



The effect of weld chemistry on the oxidation of Alloy 82 dissimilar metal welds



S.Y. Persaud^{a,*}, S. Ramamurthy^b, R.C. Newman^{a,*}

^aDepartment of Chemical Engineering and Applied Chemistry, University of Toronto, 200 College Street, Toronto, ON M5S 3E5, Canada

^bSurface Science Western, University of Western Ontario, 999 Collip Circle, London, ON N6G 0J3, Canada

ARTICLE INFO

Article history:

Received 27 June 2014

Accepted 29 October 2014

Available online 6 November 2014

Keywords:

A. Nickel

A. Alloy

C. Welding

C. Stress corrosion

C. Internal oxidation

C. Selective oxidation

ABSTRACT

Alloy 82 dissimilar weld joints between carbon steel and Alloy 600 were exposed to a simulated primary water environment consisting of hydrogenated steam at 480 °C and 1 bar. Dilution due to mixing from the parent materials to the weld was significant, particularly in the root where there was Fe enrichment (35 at.%) and Cr depletion (10 at.%). The heterogeneous composition of the weld from root to crown resulted in differences with respect to surface versus internal oxidation. A Fe-rich surface oxide formed on the weld root which may help to prevent embrittlement and SCC by internal intergranular oxidation.

© 2014 Elsevier Ltd. All rights reserved.

1. Introduction

Alloy 82, a weld metal used with Alloy 600 (Ni–16Cr–9Fe), is used for dissimilar metal weld joints in high temperature and high pressure aqueous environments in nuclear power plants. Typically, these welds are located between stainless steel or carbon steel and a nickel alloy, such as Alloy 600. The primary water stress corrosion cracking (PWSCC) resistance of these and other nickel-base alloy welds in the presence of primary coolant is debatable, and has been studied extensively [1–12].

The initial weld pass between two metals is done at a higher heat and is known as the root of the weld; the weld root is the initial point of exposure and corrosion-resistant materials are used to make this joint. In nuclear systems, the root is historically composed of Alloy 82 (~20 at.% Cr). Subsequent passes in shallow welds, similar to the welds used in this work, are usually made with Alloy 82, but welds of large depth may use Alloy 182 (~15 at.% Cr) instead. Post-weld heat treatment (PWHT) is applied to some dissimilar metal welds to redistribute residual stress, and remove martensitic phases.

The effect of welding-induced residual stress on PWSCC susceptibility has been studied extensively [1,5,11,12]. Whilst one might rely on residual stress considerations to validate the performance

of such welds, it is also useful to examine whether they have any inherent SCC resistance on the grounds of weld-metal chemistry. Welds have a complex, non-homogeneous microstructure consisting of dendrites formed during crystallization and further recrystallized grain structure. Impurities from the parent materials have been known to segregate at dendrite boundaries and grain boundaries resulting in enhanced susceptibility to cracking [11]. Dilution due to mixing of the Alloy 82 weld metal with dissimilar parent materials can result in a weld composition vastly different from Alloy 82. Dilution can result in the expected oxidation behavior and perceived SCC susceptibility of a dissimilar metal weld being altered.

Alloy 82 dissimilar metal welds are exposed to primary coolant in nuclear power systems. 20–50 cm³ H₂/kg H₂O is added to primary water in pressurized water reactors which reduces the potential to near the Ni/NiO transition potential. Several studies have shown that near the Ni/NiO transition potential, the PWSCC susceptibility of Alloy 600 and its weld metals is at a peak [1,8,9,13]; this suggests internal oxidation as a potential mechanism of PWSCC. Internal oxidation is a phenomenon that occurs in alloys which consist of a noble solvent element and a lower concentration of a reactive element. In conditions where the oxygen partial pressure is in the range of the dissociation pressure of the more-noble metal oxide, the reactive element, when below a critical concentration, can oxidize internally rather than externally [14–16]. Internal stress generated by the formation of an internal oxide is relieved through expulsion of the noble solvent metal to

* Corresponding authors. Tel.: +1 416 946 0604.

E-mail addresses: suraj.persaud@mail.utoronto.ca (S.Y. Persaud), roger.newman@utoronto.ca (R.C. Newman).

the surface; this phenomenon was first observed at the scanning electron microscopy level of resolution by Rapp et al. in Ag–In alloys [16,17].

The internal oxidation model was first proposed as a mechanism of PWSCC by Scott and Le Calvar [18] and has received support from surface embrittlement studies done in steam and hydrogen at 400 °C [19–21]. Economy et al. found that the time to 30% intergranular SCC of Alloy 600 U-bends in 400 °C hydrogenated steam and 360 °C primary water lay on one Arrhenius line [22]. While the kinetics were accelerated, the cracking mechanism and the role of microstructural variables was concluded to be similar to high pressure reducing water at 360 °C [22]. Internal oxidation has become an increasingly well-supported model of PWSCC [18–32]. Scenini et al. performed exposures of Alloy 600 in a hydrogenated steam environment at 480 °C and atmospheric pressure and found that chromium was internally oxidized resulting in the expulsion of metallic nickel nodules on the surface [26–29]; Persaud et al. extended the studies by performing similar experiments on Alloy 600, in the solution annealed condition, and found that selective intergranular oxidation of Cr resulted in intergranular embrittlement and fracture under stress [31,32].

