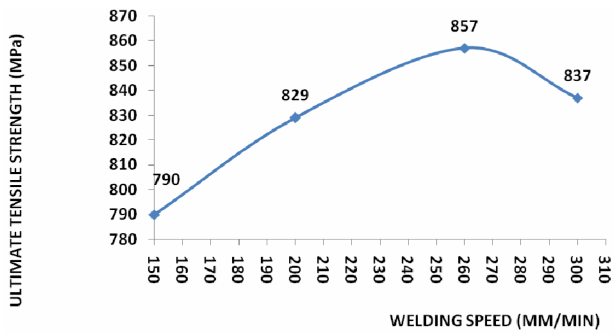


Figure 14. Variation of ultimate tensile strength.

Table 5. Comparison of weld quality characteristics.

Welding Speed (mm/minute)	Weld pool Geometry				Fusion Zone grain size (Microns)	Fusion Zone hardness (VHN)	Ultimate Strength (MPa)
	Front Width	Back Width	Front Height	Back Height			
150	1.231	1.171	0.0458	0.0358	63.956	242.56	790
200	1.253	1.188	0.0475	0.0376	50.528	243.94	829
260	1.270	1.202	0.0456	0.0356	45.774	252.58	857
300	1.153	1.075	0.0470	0.0366	52.713	247.04	837

mm/minute, where as fusion zone hardness and ultimate tensile strength increased with welding speed up to 260 mm/minute and thereafter decreased. From the results on various weld quality characteristics tests, it is understood that at the welding speed of 260 mm/minute, optimal weld quality characteristics are obtained.

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