Research & Reviews

Research and Reviews: Journal of Material Sciences

Study of Weld Quality Characteristics of Inconel 625 Sheets at Different Modes of Current in Micro Plasma Arc Welding Process

Kondapalli Siva Prasad[1]*, Chalamalasetti Srinivasa Rao[2], and Damera Nageswara Rao[3]

[1]Department of Mechanical Engineering, Anil Neerukonda Institute of Technology & Sciences, Visakhapatnam, India.
[2]Department of Mechanical Engineering, AU College of Engineering, Andhra University, Visakhapatnam, India.
[3]Vice Chancellor, Centurion University of Technology & Management, Odisha, India.

Article

Received: 20/03/2013
Revised: 14/04/2013
Accepted: 14/06/2013

***For Correspondence**

Department of Mechanical Engineering, Anil Neerukonda Institute of Technology & Sciences, Visakhapatnam, India.

Keywords: Inconel 625, pulsed current, continuous current, plasma arc welding.

ABSTRACT

Inconel 625 is a Nickel alloy which was used in fabrication of high temperature resistance and corrosion resistance components, such as metal bellows used in expansion joints in aircraft, aerospace and petroleum industry. The paper focuses on studying the effect of continuous current and pulsed current in welding Inconel 625 sheets using Micro Plasma Arc Welding (MPAW) process. Welding was carried out on 0.25 mm thick Inconel 625 sheets using continuous current mode and pulsed current mode separately keeping all other welding parameters constant. Weld quality characteristics like bead profile, micro structure, hardness and tensile properties are investigated and it is found that the usage of pulsed current leads to better weld quality characteristics when compared to continuous current mode.

INTRODUCTION

Inconel 625 is extremely versatile austenitic nickel based super alloys with 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. Inconel 625 can be joined using variety of welding methods, including Gas Tungsten Arc Welding, Plasma Arc Welding, Laser Beam Welding and Electron Beam Welding. 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. Pulsed MPAW process parameters are depicted in Figure 1.

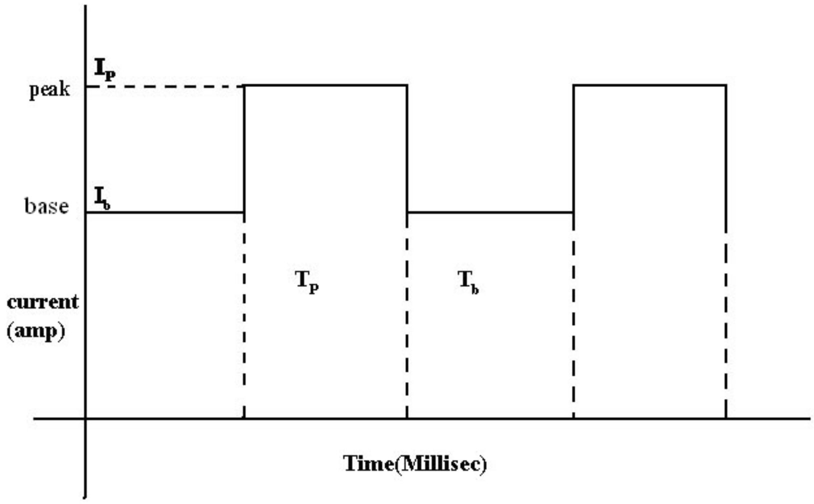


Figure 1: Pulsed MPAW process parameters

Where I_P = Pulse current, I_b = Base current, T_P = Peak current duration, T_b = Base current duration

There are four independent parameters that influence the process are peak current, base current, pulse and pulse width. The main objective of the present work is to study the weld quality characteristics of continuous current and pulsed current MPAW process.

EXPERIMENTATION

The chemical composition and tensile properties of Inconel 625 sheets are presented in Tables 1 and 2. These sheets are available in the form of rolls from which the required sizes of 50 mm x 150 mm are sheared using shearing machine (Figure 2) and the pieces are cleaned using Ultrasonic cleaner before welding, to avoid any strains of oil and grease (Figure 3). The selected pair of sheets is fixed in the welding fixture and care has been taken to see that there is no gap between the two edges to be joined. Copper sinks are fixed at the bottom of the welding fixture to minimise the weld distortion and extreme care has been taken for proper butting of sheets without any gap. Welding is carried out at a speed of 260 mm/minute.

