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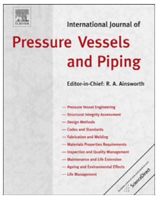

Microstructural and weldability analysis of Inconel617/AISI 310 stainless steel dissimilar welds

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ABSTRACT

In this study, the microstructural evolutions and weldability of the Inconel 617/310 austenitic stainless steel dissimilar welds were investigated. Three types of filler materials including Inconel 82, Inconel 617 and 310 austenitic stainless steel were used to fabricate dissimilar joints using the gas tungsten arc welding process. Microstructural observations showed distinct cracks in the weldment produced by 310 austenitic stainless steel filler metal. The results of varestraint weldability test showed that the joints produced by Inconel 617 and 310 stainless steel filler metals exhibited the highest and lowest resistance to solidification cracking, respectively. The relatively poor cracking resistance of the welds prepared by 310 stainless steel was attributed to the wide solidification temperature range and presence of low melting point secondary phases.

1. Introduction

Dissimilar metal welding (DMW) is widely used to join two different alloys together. In this regard, the fabrication of defect-free joints is the main concern in many engineering applications such as Pressure Vessels, petroleum, chemical, nuclear, aerospace, power generation, and other industries. The weldability, mechanical properties, and corrosion resistance of weldments is significantly controlled by solidification behavior and the resultant microstructure of the fusion zone. In many cases, stainless steels are welded to Ni-base alloys when a transition is required to accommodate more oxidizing environment or superior strength requirement at elevated temperature. On the other hand, the replacement of Ni-base alloys with stainless steels can decrease material costs [1–3].

Ni-base superalloy 617, also designated as Inconel 617 is a solid solution alloy with excellent corrosion resistance and an exceptional combination of high temperatures strength and oxidation resistance. The components made of Inconel 617 are widely used in power plants, chemical industries, aircrafts and land-based gas turbines. In addition, this alloy is of considerable interest as one of the candidate materials for manufacturing gas-cooled reactors working at high temperatures. The excellent creep strength of Inconel 617 is attributed to solid solution strengthening provided by the Co and Mo additions and precipitation strengthening of carbides such as $M_{23}C_6$. Al in conjunction with Cr improves oxidation resistance at high temperatures. However, the high Ni content increases the alloy cost [4–6].

Notwithstanding the above, Inconel 617 is an expensive alloy. Here, 310 austenitic stainless steel (SS) can be considered as an alternative to Inconel 617 where low risk parts are involved (from viewpoint of creep and oxidation). In comparison to conventional austenitic grades such as 304 and 316, 310 stainless steel exhibits superior oxidation resistance as well as higher strength at high temperatures (up to 1000 °C). These behaviors can be rationalized in terms of high nickel and chromium contents present in the alloy. This alloy is utilized to manufacture heat-treating baskets, oven linings, boiler baffles, kilns, radiant tubes and furnace components. This alloy is a unique material that exhibiting good corrosion resistance in oleum (fuming H_2SO_4) [1,7].

To replace Inconel 617 with AISI 310 stainless steel, the application of DMW is inevitable. The quality of dissimilar weldments can be evaluated in terms of microstructure, mechanical properties and weldability. The weldability term is used to describe cracking susceptibility of the joint. The chemical compositions of the base and filler materials can affect weldability [8]. In two last decades, extensive researches have been performed to recommend suitable filler materials for welding processes of austenitic stainless steels and nickel based alloys. Weiti and Tsai [9] investigated hot cracking susceptibility of fillers 52 and 82 in alloy 690 weldments by the

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Table 1
The chemical composition of materials used in this study.

Elements (Wt%)	Base metals		Filler materials		
	Inconel 617	310 SS	Inconel 617	Inconel 82	310 SS
C	0.06	0.07	Max 0.1	Max 0.1	Max 0.1
Si	0.11	1.58	1	0.5	0.45
Mn	0.06	0.95	1	3	1.75
Cu	0.12	0.13	0.5	0.5	0.75
Cr	21.84	24.23	22	20	26
Co	11.87	–	12	0.12	–
Ni	Bal.	18.96	Bal.	67 min	21
Fe	1.35	Bal.	3	3	Bal.
Mo	8.55	0.25	9	–	0.75
Al	0.68	0.02	1	–	–
Ti	0.32	–	0.6	0.75	–
Nb	0.07	–	1	3	–

varestraint test. They showed that Inconel 82 exhibited good hot cracking susceptibility because of lower melting point and a wider melting/solidification temperature range. Sireesha et al. [10] showed that 16-8-2 is the best filler metal from the viewpoint of resistance to solidification hot cracking. Dupont et al. [11] inspected the effect of filler metal chemistry on the microstructure and weldability of dissimilar welds between AL-6XN super SS and two nickel-base alloys including Inconel 625, and Inconel 622. They suggested that good cracking resistance of welds prepared with IN622 was attributed to the small amounts of secondary phases and narrow solidification range. Weldability of Inconel 657/310 SS dissimilar joint was investigated by Naffakh et al. [12]. They illustrated that the Inconel A (a nickel base superalloy) showed the best resistance to the hot cracking among the used filler materials.

