



Characterization of AISI 304/AISI 409 stainless steel joints using different filler materials



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HIGHLIGHTS

- Dissimilar stainless steel joints were characterized using different filler metals.
- The effect of microstructure on the mechanical properties was studied.
- The austenitic weld provided a balance between strength and cost of welding.

ARTICLE INFO

Article history:

Received 11 March 2016

Received in revised form 24 April 2017

Accepted 25 April 2017

Keywords:

Mechanical properties

Stainless steel

Joint

Welding

ABSTRACT

Four different industrial filler metals were selected for the joining of AISI 304 austenitic to AISI 409 ferritic stainless steel. These fillers were austenitic and duplex stainless steels and a nickel-based alloy. The microhardness and longitudinal tensile tests were performed for evaluation of the mechanical properties. The microstructural analysis indicated that the dissimilar welding led to the formation of different ferrite-austenite solidification patterns in weld metals; also, no evidence of carbide/nitride phases was detected. Although three welds showed proper tensile strength values; the weld 316L presented the best mechanical properties from the cost saving point of view.

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1. Introduction

Stainless steels have seen a large increase in civil engineering applications over the past few decades. The high corrosion resistance of these steels can decrease the need for maintenance. The two main applications of stainless steels for civil engineering structures are reinforced concretes and structural steels [1]. In these applications, stainless steels can use as a replacement for carbon steels. In corrosive media, corrugated stainless steels are applied in reinforced concrete structures. Also, they can be found as structural steels; for example, austenitic stainless steels have been used in the Spencer Street Bridge, Melbourne; and austenitic-ferritic (duplex) steels have been used in construction of the Millennium Footbridge, London [1]. Ferritic stainless steels are a good alternative to the most common adopted austenitic ones due to their better ductility, higher strength and superior corrosion resistance in caustic environments [2–5]. However, the poor ductility and low Charpy V-notch impact toughness of the weld section have limited

their application [6]. The demand for joining ferritic-austenitic stainless steels in nuclear, automotive, power generation, chemical and petrochemical industries is ever increasing. The dissimilarity between thermal expansion coefficients (CTE) of austenitic and ferritic steels could lead to the formation of hard and soft constituents in the heat affected zone (HAZ) and weld metal (WM), and probably crack propagation at the weld interface [7]. On the other hand, the microstructural variations depend on the carbon content, cooling rate and segregation of alloying elements [6,8].

Although austenitic stainless steel filler metals were usually used for ferritic-austenitic stainless steel joints, the application of other filler metals such as Ni-based ones could make a considerable improvement in performance [9–11]. The carbon diffusion as a major problem is also significantly decreased due to the reduced diffusion rate of carbon in nickel-alloy weld metal, thus segregation of carbon and carbon depletion significantly decreases when Ni-based filler metals are used [9,12].

The formation of chromium-depleted zones is also a big problem in welding of stainless steels. Somervuori et al. [13] showed that the Cr-depleted layer in the weld zone diminished the corrosion resistance of austenitic stainless steels; while Bautista et al. [14] related

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this phenomenon the formation of oxides in the welded stainless steel reinforcements.

Falat et al. [9] investigated microstructure and creep behavior in joining of TP316H austenitic steel to T91 martensitic steel using Ni-based filler material. The microstructure of nickel weld metal has reported to be very heterogeneous in size, morphology and distribution of grains; MC-type precipitates (containing Nb and Ti) as a result of dilution effects and fast non-equilibrium solidification process were observed.

Hsieh et al. [15] discussed the microstructural evolution during dissimilar gas-tungsten arc welding (GTAW) of AISI 304 and AISI 430 stainless steels. The massive δ -ferrite preferred to precipitate at the austenite phases and ferrite-austenite interface boundaries. The hardness of weld metals was higher than the base metals, and it was attributed to the massive δ -ferrite precipitation.

Khan et al. [16] investigated the effect of different process parameters on the microstructure and hardness properties in laser beam welding (LBW) of AISI 304L to AISI 430 stainless steels. They found that the weld metal contained variety of complex austenitic–ferritic microstructures. A continuous martensitic layer along ferrite grain boundaries and inter-granular carbides of Cr_{23}C_6 were formed in the fusion zone. Therefore, the weld metal was harder than both base materials. The Widmanstätten austenite was also found along some ferrite grain boundaries.

Shanmugam et al. [17] studied the effect of different filler metals (AISI 308L, AISI 430 and AISI 2209 filler metals) on the microstructure and mechanical properties of 409 stainless steel joints. They showed that the microstructure in the austenitic and the ferritic weld metals was fully austenitic and ferritic, respectively. According to their findings, the coexistence of ferrite and austenite in the microstructure presented the best mechanical properties of the weld metal at room temperature. Mukherjee et al. [18] compared the microstructure and mechanical properties of 409 stainless steel welds obtained by type 316L and 308L filler metals. They showed that two major factors affecting the microstructure were $\text{Cr}_{\text{eq}}/\text{Ni}_{\text{eq}}$ ratio and heat input. Type 308L specimen yielded better mechanical properties and higher amounts of martensite. Velasco et al. [19] found that the yield strength of austenitic and duplex stainless steels could be decreased after welding in concrete structures.

