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Improvement of localised corrosion resistance of AISI 2205 Duplex Stainless Steel joints made by gas metal arc welding under electromagnetic interaction of low intensity

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ABSTRACT

The resistance to localised corrosion of AISI 2205 duplex stainless steel plates joined by Gas Metal Arc Welding (GMAW) under the effect of electromagnetic interaction of low intensity (EMILI) was evaluated with sensitive electrochemical methods. Welds were made using two shielding gas mixtures: 98% Ar + 2% O_2 (M1) and 97% Ar + 3% N_2 (M2). Plates were welded under EMILI using the M1 gas with constant welding parameters. The modified microstructural evolution in the high temperature heat affected zone and at the fusion zone induced by application of EMILI during welding is associated with the increase of resistance to localised corrosion of the welded joints. Joints made by GMAW using the shielding gas M2 without the application of magnetic field presented high resistance to general corrosion but high susceptibility to undergo localised attack.

1. Introduction

Duplex stainless steels (DSS) are very attractive materials because their acceptable combination of mechanical properties and resistance to localised corrosion. The name of duplex comes from the phase ratio, ferrite (δ) to austenite (γ), of approximately 50/50 at room temperature. Nevertheless, it is well known that, during fusion welding, these alloys undergo severe microstructural transformations involving redistribution and phase ratio changes in the weld metal and at the high temperature heat affected zone (HTHAZ), inducing degradation of mechanical properties and resistance to localised corrosion [1].

Thermal cycles involved in the gas metal arc welding (GMAW) process induce grain coarsening and increase of the volume fraction of δ-phase in the HTHAZ, due to complete and partial dissolution of γ-phase. The austenite cannot entirely regenerate after welding because the relatively fast cooling rate arrests the transformation [1–9]. Another process taking place in the HTHAZ, is the precipitation of detrimental phases such as σ, chromium carbides and chromium nitrides which reduces toughness, ductility and resistance to localised corrosion of the alloy [10–13]. While carbides nucleate and growth in the δ-δ or δ-γ grain boundaries [1,10,11] chromium nitrides are intragranularly allocated in the δ-phase [1,2,5,14]. The undesirable formation of these phases and compounds induces the depletion of Cr and Mo at zones adjacent to the compounds making the HTHAZ susceptible to localised corrosion.

The generation of γ-phase in the weld metal depends on the heat input, chemical composition of filler wire and presence of nitrogen in the shielding gas [1,5,14–17]. During fusion welding, cooling of the weld metal must be sufficiently slow for nucleation and growth of γ-phase at grain boundaries of δ-phase facilitating the diffusion of γ-phase stabiliser elements [18]. Simultaneously, the cooling rate has to be fast enough to avoid nucleation and growth of detrimental phases at the HTHAZ.

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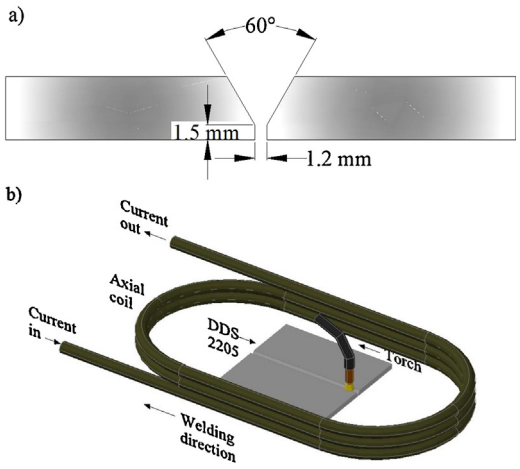

Fig. 1. (a) Single V groove preparation of DSS samples for welding, (b) experimental setup for application of magnetic field during welding.

Research efforts have been devoted to controlling the microstructure of DSS fusion welds by the application of post-weld heat treatment in order to balance the γ/δ ratio and diminish detrimental phase's quantity [1,19–23]. This study was focused on avoiding the application of post-weld heat treatment after GMAW of DSS by applying EMILI during welding. It is well known that the application of magnetic external fields during welding gives rise to electromagnetic stirring (EMS) of the weld pool, resulting in grain refinement of the weld metal [8,24,25]. Previous studies reported that the application of an external magnetic field during welding not only modifies the solidification mode of the weld metal, but also influences the HAZ in an austenitic 304 stainless steel enhancing the resistance to intergranular corrosion [26,27]. This effect has been ascribed to the EMILI generated between the magnetic field inherent to direct current (DC) welding and the external magnetic field applied. The objective of this work was to improve the resistance to localised corrosion at the weld zone of a 2205 DSS by generating an EMILI during welding and cooling using the gas mixture M1 and comparing the effects with the gas mixture M2 typically recommended during GMAW of DSS without the application of EMILI.

