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PWSCC of Alloy 600 BMI Penetrations Accelerated by DM Welds and Super-heated Doped Steam Environments

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1. Introduction

Primary water stress corrosion cracking (PWSCC) has been reported in nickel-based alloy components of pressurized water reactor (PWR) plant such as Alloy 600, 82 and 182. Among these components, bottom-mounted instrumentation (BMI) and control rod drive mechanism (CRDM) nozzles with dissimilar metal welds joining the nickel-based alloys and the carbon and stainless steels have a great importance because the cracking could lead to a leakage of primary coolant. Under these circumstances, U.S. Nuclear Regulatory Commission (USNRC) began the Program for Inspection of Nickel alloy Components (PINC) in 2003 to improve the non-destructive evaluation (NDE) techniques. The main action items of the PINC are the fabrication of representative NDE mockups to simulate PWSCC, identification of capable NDE techniques for detecting and sizing of PWSCC, characterization of flaw morphology and documentation of NDE responses from PWSCC, and incorporation of findings from other ongoing PWSCC research programs throughout the world.

In this work, to fabricate the representative NDE mockup as a contribution to the PINC, the PWSCC of the Alloy 600 BMI penetrations with DM welds is investigated by using a doped steam test method. The relationship between the residual stress due to DM welds and the PWSCC of the BMI mockup in the super-heated doped steam environments is also presented.

2. Experimentals

2.1 Fabrication of BMI mockup with DM welds

The BMI mockup with DM welds was fabricated by welding Alloy 600 nozzle with 38.0 mm outer diameter and 11.5 mm wall thickness to 304 stainless steel support plate with Alloy 182 filler as shown in Figure 1. The heat input and weld pass were controlled to enlarge the residual stress at the J-groove region of the BMI mockup to accelerate the PWSCC. The mockup was used as an autoclave for the super-heated doped steam test.

2.2 Super-heated doped steam test

The method involved exposing the Alloy 600 BMI mockup specimen inside to 20.7 MPa and 400 ^oC super-heated steam of aqueous solution containing 100 ppm each of chloride, fluoride, sulfate and nitrate sodium salts, with 75 kPa hydrogen partial pressure at the temperature, which has been successful in acceleration of the PWSCC of Alloy 600 in prior works [1-5]. The specimens were exposed in the doped steam environments for intervals of 672 h (4 weeks) to 1008 h (6 weeks). After each interval, the specimens were examined by UT/ECT techniques to identify the PWSCC of specimens inside.

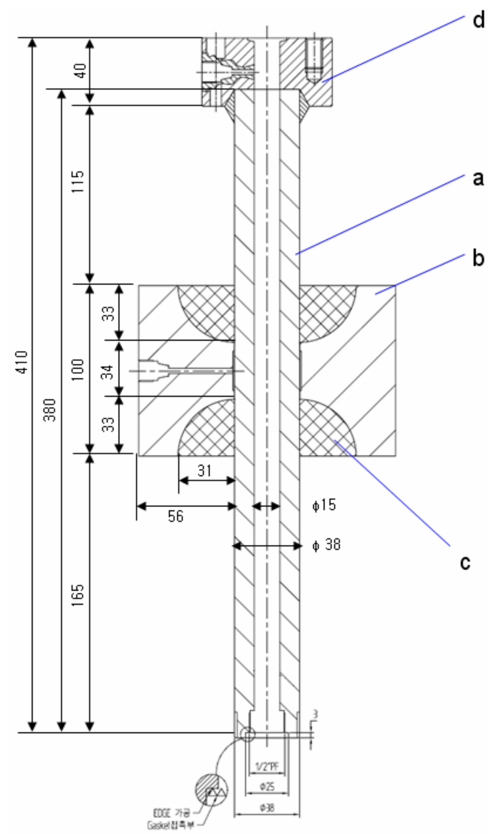

Figure 1. The schematic drawing of BMI mockup, a : Alloy 600 BMI nozzle, b : 304 stainless steel support plate, c : Alloy 182 filler, d : flange for sealing.

3. Results and Discussions

Figure 2 shows the profile of inner diameter (ID) of the BMI mockup specimen after DM welding process. ID of the BMI nozzle was decreased by 0.1~0.2 mm at the J-groove weld region, indicating that a stress was generated at the BMI nozzle due to the difference of the thermal expansion coefficient of the metals in DM welds. The residual axial and hoop stresses are under investigation using a finite element analysis.

