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Assessment of Mechanical properties of PCGTA weldments of Inconel 625

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Abstract

Inconel 625, a Nickel based superalloy has outstanding features such as high corrosion resistance and high strength. Inconel 625 is preferred and widely used in aerospace, nuclear and power plant components where they are exposed to elevated temperatures. In this work, an attempt has been made to investigate the weldability, metallurgical and mechanical properties of the PCGTA welded Inconel 625 metals employing ERNiCrMo-3 filler wire. Structure-property relationships of Inconel 625 weldments are discussed in detail.

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Keywords: Inconel 625; Pulsed Current Gas Tungsten Arc Welding; ERNiCrMo-3

1. Introduction

Inconel 625, a Ni-Cr-Mo alloy has diversified applications in the petrochemical, marine industries and in the nuclear power plants owing to its high corrosion resistance and high temperature strength. Preventing high temperature oxidation and hot corrosion at elevated temperatures due to oxidation resistance of alloy 625 is the main purpose for such a broad range of applications. Martin et al. [1] reported that significant content of molybdenum makes alloy 625 resistant to pitting and crevice corrosion; whereas a combined nickel and molybdenum content makes it resistant to non-oxidizing environments and crevice corrosion. Kuk Hyun Song et al. [2] studied the mechanical properties of friction stir welded of Inconel 625 having 2 mm thick. The authors reported the formation of MC carbides such as NbC and (Ti,Nb)C were distributed in the grains and grain boundaries. It was also noticed that the weld strength of Inconel 625 joints was found to be higher as compared to the base metals owing to the grain refinement.

Zheng et al.[3] reported that the bellows are made of the Inconel 625, which are supposed to be the candidate material to substitute for Inconel 600 because of its good cavitation corrosion. Boser [4] investigated the creep rupture behavior of Inconel 625 in a silver environment. It was reported that rupture testing at 750 °C did not reveal any detrimental effect on the creep rupture properties in comparison with the Inconel 625.

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The presence of alloying elements such as Cr, Mo and Nb when operated at high temperatures form the protective oxides such as Cr_2O_3, NiO, Nb_2O_5 and $NbCrO_4$ which prevent Inconel 625 from corrosion [Otero et al. [5]]. Cyclic air oxidation studies were demonstrated on Inconel 625 in order to evaluate its oxidation resistance. It was reported by the authors that long-term exposure leads to microstructural modification and seemed to be detrimental. The chromia scale losses its protective properties and then IN-625 exhibits lower cyclic-oxidation resistance when exposed to 900 and 1000 °C [N'dah et al. [6]].

As evident from the literatures, Inconel 625 is widely used in the high temperature corrosive environments. However there is very limited work has been reported on the PCGTA welding of Inconel 625 hitherto. This paper investigates the weldability, metallurgical and mechanical properties of the PCGTA weldments of Inconel 625. Combined techniques of optical microscopy and SEM/EDAX analysis has been carried out to understand the structure-property relationships of the weldments.

2. Experimental Work

The chemical composition of the candidate metal Inconel 625 and the filler metal ERNiCrMo-3 employed in the PCGTA welding process is represented in Table 1. The dimensions of the candidate metals employed in this research work has the dimensions of 120 mm x 50 mm x 5 mm. Standard V-groove butt configurations having root face of 1 mm and an included angle of 60° was employed to weld these similar metals by PCGTAW process using ERNiCrMo-3 filler metal. A specially designed fixture employing the copper back plate was used to avoid while welding to avoid bending and distortions. The process parameters employed in the GTA welding of Inconel 625 is represented in Table 2. The welded samples were characterized for flaw detection using X-Ray radiography NDT inspection techniques. Further the weldments were cut to various coupons using wire-EDM for further studies which are outlined below.