Square butt joint is selected as the thickness is very small and edge preparation is not required for sheets of thickness less than 1mm (As per 2007 ASME boiler & pressure vessel code). Details about weld joint dimensions are shown in Figure 4. Argon gas with 99.99% purity is used as a shielding gas and to prevent absorption of oxygen and nitrogen from the atmosphere. The same gas is also used as purging gas for fast cooling of weld. The welding has been carried out under the welding conditions mentioned in Table 3.

Figure 2: Shearing Machine

Figure 3: Ultrasonic Cleaner

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 [3,4,5,6] carried out on pulsed current MPAW it was understood that the peak current, base 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 [7,8,9,10,11,12,13,14]. The weld process parameters chosen in the present study and their values are presented in Table 4.

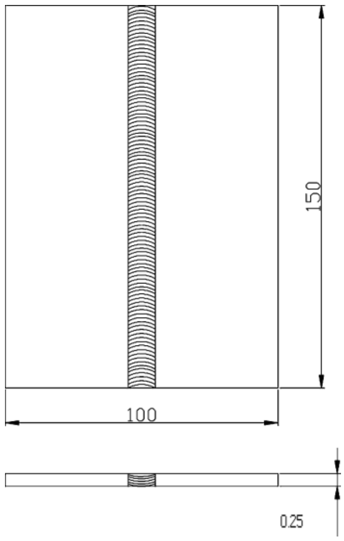


Figure 4: Dimensions of welded joint in mm

Table 1: Chemical composition of Inconel 625 (weight %)

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

Table 2: Tensile properties of Inconel 625 sheets

Yield Strength (MPa)	Ultimate Strength (MPa)	% Elongation
449	816	23

Table 3: 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 Liters/minute
Shielding gas	Argon
Shielding gas flow rate	0.4 Liters/minute
Purging gas	Argon
Purging gas flow rate	0.4 Liters/minute
Copper Nozzle diameter	1mm
Nozzle to plate distance	1mm
Welding speed	260 mm/minute
Torch Position	Vertical
Operation type	Automatic

Table 4: Important weld parameters

Pulsing Current		
Input Factor	Units	Value
Peak Current	Amperes	7
Base Current	Amperes	4
Pulse rate	Pulses/second	40
Pulse width	%	50
Mean Voltage	Volts	15
Continuous current		
Current	Amperes	7
Mean Voltage	Volts	13

Measurement of Weld Quality Characteristics

The weld quality characteristics like weld bead, microstructure, grain size, hardness and tensile properties are studied.

Measurement of weld bead

Three metallurgical samples are cut from each joint leaving the edges of defective portion of the welded length. Defective length of weld is identified visually and also by conducting dye pentrant and X-ray tests and mounted using Bakelite. Sample preparation and mounting is done as per ASTM E 3-1 standard. The transverse face of the samples are surface grounded using 120 grit size belt with the help of belt grinder and polished sequentially using grade 1/0 (245 mesh size), grade 2/0(425 mesh size) and grade 3/0 (515 mesh size) sand paper. The specimens are further polished using aluminum oxide, diamond paste and velvet cloth in a disc polishing machine. The polished specimens are etched by using Aqua Regia solution to reveal the macrostructure as per ASTM E407. Macrographs are taken using metallurgical microscope (Make: Carl Zeiss, Model: Axiovert 40MAT) at 100X magnification. It is clearly observed that in case of pulsed current uniform circular ripples are seen on the weld surface, where as in continuous current mode the surface is clear without any ripples. The macrographs for continuous current and pulsed current is shown in Figures 5 and 6.