In the present work, Alloy 82 dissimilar metal welds between Alloy 600 and carbon steel are exposed to a hydrogenated steam environment at 480 °C and 1 bar. The expected large variation in weld-metal chemistry (e.g. dilution) in different regions of the weld will be explored. Conclusions will be drawn with respect to the effect of weld-metal chemistry on the surface or internal oxidation behavior of dissimilar metal welds; finally, the effect of oxidation behavior on the likely PWSCC susceptibility of Alloy 82 dissimilar metal welds will be discussed.

2. Materials and methods

2.1. Materials

Alloy 82 dissimilar metal welds were extracted from piping joints between Alloy 600 (SB-166 NO0600) and carbon steel (SA-106 Gr. C); the nominal compositions of Alloy 82, Alloy 600 and carbon steel are given in Table 1. Welding was done using gas tungsten arc welding. PWHT is not applied due to the possibility of sensitization of Alloy 600. An illustration of the weld and the extracted Alloy 82 dissimilar metal weld cross-section is shown in Fig. 1. The root of the weld is the initial joint on the inside of the pipe and the crown of the weld is the final pass on the outside of the pipe; the root of the weld is of particular importance because it is the point of exposure. It was desirable to extract the cross-section because it was anticipated that dilution from carbon steel

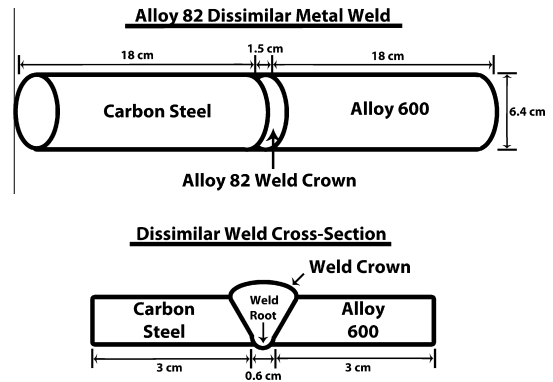


Fig. 1. Schematics of the dissimilar weld joint between carbon steel and Alloy 600 and the cross-sections which were extracted. The cross-sections were prepared by cutting across the weld, from crown to root.

would result in the composition from the root to the crown varying significantly due to different heat inputs.

The carbon steel portion of the Alloy 82 dissimilar weld cross-section in Fig. 1 was removed prior to exposure. There was a residual piece of carbon steel remaining in the root of samples, which was removed in some experiments. The coupons (Alloy 600 and Alloy 82 without the carbon steel portion) were abraded down with 400, 800, and 1200 grit paper. Following this, samples were fine polished using diamond paste (9 μm, 3 μm, and 1 μm) and then with alumina suspension to a 0.05 μm finish. The samples were ultrasonically cleaned in ethanol and de-ionized water for 10 min each between polishing stages and dried with air. A desiccator was used to store samples until time of exposure.

2.2. Experimental conditions and procedure

Experiments were carried out in a tube reactor encased in a furnace similar to the design by Scenini et al. [26–29]. A hydrogenated steam environment at 480 °C and 1 bar was used to simulate primary water conditions by maintaining an oxygen partial pressure (p_{O_2}) below the Ni/NiO dissociation pressure. For greater mechanistic clarity, nickel oxidation was definitely prevented; actual reactor conditions vary around the Ni/NiO equilibrium. Determining the equilibrium dissociation pressure of oxygen ($p_{O_2,eqm}$) was done using the thermodynamic relationship for the standard molar Gibbs free energy of formation for the NiO dissociation reaction, Eq. (1).

$$p_{O_2,eqm} = \left[\exp \left(\frac{\Delta G_{f,NiO}^0}{RT} \right) \right]^2 \quad (1)$$

$p_{O_2,eqm}$ at 480 °C and 1 bar was found to be 3.0×10^{-24} bar which is consistent with the Ni/NiO equilibrium oxygen partial pressure from an Ellingham diagram at 480 °C. The desired p_{O_2} was set 30 times below $p_{O_2,eqm}$ and is controlled in the reactor by the steam-hydrogen equilibrium reaction. Using the thermodynamic relationship for the standard molar Gibbs free energy of formation for steam at 480 °C, Eq. (2), the necessary ratio of steam to hydrogen can be determined.

$$p_{O_2} = \left[\frac{p_{H_2O}}{p_{H_2}} \cdot \exp \left(\frac{\Delta G_{f,H_2O}^0}{RT} \right) \right]^2 \quad (2)$$

The ratio of steam to hydrogen can be used to calculate the water and hydrogen flow rates required to maintain the desired p_{O_2} by performing a simple mass balance.

Fig. 2 is a process flow diagram of the reactor during operation. Ultra high purity argon gas is used to purge the system of air prior

Table 1
Nominal compositions of Alloy 82, Alloy 600 and carbon steel (in wt.%).

Element	Alloy 82	Alloy 600 (SB-166 NO0600)	Carbon Steel (SA-106 Gr. C)
Ni	Bal.	Bal.	≤0.40
Cr	18–22	14–17	≤0.40
Fe	≤3.00	6.0–10	Bal.
Ti	≤0.75	–	–
Nb + Ta	2.0–3.0	–	–
C	≤0.10	≤0.050	≤0.35
Mn	2.5–3.5	≤1.0	0.3–1.0
S	≤0.015	≤0.015	≤0.035
P	≤0.030	–	≤0.035
Si	≤0.50	≤0.50	≥0.10
Cu	≤0.50	≤0.50	≤0.40
Co	≤0.10	≤0.10	–
V	–	–	≥0.08
Mo	–	–	≤0.15

Download English Version:

<https://daneshyari.com/en/article/1468520>

Download Persian Version:

<https://daneshyari.com/article/1468520>

[Daneshyari.com](https://daneshyari.com)