Journal of Materials Processing Technology 211 (2011) 2032–2038

Contents lists available at ScienceDirect

Journal of Materials Processing Technology

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

Improving 410NiMo weld metal toughness by PWHT

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ARTICLE INFO

Article history:
Received 18 November 2010
Received in revised form 1 June 2011
Accepted 27 June 2011
Available online 2 July 2011

Keywords:
Repair welding
Toughness
PWHT
Retained austenite
Soft martensitic stainless steels
ER410NiMo

ABSTRACT

Highlights of the present study is the importance of choosing suitable temperatures for two stage PWHT to achieve desirable toughness in the weld metals produced by ER 410NiMo filler wire. Weld pads prepared using this filler wire was used for extensive metallurgical characterization of the weld metal. Results indicate by choosing appropriate temperatures for the PWHT, it is possible to obtain toughness in the weld metal which is comparable to the toughness reported for the base metal of similar composition. Good toughness of the weld metal is attributed to the presence of retained austenite in the weld metal. Two stage PWHT that gave excellent toughness for the weld metal was employed for repair of cracked shrouds of a steam turbine in a nuclear power plant. The metallurgical characterization of the mock up weld pad prepared prior to actual repair confirmed that microstructure and hardness of the weld metal are similar to those obtained during the welding procedure development.

1. Introduction

Martensitic stainless steels such as AISI 410, 414 grades are used in steam turbine components where high strength, toughness and wear resistance are mandatory. These components such as turbine blades, rotors and shrouds are produced by forging process. Therefore, these components are replaced by a new piece once it fails during operation. Repair of the cracked components by welding are not normally recommended by the original equipment manufacturers because of the mismatch in mechanical properties of the weld metal and the base metal. In spite of this repair welding are seldom used during refurbishment of power plants because it is considered to be more economical in terms of both time and money than the replacement of the component. In situ repair welding procedure was developed to repair cracked shrouds of a turbine in a nuclear power plant. In this case the shroud material conforms to AISI 414 martensitic stainless steel (ASM hand book, 1993). Toughness of 414 grade steel is more than that of 410 grade because it contains up to 2.5% Ni. Therefore, it is necessary to match weld metal toughness to that of shroud material toughness if the repair, as an option to be accepted by the utility. ER 410NiMo filler wire is used to produce weld metals with enhanced toughness because it contains ~5 wt% Ni and carbon content is considerably lower than the conventional martensitic stainless steels. Hence, this consumable is classified under soft martensitic stainless steels (Marshall and Farrar, 2001) and it finds applications in offshore oil pipelines because of its high resistance to pitting corrosion and stress corrosion cracking (Blimes et al., 2006).

Welds produced using this consumable are generally subjected to double stage PWHT consisting of a first stage tempering above the A_{c1} transformation temperature followed by cooling and a second stage tempering below the A_{c1} temperature, to ensure adequate toughness for the weld metal (Ramirez, 2007). The objective of first stage PWHT is to ensure adequate tempering of the martensite formed during weld cooling cycle; but part of this martensite would transform into austenite during the first stage of heat treatment and transform back to fresh martensite during subsequent cooling. Second stage heat treatment tempers this fresh martensite formed during the first stage PWHT. This two stage heat treatment is employed mainly because of the low A_{c1} temperature of the steel and a single stage PWHT, normally applied to alloy steels below A_{c1} would not temper the martensitic structure formed during welding. However, Das et al. reported that two stage PWHT carried out at 675 °C/2 h and 615 °C/4 h did not improve the toughness of the weld metal (Das et al., 2008). This called for a proper choice of two stage PWHT temperature employed for this weld metal before in situ weld repair of the cracked turbine components are considered using these consumables.

In the present study it is shown that two stage PWHT carried out just above A_{c1} for the first stage and below A_{c1} for the second stage can result in good toughness of the weld metal. This improvement in toughness is achieved not only by tempering of the martensite but also by the presence of retained austenite. This new two stage PWHT procedure was employed during repair welding of the cracked turbine components and the repaired components are performing satisfactorily in service for several years now.

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doi:10.1016/j.jmatprotec.2011.06.024

Table 1
Composition of ER410NiMo weld metal in wt%.

Elements	C	Cr	Ni	Mn	Mo	P	S	Si	V	Co	Cu	Sn	Cr_{eq}	Ni_{eq}
Wt %	0.02	12.5	5.0	0.45	0.50	0.025	0.045	0.40	–	–	0.32	–	13.6	5.8

Table 2
Welding parameters used for preparation of weld pads.

Current (A)	Voltage (V)	Heat input (kJ/mm)	Shielding gas	Preheat temperature, °C	Interpass temperature, °C	Post heating, °C	PWHT
50–60	12	1.1	99.99% argon	250	200	250 (15 min)	650 °C/2 h + 600 °C/4 h

The objective of the present study is to choose first stage PWHT temperature just above A_{c1} temperature and second stage just below A_{c1} temperature. This was required because instability of austenite increase with increase in temperature and very low temperature below A_{c1} is not adequate to temper the martensite. Very poor toughness ~13 J has been reported by Das et al. after 675 °C/2 h and 615 °C/4 h heat treatment (Das et al., 2008). In spite of two stage PWHT, presence of retained austenite in the weld metal influences toughness of the weld metal. This aspect has not been addressed adequately in any literature. Thus, a judicious selection of first stage PWHT temperature just above the A_{c1} temperature of the alloy and time is required to derive the full benefits of reverted austenite formed during the PWHT. The paper describes a study on welding procedure qualification for welding 414 martensitic stainless steel turbine shroud with ER 410NiMo filler wire and selection of appropriate PWHT temperatures to ensure good toughness of the weld metal.