Fig.1 PCGTA weldments of Inconel 625

Metallographic examination was carried out on the composite region [parent metal + weld + HAZ] of the weldment as shown in Fig.1(c). The composite region of the weldments were polished using the emery sheets of SiC with grit size varying from 220 to 1000 and followed by disc polishing using alumina to obtain a mirror finish of 1μ on the weldments. Electrolytic etching (10% oxalic acid solution; 6V DC supply and 1 A / Cm^2) was employed to examine the microstructure of Inconel 625. Further the samples were sliced to different dimensions to conduct various mechanical tests and assess the properties under room temperature. Tensile studies were performed on the ASTM E8 standard samples of the weldments using the Instron universal tensile testing machine with a strain rate of 2 mm/min. Three trials on each weldment were conducted to check the reproducibility of the results. The fractured samples were characterized to understand the mode of fracture by SEM analysis. Hardness studies were conducted on the composite region of the weldment by keeping weld as center using Vicker's Microhardness tester employing a load of 500 gf and 10 s dwell time at the regular intervals of 0.25 mm. The results of the metallurgical and mechanical properties were outlined in detail below.

Table 1. Chemical composition of the base and filler metals

	Chemical Composition (% Weight)						
Base Metal / Filler Metal	C	Cr	Ni	Si	Mo	Nb	Others
Inconel 625	0.059	21.05	62.1	0.434	8.23	3.3	Co – 0.024 ; Cu – 0.01; Al – 0.004; Ti – 0.016; V – 0.02; W – 0.15; P - 0.009; S - 0.014; Mn - 0.235; Fe – Bal
ERNiCrMo-3	0.10	21.5	50	0.50	9.0	3.565	Co – 8.0; Cu –0.50; Al – 0.40; Ti – 0.40; P - 0.02; S - 0.014; Mn - 0.50; Fe – Bal

Table 2. Process parameters employed for PCGTA welding of Inconel 625

Welding	**Voltage (V)**	**Current (Amps.)**	**No. of Passes**	**Filler wire diameter (mm)**
PCGTAW	13-16	140	1	2.4

3. Results and Discussions

3.1. Macro and Microstructure Examination

It is clear from the X-ray radiography NDT technique results that no macro or micro level deficiencies were observed in the as-welded PCGTA weldments. Microstructure on the composite region revealed the formation of well defined inter-dendritic growth at the weld region which would have richer amounts of Ni, Cr and Fe as evident from the EDAX analysis. Considerable black spots were found observed at the HAZ region of the weldments which could be probably the precipitates of Nb, Ti as reported by other researchers.

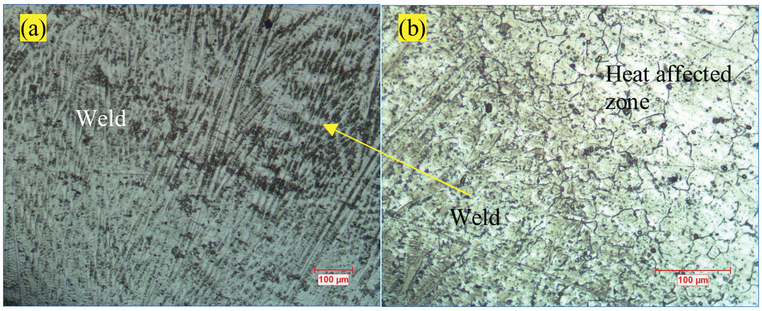

Fig. 2 (a) Microstructure showing (a) weld region (b) HAZ of Inconel 625 PCGTA Weldments

3.2. Mechanical Properties of the weldments

3.2.1. Hardness Studies

Hardness profile of the PCGTA welded Inconel 625 as shown in Fig. 3 clearly indicate the peak hardness values were found observed at the weld interface. The average hardness value of the weldment was found to be 268.5 HV and at the weld region, it was 251.8 HV. The greater hardness at the weld interface and the HAZ could be probably due to the formation of precipitates as evident from the microstructure examination.