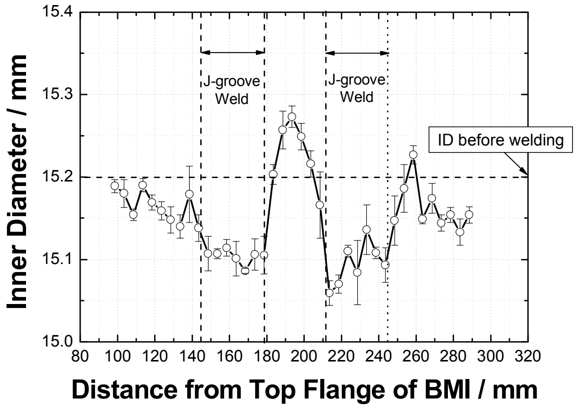

Figure 2. Profile of inner diameter (ID) of BMI nozzle after welding process.

Figure 3(a) presents the temperature dependence of the redox potentials of NiO/Ni and H_2/H^+ couples vs. the standard hydrogen potential (SHE) at pH of 5.5 and 7.5, and the hydrogen partial pressure of 0.01, 0.5 and 7.5 atm. From the results, the hydrogen partial pressure was determined as 75 kPa at which the redox potentials of NiO/Ni and H_2/H^+ couples are same so Ni-based Alloy 600 is supposed to suffer the PWSCC as shown in Figure 3(b).

Acceleration of the PWSCC of the Alloy 600 BMI penetration mockup in the super-heated steam environments and the effect of the residual stress due to welding process will be evaluated and discussed in detail.

4. Conclusion

As a contribution to the PINC, the BMI mockup with DM welds was fabricated by welding Alloy 600 nozzle to 304 stainless steel support plate with Alloy 182 filler and then was exposed to the super-heated doped steam environments. To accelerate the PWSCC of the BMI mockup with DM welds, the residual stress at the J-groove region was enlarged by controlling the welding process parameters, and also the hydrogen partial pressure of the doped steam environments was determined from the redox potential calculation. The effect of the residual stress due to DM welds on the PWSCC of the BMI mockup will be discussed in detail.

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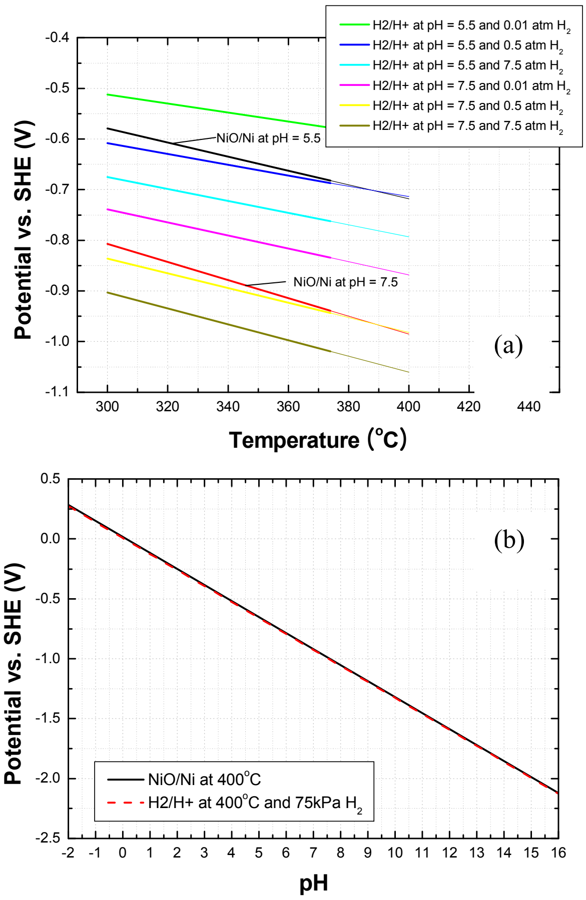

Figure 3. (a) Temperature dependence of the redox potentials of NiO/Ni and H_2/H^+ vs. SHE calculated at various pHs and hydrogen partial pressures, (b) the redox potentials of NiO/Ni and H_2/H^+ vs. SHE calculated at 400°C.