Iodine-Induced Stress Corrosion Cracking of HANA-4 Claddings

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1. Introduction

Since 1960's, it has been firstly reported the fractures of cladding induced by Pellet-Cladding Interaction (PCI) in BWR and CANDU-type reactors. With the changes in pellet shapes and the development of barrier cladding using an inner layer of pure zirconium in BWR fuel design in the 80's, PCI has since received little attention, except for power transient conditions in PWR[1]. Indeed, it is well-known that cladding failure by Iodine-Induced Stress Corrosion Cracking (I-SCC) may occur under PCI conditions during power transients in PWRs. Under PCI conditions, I-SCC then results from the synergic effect of (i) the hoop tensile stress and strain imposed on the cladding by fuel thermal expansions during power transients and (ii) the corrosion by iodine released from the UO_2 fuel as a fission product[2]. Nowadays, many power plants adopt high burn-up operation which includes high power, enlarged fuel cycle, and so on. At a high burn-up, the cladding is getting more brittle because of hydride formed by waterside corrosion and its possibility of fracture by PCI is increased. So, newly developed cladding designed for high burn-up operation needs higher resistance against PCI.

It is known that the basic feature that controls the material resistance to crack propagation in aggressive environment is threshold stress intensity factor (K_{ISCC}), which is an index of the crack resistance of material against aggressive environment and stress[3]. The objectives of this study are to evaluate the I-SCC resistance of the HANA4 claddings developed by KAERI for the high burn-up nuclear fuel. Internal pressurization tests were carried out with pre-cracked HANA4 claddings in iodine environment, crack propagation rates and threshold stress intensity factor were evaluated. The effects of heat treatment and microstructure on I-SCC were also tested.

2. Experimental

2.1 Specimen and Sample preparation

The cladding used in this study is HANA-4 (Zr-1.5Nb-0.4Sn-0.2Fe-0.1Cr) developed in KAERI for the high burn-up fuel. Test specimens of about 130 mm in length were cut from the cladding. Pre-crack is made at the inner surface of the tube by 4-point bent beam fatigue technique. Cyclic loading with frequency of 5Hz, mean load 50 kgf, and amplitude of 50 kgf let the longitudinal pre-crack be made. After 5000 cycle, maximum depth of the crack is about 25 ~ 50% of total tube thickness and the shape of the pre-crack is elliptical. The crack was measured after I-SCC test by optical microscope (OM) and scanning electron microscope (SEM). Figure1 shows the typical fracture surface after the I-SCC testing.

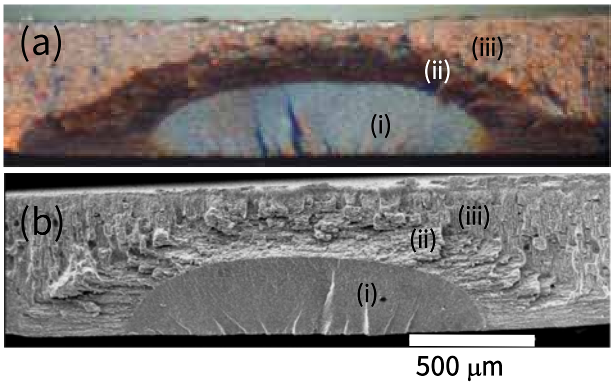

Figure 1. Cross-section of fracture surface showing (i) fatigued pre-crack, (ii) I-SCC crack and (iii) ductile fracture; (a) optical image and (b) SEM image.

2.2 I-SCC experiment

To evaluate the I-SCC characteristics of the pre-cracked specimens, internal pressurization technique was used in iodine environment at 350^oC. Pressurization can be achieved by the high purity helium compressed-air-driven pressure booster. This helium was used for the rapid pressurization of the sample right after it is at 350^oC. The amount of iodine was added at the amount of 1.0 mg/cm^2. It was introduced as small crystals of ultrapure iodine placed in quartz U-shaped crucible. The stress range of the test was selected in the condition for a plane strain.

3. Results and Discussion

3.1 I-SCC Properties of Zry-4

Figure 2 shows crack propagation rates versus stress intensity factor for Zry-4 claddings of as-received (stress relived, SR) and re-crystallized (RX) at 620^oC for 3 hr. The arrangement of the data points is typical of I-SCC with steep rise in the neighborhood of K_{ISCC}. K_{ISCC} of the Zry-4 was 3.3 and 4.8 MPa.m$^{1/2}$ for SR and RX, respectively. And the crack propagation rates at the region II of the RX specimens were the range of 1/10 to that of the SR specimens. It means that I-SCC resistance of the RX Zry-4 is higher than that of SR Zry-4. Such an increased resistance against corrosion propagation may have a relation to the higher ductility of RX Zry-4 than SR one.

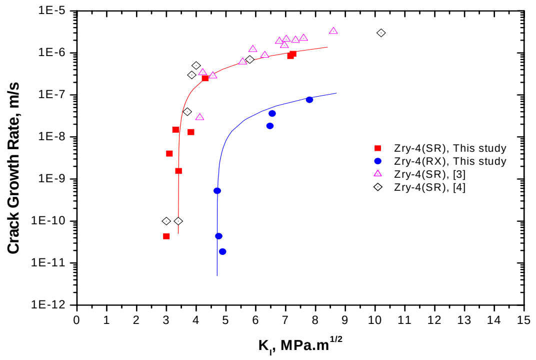

Figure 2 Crack propagation rate versus stress intensity factor of Zry-4 claddings.

3.2 I-SCC Properties of HANA4 Cladding

Figure 3 shows crack propagation rates versus stress intensity factor for HANA-4 cladding of stress relived (SR) at 470^oC for 2.5 hr and re-crystallized (RX) at 620^oC for 2.5 hr. K_{ISCC} of the HANA-4 was 4.4 and 4.8 MPa.m$^{1/2}$ for SR and RX cladding, respectively. Compared to Zry-4, K_{ISCC} of the HANA-4 cladding is higher than that of the Zry-4 and the crack propagation rates of the HANA-4 cladding at region II were lower about 1/10 value than that of the Zry-4. It means that the I-SCC resistance of the HANA-4 cladding is improved when compared with Zry-4.

4. Conclusions

I-SCC resistance of the HANA-4 and Zry-4 claddings was evaluated by using internal pressurization test in iodine environment at 360^oC. The effect of final heat treatment was tested and the followings can be summarized.

1) I-SCC resistance of the recrystallized claddings was higher than that of stress relieved claddings. It would be resulted from higher ductility of RX claddings than SR one.

2) K_{ISCC} of the HANA-4 and Zry-4 claddings were 4.4 and 3.3 MPa.m$^{1/2}$, respectively. And the crack propagation rates of HANA-4 at region II were lower about 1/10 value than that of the Zry-4. It means that the I-SCC resistance of the HANA-4 cladding is improved than that of Zry-4

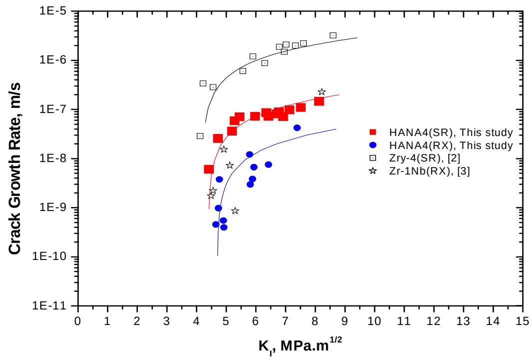

Figure 3 Crack propagation rate versus stress intensity factor for HANA-4 claddings.

Acknowledgement

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Reference

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