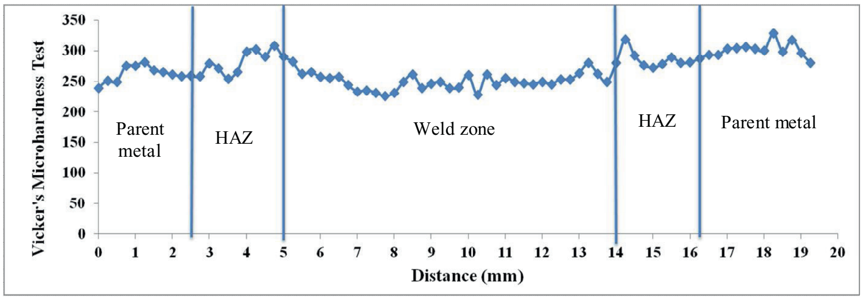

Fig. 3 Hardness Profile of the PCGTA weldments of Inconel 625

3.2.2. Tensile Properties

Tensile results of the PCGTA weldments clearly depicted that the fracture occurred at the weld zone in all the trials. Considerable amount of plastic deformation was found observed before the failure. As evident from hardness profile, the lower hardness values were observed at the weld zone as compared to other zones of the weldment. It is also well proven from the tensile plot. Hence the tensile failure also occurred at the weld zone.

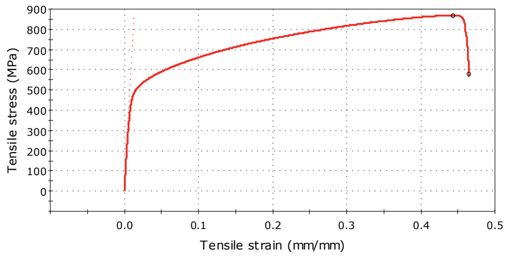

Fig.4 Stress-strain curve of PCGTA Inconel 625 weldments

SEM fractographs showed that the formation of micro-voids and dimples in the fibrous matrix of the sample contributed for the ductile mode of failure in the weldments. The average tensile properties obtained from the studies are represented in Table 3.

Table 3. Average Tensile properties of Inconel 625 PCGTA weldments

Ultimate Tensile Strength (MPa)	Young's modulus (GPa)	Ductility (%)	Fracture Zone
852.5	64	42.3	Weld

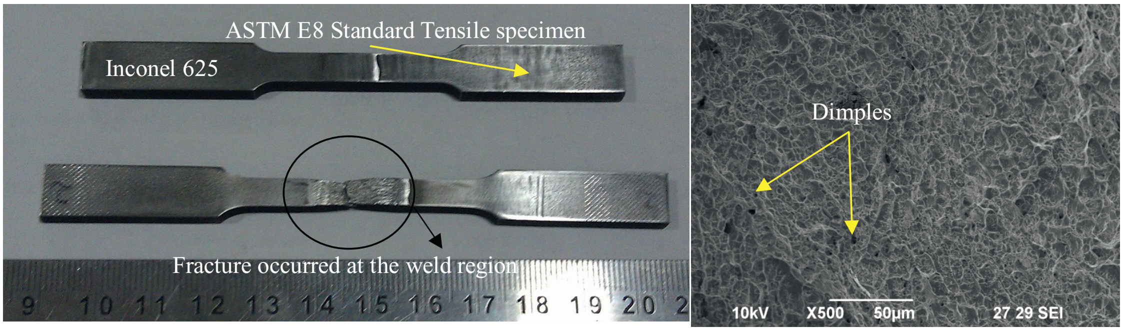

Fig. 5 (a) Fractured Tensile Sample (b) SEM Fractograph of the fractured PCGTA Inconel 625 weld sample

3.2.3. SEM/EDAX Analysis

SEM/EDAX analysis was performed on the various zones of the PCGTA Inconel 625 weldments in the as-welded conditions. All the zones of the weldments have considerable amounts of Ni, Cr, Mo. Niobium was found to be present at all the zones. However the presence of Ti and Mo was more in the HAZ as compared to the weld zone. As reported by Shah Hosseini et al. [7], the solidification mode is changed from cellular to dendritic as Nb has an intense tendency to increase the degree of constitutional under-cooling. Mo has been found as richer constituent in the weld region, weld interface and the HAZ of Inconel 625. It is known fact the PCGTA welding employs lower heat input which resulted in higher cooling rates. It was reported by Shah Hosseini et al. [7] that a lower heat input significantly forms the finer microstructure has a lower segregation ratio of Mo which makes the welds brittle at room temperature. That would be the probable reason the fracture occurred at the weld zone.