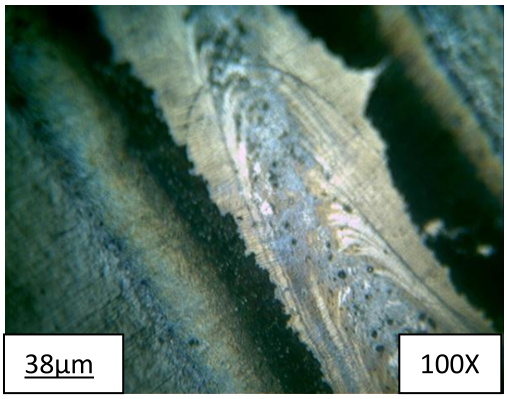


Figure 5: Macrograph of Pulsed current

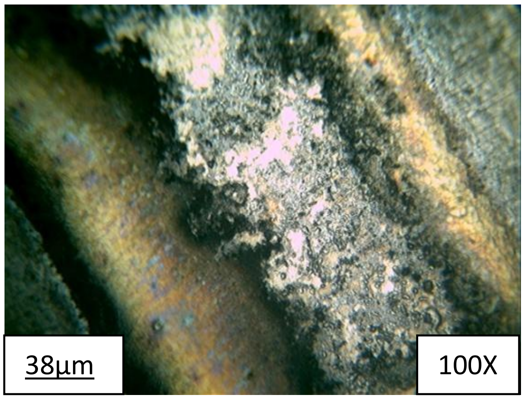
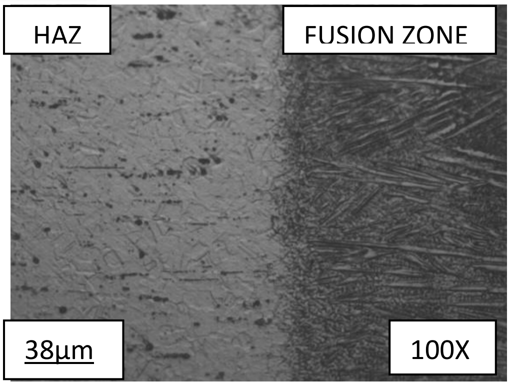


Figure 6: Macrograph of Continuous current

Microstructure & Grain Size

The procedure which was discussed in section 3.1 is followed by varying the etching time to reveal the microstructure as per ASTM E407. Micrographs are taken using metallurgical microscope (Make: Carl Zeiss, Model: Axiovert 40MAT) at 100X magnification. The micrographs of HAZ and weld fusion zone are shown in Figures 7 and 8.



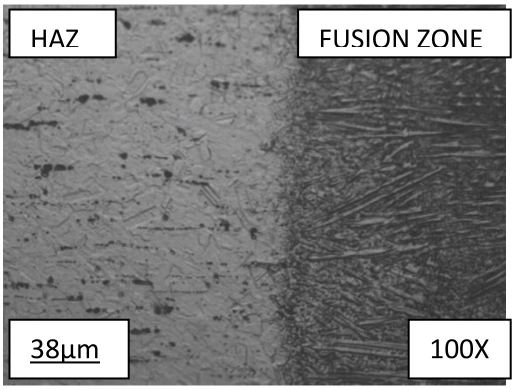
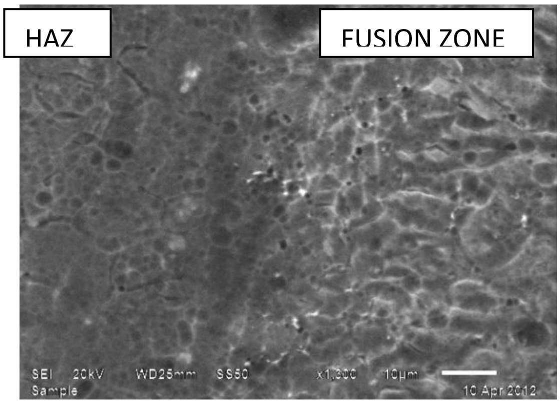


Figure 7 Microstructure for continuous current   **Figure 8 Microstructure for pulsed current**

Grain size of continuous current and pulsed current is measured by using Scanning Electron Microscope (SEM) (Make: INCA Penta FETx3, Model:7573). Figures 9 and 10 indicate the measurement of grain size of HAZ and weld fusion zone.



