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Microstructural characterization of dissimilar welds between Incoloy 800H and 321 Austenitic Stainless Steel

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ABSTRACT

In this work, the microstructural character of dissimilar welds between Incoloy 800H and 321 Stainless Steel has been discussed. The microscopic examination of the base metals, fusion zones and interfaces was characterized using an optical microscope and scanning electron microscopy. The results revealed precipitates of Ti (C, N) in the austenitic matrix along the grain boundaries of the base metals. Migration of grain boundaries in the Inconel 82 weld metal was very extensive when compared to Inconel 617 weldment. Epitaxial growth was observed in the 617 weldment which increases the strength and ductility of the weld metal. Unmixed zone near the fusion line between 321 Stainless Steel and Inconel 82 weld metal was identified. From the results, it has been concluded that Inconel 617 filler metal is a preferable choice for the joint between Incoloy 800H and 321 Stainless Steel.

1. Introduction

The success of the dissimilar metal weld lies in producing a weldment that meets the intended service requirement. Dissimilar welding comprises two or more chemically different metals (base metal and filler metal) that may affect the final chemical composition of the weldment. This weldment is accountable for mechanical and corrosion properties [1]. At high temperature, it is observed that the weldment fails in service condition even though it possesses adequate mechanical and corrosion strength. The failure is attributed to the filler wire, which is unable to bridge the gap between two different base metals in terms of the coefficient of thermal expansion. Hence, the selection of filler wire plays a vital role in dissimilar welding, particularly when the weldment is exposed to high temperature environment.

1.1. The failure mechanism

The steam-naphtha reformer in a petrochemical plant is used to crack the feed (Naphtha) into carbon and hydrogen. The feed for the individual tubes is sent through the inlet, small-diameter flexible pipes (called "pigtails") and these pigtails are connected to inlet headers. Naphtha is preheated to a temperature of 370 °C in the convection section of a fired heater, passed through a sulfur absorber vessel, preheated further to 517 °C and then mixed with steam before entering the inlet header at a pressure of 25 bar. It then enters the vertically placed radiant section furnace tubes filled with Nickel Oxide catalyst where the reaction takes place.

Similarly, the process gas from the catalyst tubes is sent out through outlet pigtails which further connect to outlet headers at a temperature of 630 °C. In the same reformer, feed preheat coil inlet tubes are made of Alloy 800H (UNS N08810: Fe–21Cr–32Ni) and the header with AISI 321 Stainless Steel (UNS S32100). The general welding process to join the header to the tube is fusion welding. After 9 years of service, cracks were observed in weld metal in the heat affected zone of Alloy 800H pipe welds and weldolets-to-outlet header welds [2]. It is attributed to stress relaxation cracking triggered by migration of the carbides at the grain boundary in the heat-affected zone (HAZ) and thermal stress induced by residual stresses from welding [3].

1.2. Work reported

The selection of a proper filler metal in dissimilar welding is one of the most challenging factors in high temperature environment like petrochemical industries. The filler metal chemistry should match with the major elements of the base metal chemistry. These elements are primarily nickel and chromium, but the filler metals available typically match the other elements, also forming an undesirable composition in the weld zone [4]. An extensive literature review was conducted in order to get a clear picture of the work done in the past in relation to this work to find suitable filler materials in dissimilar welding processes.

Dupont et al. [5] investigated the effect of processing parameters and filler metal chemistry on the microstructure and weldability of dissimilar welds between AL-6XN stainless steel and two nickel base alloys, Inconel 625 and Inconel 622. Sireesha et al. [6] tested four types of filler

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metals to join AISI 316 stainless steel and alloy 800. Their results showed the filler metal 16-8-2 to be superior in mechanical property and coefficient of thermal expansion viewpoints. Also, they concluded that long-term elevated-temperature aging of the weld metals resulted in embrittling sigma phase precipitation in the austenitic stainless steel weld metals [7]. Weldability of Inconel 657 and 310 Stainless Steel were investigated by Naffakh et al. [8]. They clarified that the Inconel A was the best choice amidst four filler metals based on the hot cracking test. Shamanian et al. [9] probed Inconel 617/310 Stainless Steel dissimilar welds. Their work elucidated that there was no evidence of any possible cracking in the weldments achieved by the nickel base filler materials when compared to Stainless Steel filler metal. Dehmolaei et al. [10] found that the migration of grain boundaries in the Inconel 82 weld metal was very extensive when compared to Inconel 617 weld metal in 25Cr–35Ni heat resistant steel to alloy 800 dissimilar welding. Lee et al. [11] exposed that the increase in Ti addition prompts a significant increase in the elongation of the weldment in the welding of nickel base alloy 690 to SUS 304L. Dehmolaei et al. [12] applied electromagnetic vibration on 25Cr–35Ni heat resistant steel to alloy 800 dissimilar welds to eliminate unmixed zones in dissimilar welding. Bhaduri et al. [13] recommended filler metal 16-8-2 to minimize micro-fusing and coefficient of thermal expansion in AISI 304 stainless steel to alloy 800 dissimilar welds. Bhaduri et al. [14] conducted experiments on the effect of aging in dissimilar welding of Incoloy 800 to 9Cr–1Mo and concluded that the effect of aging on the tensile property was very marginal. Song et al. [15] stated that friction stir welding process leads to reduction of grain size in stir zone in dissimilar welding of Inconel 600 to stainless steel 400. A.H. Yaghi et al. [16] predicted residual stress induced by the dissimilar welding of a P92 steel pipe with weld metal IN625 using Finite Element simulation. A. Skouras et al. [17] measured residual stress using neutron diffraction in a ferritic steel/In625 super alloy dissimilar metals. Mortezaie et al. [18] concluded that Inconel 82 exhibited the highest corrosion resistance among all tested filler metals and offers the optimum properties at room temperature for the dissimilar welding between Inconel 718 and 310S. Yub Soo Lim and Hong pyo Kim [19] found that the precipitates of (Nb,Ti)C, Al_2O_3 type and TiO_2 type oxides were found in the Alloy 182 weld metal in 600/182 weld.