2. Experimental

Elemental composition of ER 410NiMo weld metal employed in the present study is given in Table 1. In order to choose the appropriate temperatures of PWHT, A_{c1} temperature of the weld metal was determined experimentally. For this purpose filler wire was deposited on a steel plate using GTAW process. This weld metal deposit was first given a solutionizing heat treatment at 1000 °C/1 h followed by air cooling. Subsequently, specimens extracted from it were subjected to tempering in the temperature range 450–825 °C for 1 h at each temperature. Subsequently, the hardness of the weld metal was measured using Vickers hardness tester and values were plotted as a function of tempering temperature. The temperature that gives minimum hardness and above which hardness increases with increase in tempering temperature is chosen as A_{c1} temperature.

A weld pad was prepared using Gas Tungsten Arc Welding (GTAW) process with12 mm thick AISI 410 stainless steel plate and 410NiMo consumable using the welding parameters given in Table 2 for evaluation of weld metal toughness. Another weld pad was prepared using pieces from the original shroud piece that was employed for repair welding and 410NiMo consumable. The welding process and parameters employed were same as those used for the weld pad prepared for toughness evaluation. This weld pad was used for tensile and bend tests during the procedure qualification. After completion of the two stage PWHT, the weldments were subjected to radiographic examination and found to be defect free. Metallographic specimens were prepared from the welds after first and 2nd stage heat treatments using standard grids of emery papers for grinding and diamond slurry of 0.25 μm for final polishing. Specimens were etched using Villela's reagent and were examined using optical and scanning electron microscope (SEM). Energy dispersive spectra (EDS) were taken at different locations on the specimens and variation in the composition was studied assuming that weld metal is essentially a Fe–Cr–Ni alloy. Hardness of the weld metal was measured using Vickers hardness tester. Weld metal was examined for retained austenite using X ray diffraction (XRD) technique which was carried out using a Fe-Kα radiation for the 2θ range 40°–120° in step interval of 0.01°.

Flat, sub size cross weld tensile specimens of dimension $100 \times 10 \times 3$ mm, gauge length 25 mm and $L_0/\sqrt{A_0} = 4.5$ and bend test specimen of size $100 \times 20 \times 3\,mm^3$ were fabricated from the weld pad prepared in the laboratory using shroud piece and the ER 410NiMo filler wire. The room temperature transverse tensile and bend tests were carried out for the weldments as per ASTM practice E8-04 (American Standards, 2009) and ASTM practice E 190-92 (American Standards, 2008) respectively after the PWHT. The strain rate employed for the tensile test is $3.3 \times 10^{-4}\,s^{-1}$. The full size cross weld Charpy impact specimens were prepared from the weld pad prepared from 12 mm thick 410 martensitic stainless steel plates with the notch in the weld metal along the welding direction. Charpy impact tests were conducted at room temperature and fracture surfaces of the specimens were examined using scanning electron microscope (SEM).

After successful completion of the repair welding procedure, the shroud piece subjected to mock up welding was used for metallography and hardness measurements. Microstructure was examined using optical microscope and SEM.

2.1. Results

2.1.1. A_{c1} temperature for weld metal

The variation of hardness of the weld metal with tempering temperature for fixed duration of 1 h is shown in Fig. 1. Hardness of the as welded sample was 450 VHN and it decreased to

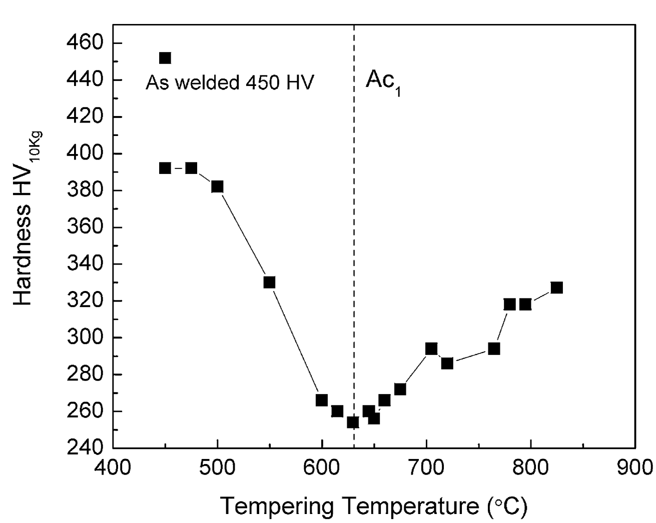

Fig. 1. Hardness variation with tempering temperatures for 410NiMo filler wire.