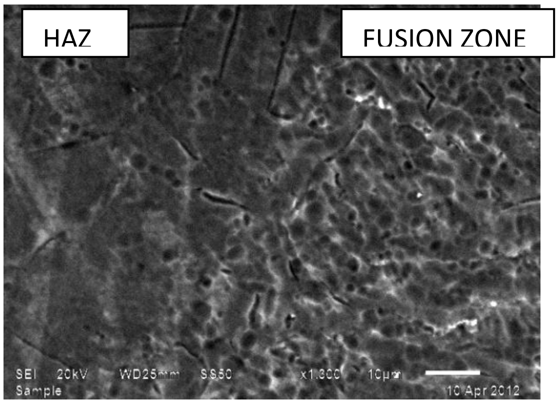


Figure 9: SEM image of continuous current   **Figure 10: SEM iamge of pulsed current**

From the SEM iamges it is very clear that the grains in pulsed current mode are smaller than continuous current mode. The smaller size in pulsed current may be due to grain refinement taking place in the fusion zone.

Measurement of hardness

The hardness of the weld fusion zone of the welded samples are measured using Vickers's micro hardness testing machine (Make: METSUZAWA CO LTD, JAPAN, Model: MMT-X7) by applying a load of 0.5 Kg as per ASTM E384. Readings were taken at an interval of 0.3 mm across the weld in both fusion zone and HAZ. The variation of hardness across the weld is represented in Figure 11 and location of hardness measuring points is shown in Figure 12.

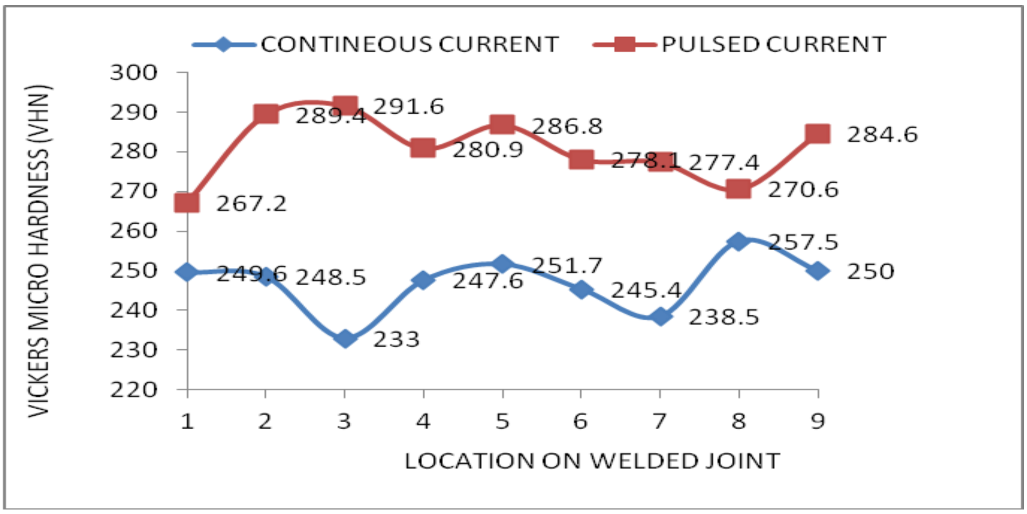


Figure 11: Variation of hardness across the welded joint

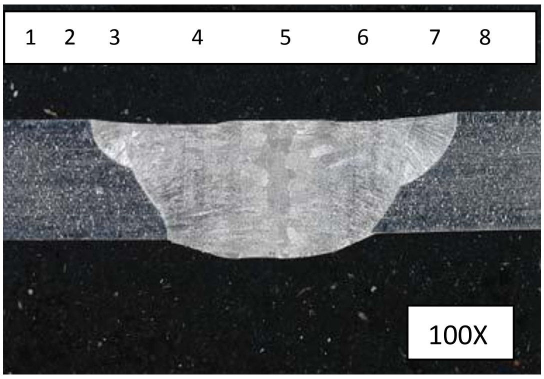


Figure 12: Location of hardness along the weld joint

The hardness values obtained using pulsed current mode are higher than continuous current mode. Also the variation of hardness is varaying between 267.2 VHN to 291.6 VHN for pulsed current mode and 233 VHN to 257.5 VHN for continuous current mode.