2. Experimental procedure

2.1. Materials and welding

Plates of AISI 2205 DSS (6.35 mm × 70 mm × 150 mm) with a single V groove configuration, as shown in Fig. 1a, were joined using the GMAW process with an ER-2209 filler wire, 1.2 mm in diameter, fed at 160 mm/s. Two shielding gas mixtures: 98% Ar + 2% O_2 (M1) and 97% Ar + 3% N_2 (M2) flowing at 17 L/min were used. The chemical composition of the base metal (BM) and filler wire are listed in Table 1. The welding torch was displaced at 3.6 mm/s with a stick out of 10 mm. A constant voltage power supply was used with direct current-electrode positive. Welding parameters were adjusted to obtain a heat input of 1.4 kJ/mm (approximately), considering an efficiency of 75% for the GMAW process.

Fig. 1b shows the experimental setup for welding with the application of EMILI using an external power supply. The external axial magnetic fields applied to induce EMILI during welding were of 0, 3, 6, 9, 12 and 15 mT, using as shielding gas the mixture M1. Another weld was performed without EMILI with the M2 gas mixture. Magnetic fields were measured using a Hall Effect device.

In order to determine the temperature at which the principal metallurgical transformations take place during welding, an empirical calculation of the cooling rate from the peak temperature raised in the HTHAZ was performed assuming that the $\gamma \rightarrow \delta$ transformation temperature is approximately 1300 °C, according to the time/temperature function developed by Lindblom and co-workers [28].

2.2. Microstructural characterisation

Optical microscopy analysis (OM) was conducted on samples in the as-received condition and on samples taken from transverse sections of the welded joints after standard metallographic preparation followed by electrochemical etching in KOH 10 M solution.

Phase quantification in the HTHAZ, weld metal (WM) of joints and samples in the asreceived condition, was performed with commercial software by determining the area fraction of γ-phase from digital images. Samples were also analysed in a scanning electron microscope (SEM) equipped with an energy dispersive X-ray (SEM-EDX) detector. For transmission electron microscopy (TEM) characterisation, thin foils of 3 mm diameter and 0.5 mm thick, were cut from the HTHAZ. The samples were thinned down to 40 μm with emery paper and subjected to electropolishing for TEM analysis using bright field (BFTEM) and high resolution (HR-TEM) techniques. A Tecnai F20 TEM operating at 200 kV and equipped with an energy dispersive X-ray (TEM-EDX) analyser was used.

2.3. Evaluation of resistance to localised corrosion

The effect of EMILI during welding on the resistance to localised corrosion on samples of the HTHAZ and WM was evaluated using two sensitive electrochemical methods, the double loop electrochemical potentiokinetic reactivation (DL-EPR) to determine the degree of sensitisation (DOS) and electrochemical noise measurements (EN). Tests were carried out on samples of 4 mm × 6 mm cut from the welded plates at the same position than those used for the microstructural analysis as indicated by the white line rectangle in Fig. 2. For the DL-EPR tests samples were embedded in epoxy resin to be used as working electrodes with a copper wire attached to the rear part for electric contact. A conventional three electrode electrochemical cell was used with the DSS samples as working electrodes, a saturated calomel electrode (SCE) as reference electrode and graphite bar as auxiliary electrode.

Tests were made three times for reproducibility using samples subjected to identical surface preparation; grinding with SiC paper until 1200 grid, rinsing with distilled water and degreasing with acetone. Fresh electrolyte was used for every electrochemical test.

The DL-EPR technique was used originally to measure the DOS of austenitic stainless steels [29], but its application for evaluating the DOS in DSS has been put into practice using more aggressive electrolytes. For the present case the electrolyte was 2 M H_2SO_4 + 1 M HCl as reported by Gong et al. [30]. Cyclic potentiokinetic polarisation was conducted from the open circuit potential to 200 mV vs CSE with a scanning rate of 1 mV/s at 30 ± 1 °C using a Potenciostat/Galvanostat PAR EG&G 273 A.

Table 1
Chemical composition of BM and filler wire, (wt.%).

	C	P	Si	Ni	Cu	N	Mn	S	Cr	Co	Mo	Fe
2205	0.016	.0021	0.400	5.720	0.150	0.170	1.370	0.001	22.420	0.240	3.130	Balance
ER2209	0.03 max	0.03 max	0.90 max	7.5–9.5	0.75 max	0.08–0.20	0.50–2.0	0.03 max	21.5–23.5	–	2.5–3.5	Balance