Cryogenics 83 (2017) 1–7

Contents lists available at ScienceDirect

Cryogenics

journal homepage: www.elsevier.com/locate/cryogenics

Research paper

Effect of post weld heat treatment on the microstructure and mechanical properties of ITER-grade 316LN austenitic stainless steel weldments

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ARTICLE INFO

Article history:
Received 8 November 2016
Received in revised form 29 December 2016
Accepted 2 February 2017
Available online 4 February 2017

Keywords:
316LN austenitic stainless steel
Post weld heat treatment
Impact toughness
Fracture
σ-Phase

ABSTRACT

The effect of postweld heat treatment (PWHT) on the microstructure and mechanical properties of ITER-grade 316LN austenitic stainless steel joints with ER316LMn filler material was investigated. PWHT aging was performed for 1 h at four different temperatures of 600 °C, 760 °C, 870 °C and 920 °C, respectively. The microstructure revealed the sigma phase precipitation occurred in the weld metals heat-treated at the temperature of 870 °C and 920 °C. The PWHT temperatures have the less effect on the tensile strength, and the maximum tensile strength of the joints is about 630 MPa, reaching the 95% of the base metal, whereas the elongation is enhanced with the rise of PWHT temperatures. Meanwhile, the sigma phase precipitation in the weld metals reduces the impact toughness.

1. Introduction

The 316LN austenitic stainless steel has been the backbone structural material for many components due to its increase of strength at cryogenic temperature and the nitrogen stabilizes the austenitic phase. However, the relatively high contents of chromium and molybdenum, which improve the corrosion resistance of these steels, make the austenite unstable in the temperature range of 650 °C to 900 °C with respect to formation of chromium-rich carbides and intermetallic phases [1–4]. In particular, the presence of the σ-phase, which is hard and brittle, harmfully affects the mechanical properties by creating local embrittlement and forming microcracks at the σ/γ-phase interfaces during loading.

The 316LN austenitic stainless steel used in ITER components is often welded, such as the cases of superconducting magnets of the TF(Toroidal coil) and CC(Correction coil) [5–8]. The residual stress and deformation of these components caused by welding and machining should be closely monitored during fabrication. Obviously, the stress relieving after the welding is a critical process to insure the manufacturing precision. Post weld heat treatment (PWHT) was considered as a feasible method of reducing the residual stress and of minimizing the strength gradient across the weld joint. Many papers have reported the effect of PWHT on microstructure and mechanical properties of martensitic and duplex stainless steel welds [9–13], few is known about the weld joints in austenitic stainless steel. Thus, their PWHT process must be done carefully and observation of their following changes must be closely studied to avoid the detrimental effects.

The present investigation was concerned with an evaluation of the effect of post weld heat treatment at 600 °C, 760 °C, 870 °C and 920 °C on the microstructure, tensile properties and impact toughness of 316LN austenitic stainless steel weldments conducted through TIG welding technique with 316LMn filler metals since the wires are expected to provide a fully austenitic microstructure in the weld. The correlation between the changes in the microstructure during aging treatment, and impact toughness of the investigated materials was assessed in order to obtain the optimum PWHT temperature for reducing the residual stress in the weld and assure the manufacturing precision.

2. Experimental

The 316LN austenitic stainless steel plates were manufactured by TISCO(China) and the plates are solution-treated at 1050 °C for 140 min and water quenched. The chemical compositions of 316LN and its filler metal ER 316LMn (1.4455) were shown in Table 1 which detected by atomic emission spectrometer, and the mechanical properties of the base metal at room temperature is shown in Table 2. The XRD analysis of the base metal shows the single austenitic phase, no carbide or nitride was found in

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http://dx.doi.org/10.1016/j.cryogenics.2017.02.001
0011-2275/

Table 1
Chemical composition of base material (316LN) and filler material (ER 316LMn).

	C	Cr	Ni	Si	Mn	Mo	N	P	S	Co	Nb	B	Fe
316LN	0.014	16.46	12.98	0.51	1.70	2.10	0.14	0.012	0.002	0.03	0.011	0.001	Balance
ER316LMn	0.009	20.3	15.5	0.49	7.0	2.9	0.17	0.01	0.005	–	–	–	Balance

Table 2
Mechanical properties of the base metals.