Tensile strength

Tensile specimens are prepared as per ASTM E8M-04 guidelines using wire cut Electro Discharge Machining (Figure 13) in the transverse direction of the weld from each welded sample. Tensile tests are carried out on 100 KN computer controlled Universal Testing Machine (ZENON, Model No: WDW-100). The specimen is loaded at a rate of 1.5 KN/min as per ASTM specifications, so that the tensile specimens undergo deformation. The deformed specimens are shown in Figure 14.

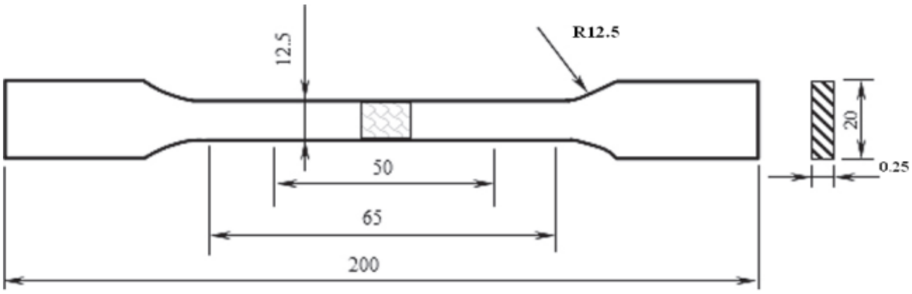


Figure 13: Cross section of tensile specimen

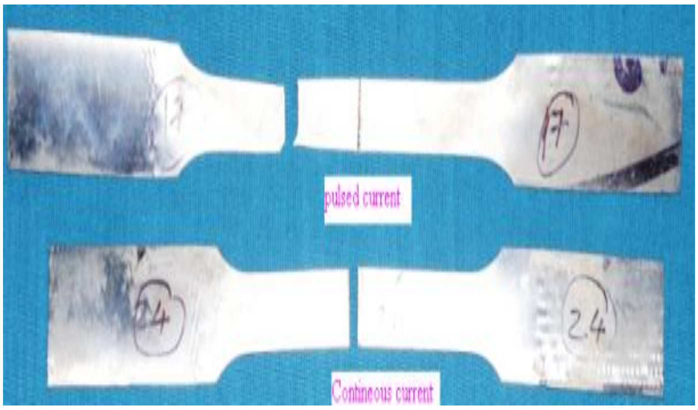


Figure 14: Tensile specimens after failure

The tensile properties of continuous and pulsed current mode are presented in Table 5. It is understood that pulsed current specimen failed at Heat Affected Zone (HAZ), where as continuous current specimen failed at Fusion zone.

Table 5: Tensile properties

Current mode	Yield Strength (MPa)	Ultimate Strength (MPa)	% Elong ation
Pulsed	445	798	21
Continuous	441	784	20
Parent metal	449	816	23
Current mode	Yield Strength (MPa)	Ultimate Strength (MPa)	% Elong ation
Pulsed	445	798	21
Continuous	441	784	20
Parent metal	449	816	23

From Table 5 it is clear that the ultimate tensile strength of pulsed current is 798 MPa, where the ultimate tensile strength of continuous current is 784 MPa. It is understood that weld joint strength of pulsed current is better than continuous current.

CONCLUSIONS

Inconel 625 sheets of 0.25 mm thick are joint using pulsed and continuous current mode of MPAW process. From the weld macrographs it is observed that circular uniform ripples are seen in case of pulsed current, which indicates uniform melting of base metal. In case of continuous current mode the weld bead is wider and in irregular fashion. Finer grains are observed in weld fusion zone in pulsed current mode, where as in continuous mode coarse grains are present. The finer grains in the pulsed current mode are due to faster cooling rates of weld molten pool. Because of grain refinement, the hardness and tensile properties of pulsed current mode welding are better than continuous current mode. It is clearly understood that pulsed current mode gives better weld quality characteristics compared with continuous current.

ACKNOWLEDMENTS

This paper is revised and expanded version of a paper entitled “Effect of welding current mode on weld quality characteristics of Micro Plasma Arc Welded Inconel 625 welds” presented at AIMTDR 2012, Jadhavpur University, and December 2012.