From the literature, it is concluded that no work has been reported on the dissimilar joint of Incoloy 800H to 321 Stainless Steel. The main objective of this work was to identify the most appropriate welding filler wire between Inconel 82 and Inconel 617 and to minimize the failure of a reformer unit in the petrochemical environment by investigating the microstructural aspects that could affect the stress relaxation cracking susceptibility of the Incoloy 800H/321 Stainless Steel weldment. The microstructure, grain boundary and the interface were examined with an optical microscope (OM), scanning electron microscope (SEM) and an energy-dispersive X-ray spectrometer (EDS).

2. Materials and experimental procedures

To simulate the original fabrication, Incoloy 800H (Special Metal Corporation) and 321 Austenitic Stainless Steel (ThyssenKrupp) were used as the base metal in the form of 6 mm thick plates. Undiluted Inconel 82 and Inconel 617 (Special Metal Corporation) were used as filler metal with a diameter of 2.4 mm. The chemical compositions of the base and filler materials are given in Table 1. The base metal plates were subjected to electrical discharge machine and machined to the size of 150 mm × 125 mm × 6 mm to ensure that the weld pad prepared for testing simulates the actual fabrication conditions and the thermal history that the weld undergoes in actual fabrication closely. The specimens were machined to make a single V groove butt joint configurations with 80° groove angle and the root face and root opening were 0.8 mm and 2.4 mm respectively. Welding (Kemppi Arc) procedure was performed in four passes by the gas tungsten arc welding process with direct current electrode negative. The welding parameters and the heat input in each welding pass are given in Table 2. The completed welds were tested by X-radiography using 2% pentameter standard (AWS D1.1) and less than 1.6% defects were found. For metallography examinations, specimens were prepared from the transverse cross section of the weldment. The specimens were prepared by grinding using 400, 600, 800, 1000, and 2000 grits of SiC paper, followed by the final polishing with 1 μm diamond paste (Struers-Tegramin 25). The specimens were then etched in an Aqua regia solution (100 ml H_2O + 60 ml HCl + 20 ml HNO_3) for 30 to 60 s at room temperature for 321 Stainless Steel and Marble regent (100 ml H_2O + 50 ml HCl + 10 ml $CuSO_4$) for weld and Incoloy 800H. The microstructural features were investigated using an OM (Axio Scope.A1 Zeiss) and SEM (Supra 55 Carl Zeiss) equipped with EDS (Oxford) point analysis. The comparative evaluation was based on metallurgical analysis.

Table 1
Chemical composition of materials used, the weight percentage (%).

Elements	Base materials		Undiluted filler materials	
	Incoloy 800H	321 Stainless Steel	Inconel 82	Inconel 617
C	0.06	0.030	0.10	0.15
S	0.002	0.001	0.0015	0.015
N	0.013	0.015	–	–
Cr	20.63	17.20	19.94	22.3
Ni	30.56	9.11	71.24	54.1
Mn	0.69	0.915	2.5	1.00
Si	0.46	0.670	0.485	1.00
Ti	0.34	0.255	0.7	0.60
Nb	0.01	–	2.00	–
Cu	0.10	0.255	0.30	0.50
Fe	46.787	71.322	2.69	1.1
P	0.008	0.027	0.03	0,03
Al	0.26	–	–	1.5
Co	0.08	–	–	8.00
Mo	–	0.20	–	8.8
B				0.005

3. Results and discussions

3.1. Microstructure

3.1.1. Incoloy 800H

Incoloy 800H is a solid solution-strengthened iron–nickel base super alloy. Fig. 1(a) shows that the microstructure of solution annealed Incoloy 800H with fully austenitic matrix containing several annealing twins across the grains can be observed in the microstructure formed by stress relieving after cold working, which are surrounded by fine grains formed by dynamic recrystallization during hot rolling. The coarse grain size (80 to 90 μm) of Incoloy 800H has a distinguished reputation for being very strong at high temperature and resistance to

Table 2
GTAW welding parameter.

Filler material	Pass number	Welding parameters			Heat input (kJ/cm)	Total heat input (kJ/cm)
		Current (A)	Voltage (V)	Welding speed (cm/min)		
Inconel 82	1	110	10	10	6.6	
	2	130	12	10	9.36	
	3	130	13	10	10.14	
	4	130	14	10	10.92	37.02
Inconel 617	1	110	10	10	6.6	
	2	130	12	10	9.36	
	3	130	13	10	10.14	
	4	130	14	10	10.92	37.02