In our previous study [13], microstructure and mechanical properties of the Inconel 617/310 SS dissimilar joints were investigated. According to the author's knowledge, the weldability of this joint has not been reported in the literature yet.

The aim of this study was to characterize weldability of the Inconel 617/310 stainless steel joints using different filler metals. Here, Inconel 617, Inconel 82, and 310 stainless steel were used as filler materials.

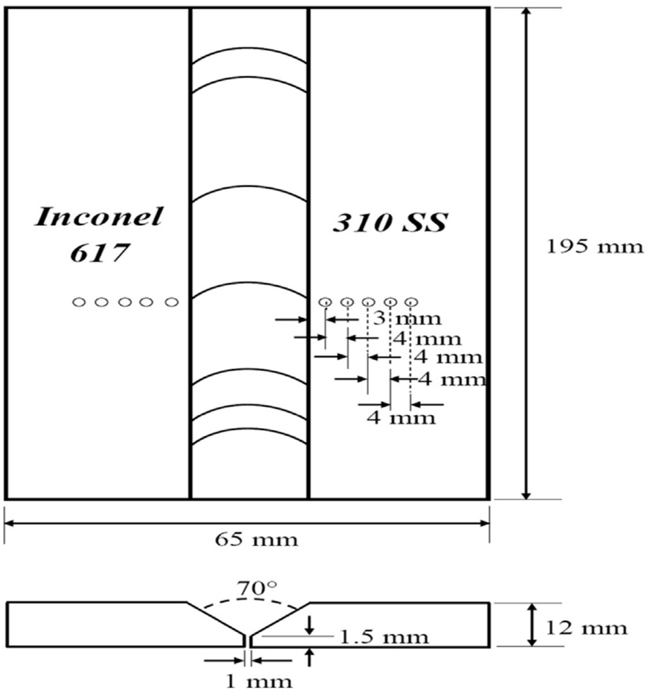

Fig. 1. The design of weldments.

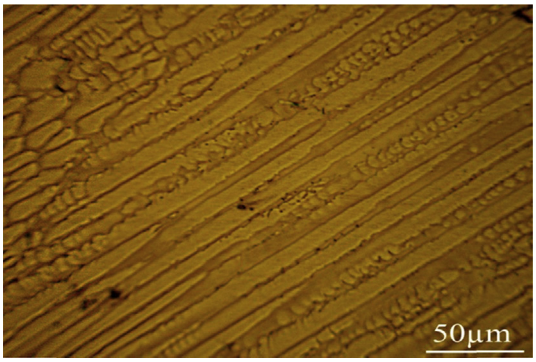

Fig. 2. The microstructure of 310 SS weld metal near the fusion line.

2. Experimental procedures

The base materials were 310 austenitic stainless steel and Inconel 617. The alloys were used in the rolled and solution annealed condition and in the form of 12 mm thick plates. ERNiCr3 (Inconel 82), ERNiCrMo1 (Inconel 617), and ER310 (310 SS) welding wires with 2.4 mm diameter were selected to join the base alloys. Table 1 shows chemical compositions of the base and filler materials. The plates were cut in to the proper size and then machined to make a single V groove butt joint configuration. Fig. 1 shows the experimental arrangement adopted for the welding process. Five holes with the diameter of 1.5 mm and depth of 6 mm were made on both base metals to install the thermocouples connected to data lager to record temperature variations during welding. The joints were produced using the gas tungsten arc welding process with direct-current electrode negative (DCEN) mode. The welding parameters were selected as current = 140 A; voltage = 17–20 V; welding speed = 1.06–1.73 mms^{-1}.

After welding, several transverse cross sections of different weldments were metallographically characterized after etching in Marbel solution. In another case, Murakami and 10% NaOH etchant were used to reveal eventual ferrite and sigma phase. The microstructural features were investigated using an optical microscope and a scanning electron microscope (SEM Philips XL30) equipped with energy dispersive spectroscopy (EDS).

Hot cracking susceptibility was determined using longitudinal varestraint testing with sub' size specimens ($150 \times 25 \times 3.2\ \mathrm{mm}^3$). The crown of each weld deposit was first machined and adjusted with the top surface of the plate. The backside of the surface was then machined to achieve the final thickness (3.2 mm).

Hot cracking susceptibility of the different weld metals was tested on a moving torch varestraint hot cracking test device. During the test, an augmented bending strain was applied to specimens to induce solidification cracking through a pneumatically activated ram. The strain related to the radius of die blocks is given by:

Table 2
The amount of equivalent Cr, Ni and their ratio in 310 SS weld metal.

	Cr_{eq}	Ni_{eq}	Cr_{eq}/Ni_{eq}
Non-diluted	28.47	24.87	1.14
Diluted	30.14	29.16	1.03