The authors would like to thank Shri. R .Gopala Krishnan, Director, M/s Metallic Bellows (I) Pvt Ltd, Chennai for his support to carry out experimentation work.

REFERENCES

1. Balasubramanian M, Jayabalan V, Balasubramanian V. Effect of process parameters of pulsed current tungsten inert gas welding on weld pool geometry of titanium welds. Acta Metall Sin (Engl Lett). 2010: 23(4): 312-320.
2. Balasubramanian B, Jayabalan V, Balasubramanian V. Optimizing the Pulsed Current Gas Tungsten Arc Welding Parameters. J Mater Sci Technol. 2006; 22(6):821-825.
3. Rajesh Manti, DK Dwivedi, AAgarwal. Microstructure and hardness of Al-Mg-Si weldments produced by pulse GTA welding. Int J Adv Manuf Technol. 2008;36: 263-269.
4. T Senthil kumar, V Balasubramanian, S Babu, MY Sanavullah. Effect of pulsed current GTA welding parameters on the fusion zone microstructure of AA 6061 Aluminium alloy. Met Mater Intl. 2007; 13(4): 345-351.
5. N Karunakaran, V Balasubramanian. Effect of pulsed current on temperature distribution, weld bead profiles and characteristics of gas tungsten arc weleded aluminium alloy joints. Trans Nonferrous Met Soc China. 2011; 21:278-286.
6. G Padmanaban, V Balasubramanian. Influences of pulsed current parameters on Mechanical and metallurgical properties of gas tungsten arc welede AZ31B Magnesium alloy. Met Mater Intl. 2011; 17(4): 679-687.
7. Kondapalli Siva Prasad, Ch Srinivasa Rao, D Nageswara Rao. Optimizing pulsed current micro plasma arc welding parameters to maximize ultimate tensile strength of Inconel 625 Nickel alloy using response surface method. Intl J Eng Sci Technol. 2011;3(6): 226-236.
8. Kondapalli Siva Prasad, Ch Srinivasa Rao, D Nageswara Rao. Establishing Empirical Relationships to Predict Grain Size and Hardness of Pulsed Current Micro plasma Arc Welded Inconel 625 Sheets. J Mat Metall Eng. 2011;1(3):1-10.
9. Kondapalli Siva Prasad, Ch Srinivasa Rao, D Nageswara Rao. Optimizing Fusion Zone Grain Size and Ultimate Tensile Strength of Pulsed Current Micro Plasma Arc Welded Inconel 625 Alloy Sheets using Hooke & Jeeves Method. Int Trans J Eng Manag App Sci Technol. 2012; 3(1):87-100.
10. Kondapalli Siva Prasad, Ch Srinivasa Rao, D Nageswara Rao. Study on weld quality characteristics of pulsed current micro plasma arc welding of Inconel 625 sheets. The J Min Mat Charact Eng. 2012; 11(2):133-141.

11. Kondapalli Siva Prasad, Ch Srinivasa Rao, D Nageswara Rao. Application of Hooke & Jeeves method to optimize Ultimate Tensile Strength of Pulsed Current Micro Plasma Arc Welded Inconel 625 Nickel alloy. Int J Lean Thinking. 2012; 3(1),42-52.
12. Kondapalli Siva Prasad, Ch Srinivasa Rao, D Nageswara Rao. Effect of pulsed current micro plasma arc welding process parameters on fusion zone grain size and ultimate tensile strength of Inconel 625 sheets. Acta Metallurgica Sinica (English letters). 2012; 25(3):179-189.
13. Kondapalli Siva Prasad, Chalamalasetti Srinivasa Rao, Damera Nageswara Rao. Effect of process parameters of pulsed current micro plasma arc welding on weld pool geometry of Inconel 625 welds. Kovove Materialy - Metallic Materials. 2012; 50(3):153-159.
14. Kondapalli Siva Prasad, Chalamalasetti Srinivasa Rao, Damera Nageswara Rao. Unconstrained Optimization for Maximizing Ultimate Tensile Strength of Pulsed Current Micro Plasma Arc Welded Inconel625sheets,Proceedings of the In Con INDIA, 2012, AISC 132, Springer-Verlag Berlin Heidelberg: 245-352.