Fuel xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Fuel

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

Addition of nitrogen to GTAW welding duplex steel 2205 and its effect on fatigue strength and corrosion

D. Reyes-Hernández [a], A. Manzano-Ramírez [a], A. Encinas [b], V.M. Sánchez-Cabrera [c], Á. Marroquín de Jesús [d], R. García-García [d], G. Orozco [e], J.M. Olivares-Ramírez [d,*]

[a] Centro de Investigaciones y de Estudios Avanzados del I.P.N., Materiales, Unidad Querétaro, C.P. 76230, Mexico
[b] Instituto Potosino de Investigación Científica y Tecnológica, Advanced Materials, Camino a la Presa San José 2055, Lomas 4a sección, 78216 San Luis Potosí, Mexico
[c] Instituto Tecnológico de Querétaro, Av. Tecnológico, Materiales, Col. Centro, Querétaro CP 76000, Mexico
[d] Universidad Tecnológica de San Juan del Río, Energías Renovables, Av. La Palma No. 125, Col. Vista Hermosa, San Juan del Río, Querétaro 76800, Mexico
[e] Centro de Investigación y Desarrollo Tecnológico en Electroquímica, Electroquímica, Parque Tecnológico Querétaro, Sanfandila, Pedro Escobedo, C.P. 76703 Querétaro, Mexico

ARTICLE INFO

Article history:
Received 11 May 2016
Received in revised form 1 December 2016
Accepted 4 January 2017
Available online xxxx

Keywords:
Corrosion
Protective atmosphere
Heat input

ABSTRACT

The microstructural evolution of Duplex Stainless Steel 2205 was investigated during Gas Tungsten Arc Welding with three types of protective atmosphere: (a) Ultra-high purity Ar, (b) 98% Ar-2% N_2 mixture, and (c) 95% Ar-5% N_2 mixture. The microstructural evolution was also characterized for three different heat inputs: low, medium, and high (0.5, 1.5, and 2.5 J mm^{-1}. In terms of the effect of fatigue resistance and corrosion leading, the best performance was seen at values of 0.5 and 2.5 J mm^{-1}, respectively. The decrease of the (Austenite) phase in Ar welding was associated with low performance in terms of resistance to fatigue and corrosion. On the other hand, the N_2 content had a slight effect on the fatigue strength, tension, and impact resistance. A ductile fracture, which is desirable in this type of testing, was consistently observed. Protection with 2% and 5% N_2 atmospheres and the control of heat input in the plasma process enabled a 45-fold lowering of the corrosion rate, increasing the life of the welded joint.

1. Introduction

Austenitic stainless steels with high Nitrogen (HNS) content generally contain more than 0.4 wt% N_2. In solid solutions, Nitrogen is a beneficial element for increasing the resistance level without significant loss of ductility and toughness. It can significantly improve the corrosion resistance, intergranular stress, pitting, and cavities [1–5].

In stainless steel, Nitrogen is generally considered an undesirable impurity that causes porosity and the formation of brittle nitrides [6]. In the manufacture of industrial components, the substitution of ferritic and austenitic stainless steel by duplex stainless steel (DSS) has its origin in the excellent combination of mechanical properties and corrosion resistance of DSS. From this point of view, there is great interest in the study of these materials and their welding. Presently, these steels are very frequently used in the chemical and petrochemical industries, particularly in oil refining plants due to their high resistance to pitting corrosion [7].

Base metals with decreased Nitrogen content are produced when welding is performed in HNS steels without a Nitrogen blanket. This results in a loss of corrosion resistance and mechanical properties. When the protective atmosphere contains more than 7% Nitrogen, pores form easily in the welding zone [8–10,2,11,12].

To avoid the loss of Nitrogen and porosity, it is essential to have a fundamental understanding of the mechanism of Nitrogen adsorption and desorption. Many studies have been conducted to study the adsorption and desorption of Nitrogen during the welding process. The results show that this is a complex phenomenon that is influenced by many variables, such as the Nitrogen content in the base metal, concentration of active elements on the surface, pressure of Nitrogen in the protective atmosphere, Nitrogen content in the filler metal, and actual welding process used [13–15,11,12].

Some theories of dissolution mechanisms have been proposed for the welding process. M. du Toit & PC Pistorius mentioned that Sievert's law cannot be applied to describe the dissolution of a diatomic gas into a liquid metal in the presence of plasma because the results may show discrepancies in the content of Nitrogen for the solubility conditions in the equilibrium state during a Gas Tungsten Arc welding (GTAW) process. This is the reason for the

* Corresponding author.
E-mail address: jmolivar01@yahoo.com (J.M. Olivares-Ramírez).

http://dx.doi.org/10.1016/j.fuel.2017.01.008
0016-2361/© 2017 Published by Elsevier Ltd.

experimental need for different Nitrogen atmospheres and heat inputs. Nitrogen is an excellent producer of gammagene elements in solid solution for stainless steels and is considered to be thirty times more powerful than nickel as an austenite. Another studied gas is Argon, which is related to the formation of ferrite. Decomposition of ferrite-δ to austenite occurs through two different mechanisms, depending on the transformation temperature (the temperature of the surface weld puddle is considered to be approximately 1600 °C). The weld pool refers to a volume the size of a coin in the base metal that has reached its point of fusion and is ready to be mixed with the filler material. The first mechanism occurs at high temperatures (1600 °C). The reaction occurs by a process of nucleation and diffusional growth, while the second mechanism occurs when austenite is formed by displacement at low temperatures (700 °C) [16].