	Elongation [%]	Yield strength [MPa]	Ultimate tensile strength [MPa]	Impact toughness [J/cm^2]
316LN	55.0	352	665	>300

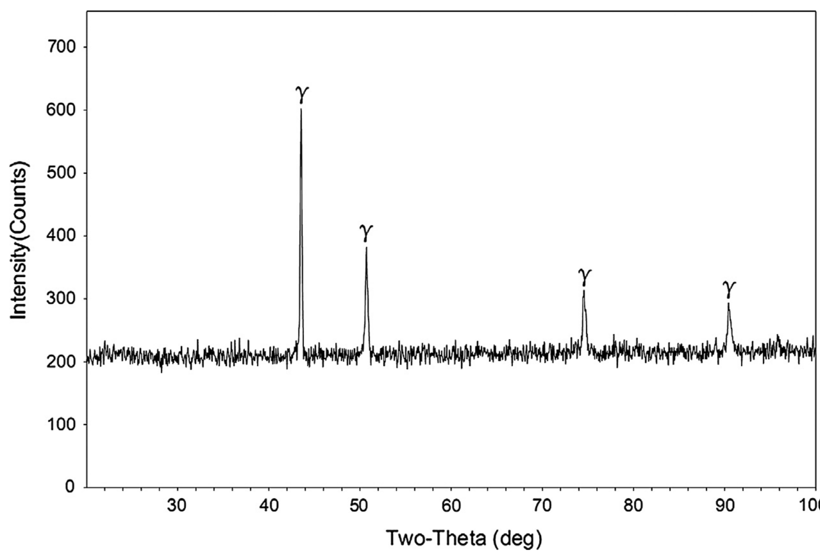

Fig. 1. XRD result of the 316LN austenitic stainless steel.

Fig. 1. The butt joints of 360 × 150 × 35 mm 316LN plates were welded by TIG with the welding parameters which shown in the Table 3 and the welding groove is shown in Fig. 2. The shield gas was Argon and the maximum inter-pass temperature was strictly controlled below 80 °C. The joints were held at temperatures of 600, 760, 870 and 920 °C in the RVSB-7816 vacuum furnace for 1 h, and then cooled at ambient temperature in the air. The microstructure of joints and basic metal were analyzed with optical microscopy (OM), scanning electron microscopy (SEM, SU8020) with energy dispersion system (EDS) techniques. The phases in the different PWHT temperature of the 316LN weldments were analyzed by using a D8 ADVANCE X-ray diffractometer with Cu Ka radiation of wavelength 1.544 Å.

The tensile strength and impact toughness with Charpy V notch of different aging temperatures were investigated according to the EN ISO4136:2012 and EN ISO9016:2012 standards, respectively. Impact test and cross-weld tensile specimens were extracted from the steady state region of the joints using the wire-electrode cutting process. The dimensions of the samples extracted from the joints were shown in Fig. 3. The tensile test was performed on the WA-1000A electro-hydraulic universal testing machine, the impact test specimens were immersing in the liquid nitrogen and then tested on the impact testing machine in few seconds. The fractured morphologies of weldments were characterized by SEM and EDS.

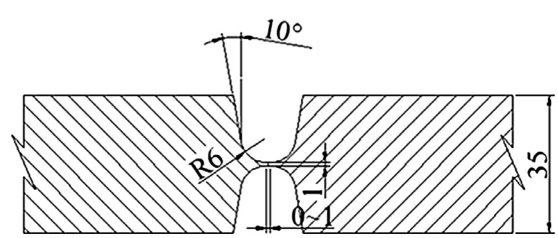

Fig. 2. Groove design of welding joint.

Table 3
Process parameters of TIG welding,

Passes	Voltage [V]	Current [A]	Flow rate [L/min]	Welding speed [mm/min]	Filler wire dia. [mm]
Root pass	8–15	140	10–15	100–140	2.4
Fill passes	8–15	180–200	10–15	100–140	2.4
Cover pass	8–15	140–160	10–15	100–140	2.4