As evident from the microstructures, the dark spots found at the HAZ would be the NbC, (Nb,Ti)C which would have contributed for greater hardness and strength at the HAZ than the weld zone.

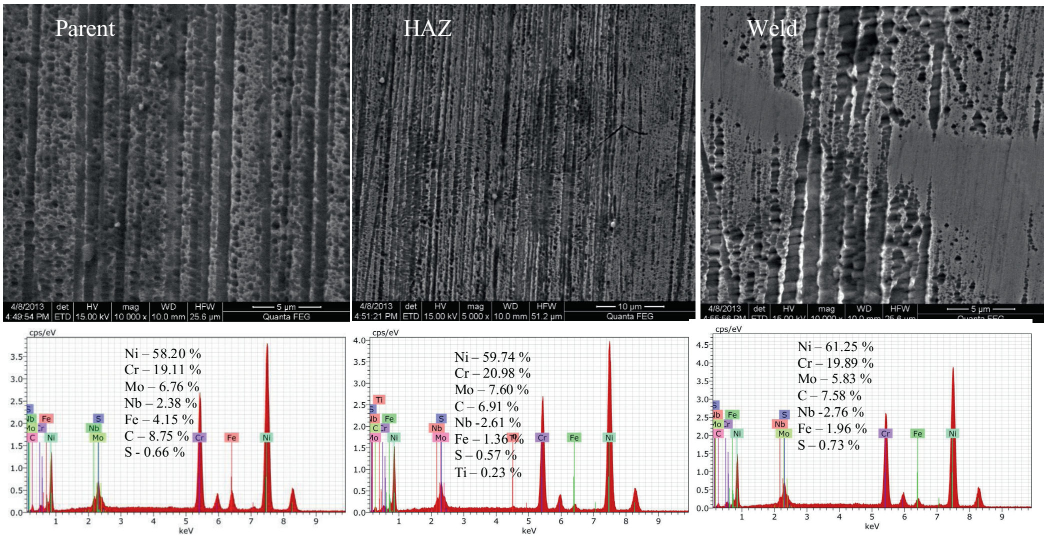

Fig.6 SEM/EDAX analysis on the PCGTA weldments in the as-welded conditions

4. Conclusions

Based on the studies, the major conclusions have been drawn and reported as below:

1. Successful defect free weldments of Inconel 625 could be obtained from the PCGTA welding technique
2. Tensile failures occurred at the weld region and the average tensile strength of the PCGTA weldments of Inconel 625 employing ERNiCrMo-3 was found to be 852.4 HV
3. Presence of richer amounts of Nb, Ti and Mo contributed for enhanced mechanical properties.

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References

[1] F.J. Martin, P.M. Natishan, K.E. Lucas, E.A. Hogan, A.M. Grolleau, E.D. Thomas, 2003. "Crevice corrosion of alloy 625 in natural seawater", Corrosion 59, p.498

[2] Kuk Hyun Song, Kazuhiro Nakata, 2009. "Mechanical Properties of Friction-Stir-Welded Inconel 625 Alloy", Materials Transactions, Vol. 50, No. 10 p. 2498

[3] H.X. Hu, Y.G. Zheng, C.P. Qin, 2010. "Comparison of Inconel 625 and Inconel 600 in resistance to cavitation erosion and jet impingement erosion", Nuclear Engineering and Design 240, p.2721

[4] O. Boser, 1979. "The Behavior of Inconel 625 in a Silver Environment", Materials Science and Engineering, 41, p.59.

[5] E. Otero, A. Pardo, J. Hernaez, F.J. Perez, 1991. "The hot corrosion of in-657 superalloy in Na_2SO_4–V_2O_5 melt eutectic", Corros. Sci. 32, p.677.

[6] E. N'dah, M. P. Hierro, K. Borrero, F. J. Pe´rez, 2007. "Study of the Cyclic Oxidation Resistance of Superalloy IN-625: Lifetime Predicted by COSP-Modelling Program", Oxidation of Metals, Vol. 68.

[7] H. Shah Hosseini, M. Shamanian, A. Kermanpur, 2011. Mater. Charact. J., 62, p. 425.