Depending on the variables, i.e., Nitrogen content and heat input, studies have been conducted with three heat inputs (0.528, 1.350, and 2.340 J mm^{-1}) in which it was observed that when there is 10% or more Nitrogen in the protective atmosphere, porosity occurs in the welded metal. However, it is necessary to establish the relation between Nitrogen content and corrosion rates in welded joints [17].

Thus, there is a need for studies on heat input as it relates to the formation of ferrite. This work aims to find the relation between different protective atmospheres of Nitrogen mixed with Argon and heat inputs in stainless steel 2205 when welded using the GTAW technique under different conditions to improve corrosion resistance and mechanical properties.

2. Methodology

2.1. Materials and specimen

A stainless steel plate (Outokumpu® UNS S32205 duplex 2205) 914.4 × 914.4 × 6.35 mm in size, with the chemical composition shown in Table 1, was used. This was labeled the base metal.

Base metal plates 60 × 200 × 6.35 mm in size were cut to be welded using GTAW with an ER 2209 input. During the welding process, the standard Welding Procedure Specifications (WPS) were observed, in compliance with the American Welding Society's (AWS) code D1.1.

2.2. Methods

The welding process was conducted using the automatic device "bug-o-system Go-Fer III" (Fig. 1), in which two plates are clamped to a workbench that allows horizontal displacement at a controlled rate between 200 and 2500 mm min^{-1} during the welding process. In displacement welding, welding occurs during forward movement. During recoil, there is no welding work. The equipment allows the flow of a gas (Argon-Nitrogen) feed from four points: top, floor, front, and rear. The main purpose of the device is the measured addition of the protective atmosphere and the heat input into the welding pool by controlling the speed of the electrode. The edges of the plates are discarded to avoid any imperfections during welding due to the inlet and outlet of the torch.

The parameters used in the GTAW process are shown in Table 2. The combinations of shielding gas were as follows: (a) Argon, Ultra-high purity, (b) Mixture of 98% Ar-2% Nitrogen and (c) Mixture of 95% of Ar-5% N_2. A flow rate of 0.7084 $m^3 h^{-1}$ was applied to the torch and back in all experiments. The union was performed by five passes through the top and one on the back. After welding, the specimens were obtained from the center, cutting perpendicular to the direction of welding.

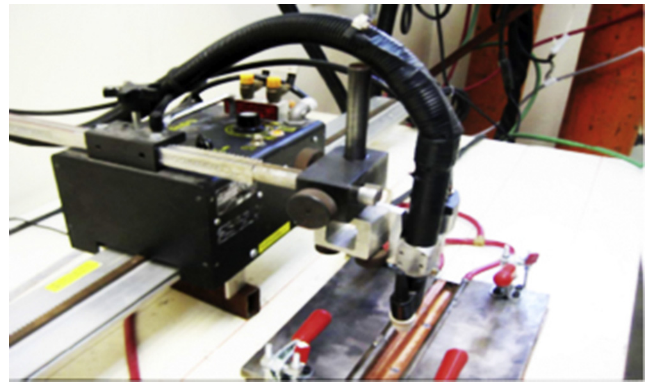

Fig. 1. Automatic device Go-Fer III; generates a spherical atmosphere in 30 s, wireless control, current between 0 and 300 A, supply tension 220 V, and automatic power supply.

For mechanical characterization of the material, tensile tests were carried out in a hydraulic servo universal machine, Instron Model 4482 STD-C 8030, with a capacity of 100 kN and an extensometer MTS Mark specimens® (634.11F-25 model), at a loading speed of 1 mm min^{-1}. The tests were conducted according to the ASTM E 466-96 standard.

For the Charpy impact test, rigid pendulum-type Satec SI 1K3 equipment was used. The surfaces of the specimens obtained from the plate welded in the GTAW process were machined according to the ASTM E23 standard. Polishing was not required, and the test was conducted at room temperature. The specimens were placed exactly in the center, using V-Notch Charpy sample forceps against the anvil clamps of the pendulum. Free oscillation of the pendulum was monitored, and the tangential velocity in the area of impact remained constant at a value of 3 m s^{-1}. Care was taken to report whether there was full or no fracture.

Micro-hardness was tested on a smooth, flat surface, free of dust and grease, in a Rockwell Future Tech Corp® machine, with FR micro-hardness 3. Future Tech® equipment, model FM 7, was used to evaluate the profile. The measurements were carried out perpendicular to the direction of welding. A preloading of 200 gF for 13 s was applied to each indentation. Moreover, the specimens tested were normalized according to ASTM E3 84.

Specimens with a cross-section of 5.0 × 4.46 mm^2 were used in an 810 MTS® Universal Machine; for all specimens, the cyclic sinusoidal load was applied at a rate of 30 Hz at room temperature, with amplitude σ_{min} = 52 MPa and σ_{max} = 520 MPa. The corresponding ratio, $R = \sigma_{min}/\sigma_{max} = 0.1$, was equivalent to 80% of σ_{CED}. Different numbers of cycles obtained in the fatigue test allowed the determination of stress-cycle (S-N) curves for a comparison of behaviors and to obtain repeatability in the tests, ensuring consistent performance between them.

An Optical Emission Spectrometer, Spectrolab Lab MB 18B Spectra 220®, was used for chemical analysis. The specimen was a flatbed with a 6.3 mm thickness.

Table 1
Chemical composition of steel Duplex 2205, obtained from the certificate of origin.

2205 UNS 32205	C (%)	Si (%)	Mn (%)	P (%)	S (%)	Cr (%)	Mo (%)	Ni (%)	Nb (%)	Cu (%)	Co (%)	N (%)
	0.018	0.39	1.50	0.021	0.001	22.37	3.23	5.75	0.006	0.14	0.09	0.177