Kim et al. [20] studied the effect of $\text{Cr}_{\text{eq}}/\text{Ni}_{\text{eq}}$ ratio on the microstructure and mechanical properties in joining 316L stainless steel. They showed higher $\text{Cr}_{\text{eq}}/\text{Ni}_{\text{eq}}$ values altered the solidification path/microstructure of AISI 316L welds from austenite–ferrite (AF) mode/vermicular ferrite to ferrite–austenite (FA) mode/lathy ferrite. Also, they showed among $\text{Cr}_{\text{eq}}/\text{Ni}_{\text{eq}}$ ratios varying between 1.3 and 2.2, the specimen with 1.3 of $\text{Cr}_{\text{eq}}/\text{Ni}_{\text{eq}}$ ratio showed the best impact toughness in as-weld and after post-weld heat treatment (PWHT) conditions. Muthupandi et al. [21] reported no chromium nitrides were formed in the weld metal of duplex stainless steel when GTAW process was applied. Also, Compared to the weld interface, the more amount of austenite was found in the weld center.

Although several research work exist on the welding of stainless steels in civil engineering applications, the understanding of intricate issues in these joints is still a hot topic. Austenitic stainless steels like AISI 304 were reference alloys because of their utilization in civil engineering for many years [22]. On the other hand, the extraordinary properties of duplex stainless steels have led to the increased application of these metals in this field [23]. In this study, the effect of different austenitic, duplex and nickel-based filler materials on the microstructure and mechanical properties of dissimilar welds between AISI 304 austenitic and AISI 409 ferritic stainless steel was investigated.

2. Materials and methods

The base plates in this study were AISI 304 austenitic and AISI 409 ferritic stainless steel. These materials were received in the form of 3 mm thickness plates and were cut into the required dimensions (250×140 mm). Three different stainless steel filler metals and Nichrome 80/20 rod were used to produce the weldments. Table 1 shows the nominal compositions and the values of $\text{Cr}_{\text{eq}}/\text{Ni}_{\text{eq}}$ ratio for base and standard filler materials. The butt joint configuration was employed for single pass gas tungsten arc welding process. Several trial runs were performed to obtain the optimum welding variables. The details of welding parameters are as written in Table 2.

The metallographic sections were prepared transverse to the welding direction for optical microscopy. These specimens were polished using different grades of emery papers, and then stainless steel samples were electrically etched with a solution containing 10 g oxalic acid and 100 ml H_2O at 6 V DC-supply for 35 s. The Ni-based sample was etched with Vilella's reagent and also a solution containing 7.5 mL HF, 2.5 mL HNO_3 , and 200 mL methanol to observe all microstructural details.

Also, the welded joints were cut by a water jet cutter in the longitudinal direction to prepare sub-sized tensile test specimens according to ASTM E8 standard (Fig. 1). Tensile tests were then carried out using a Zwick Z250 testing machine (with a load capacity of 250 kN) at room temperature with a nominal strain rate of 1 mm/min. The Vickers hardness measurements with a load of 500 g were performed in a line approximately 1 mm below the surface to obtain the hardness profile in different regions of the welds.

More investigations on the microstructures and fracture surfaces were performed by a LEO VP 1450 scanning electron microscope. The phase characterization was done using a Philips PW 3040/60 X'pert X-ray diffractometer (XRD).

3. Results

Fig. 2 shows the microstructure of type 310 weld metal on the austenitic side of the joint. The equiaxed austenite grains were observed in the microstructure of 304 stainless steel. In all specimens, the HAZ microstructure on the austenitic side consisted of the untransformed δ -ferrite at austenite grain boundaries. The HAZ microstructure was generally finer than the base metal (BM) microstructure and this could result in the higher mechanical properties.

The microstructure of ferritic base metal consisted of fine equiaxed alpha ferrite grains. Fig. 3 shows the microstructure of HAZ adjacent to the ferritic base plate. In all specimens, the heat affected zone on the ferritic side had a similar microstructure and could be divided to the high and the low temperature HAZ. In the low temperature HAZ (LTHAZ) huge δ -ferrite grains were present; and martensite laths were found at δ -ferrite grain boundaries in the high temperature HAZ (HTHAZ).

The microstructure of 310 stainless steel weld metal was finer than other specimens and consisted of δ -ferrite with different morphologies in the austenitic matrix (Fig. 4(a)). The FA solidification mode was dominant in this weld. During cooling, ferrite was the primary solidification phase and austenite was formed by a peritectic–eutectic reaction at lower temperatures. The final microstructure was the combination of lathy and vermicular ferrite in the austenitic matrix while the proportion of vermicular ferrite was higher.

Fig. 4(b) shows the microstructure of 316L stainless steel weld metal. The microstructure consisted of a random arrangement of acicular ferrite in the austenitic matrix. This mixture was surrounded by an austenitic net which has been reported by other researchers [24]. Small amounts of vermicular and untransformed ferrite were also found in the weld metal. The solidification path for this weld was the FA mode with higher $\text{Cr}_{\text{eq}}/\text{Ni}_{\text{eq}}$ ratio compared to type 310 weldment. Therefore, acicular ferrite with sharp needle features was present in the microstructure (Fig. 5). It could be expected that this acicular morphology yields proper mechanical properties.

According to Fig. 6(a), the microstructure of type 2209 weld metal was a predominantly grain boundary nucleated austenite.

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