Out-Pile Pellet-Cladding Interaction Resistance of HANA 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 PCI resistance of the HANA claddings developed by KAERI for the high burn-up nuclear fuel. Internal pressurization tests were carried out with and without pre-cracked HANA claddings in iodine environment, crack propagation rates and threshold stress intensity factor were evaluated.

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) and HANA-5 (Zr-0.4Nb-0.8Sn-0.3Fe-0.15Cr) 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). Figure 1 shows the schematic diagram of the pre-cracking process.

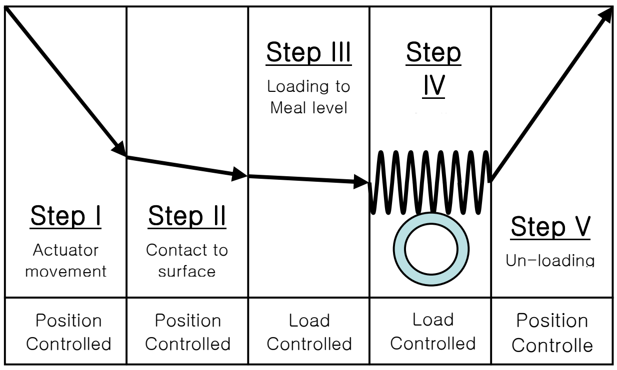

Figure 1. Schematic diagram of the pre-cracking process

2.2 PCI simulation test

To evaluate the PCI resistance of the specimens, internal pressurization technique was used in iodine environment at 350°C. Pressurization can be achieved by the high purity helium compressed-air-driven pressure booster. Helium was rapidly pressurized at the sample right after temperature reaches at 350°C. The amount of iodine was added at the amount of 1.0 mg/cm^2. It was introduced as small crystals of ultra-pure 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 PCI behavior of HANA cladding without pre-crack

Figure 2 shows the applied hoop stress versus rupture time for the non pre-cracked specimens. Failure time of the HANA cladding is longer than that of the Zry-4 and similar to that of A cladding. For example at 400 MPa of hoop stress, the failure time for the Zry-4, HANA5 and A cladding are 3, 12 and 16 hr, respectively. It means that the PCI resistance of the HANA cladding is higher than that of Zry-4 and similar to A.

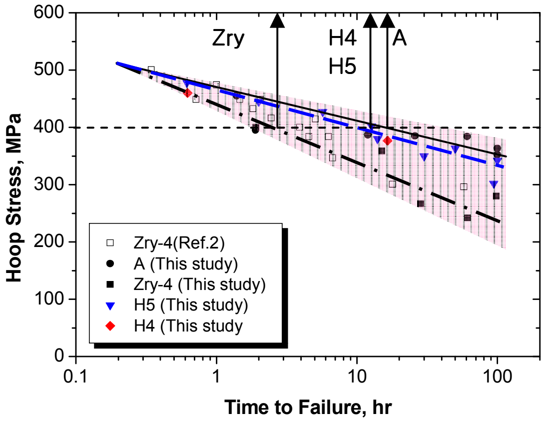

Figure 2 Applied hoop stress versus failure time plots.

3.2 PCI crack growth behavior of HANA cladding

Figure 3 shows crack propagation rates versus stress intensity factor for HANA-4 cladding. K_{ISCC} of the HANA-4 was 4.4 and that of Zry-4 was 3.3 MPa.$m^{1/2}$. 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

Out-pile PCI resistance of the HANA4, HANA5 and Zry-4 claddings was evaluated by using internal pressurization test in iodine environment at 360°C and the followings can be summarized.

1) In the time-to-failure behavior for non pre-cracked cladding, failure time of the HANA cladding was 4 times longer than that of Zry-4.

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 PCI resistance of the HANA-4 cladding is improved than that of Zry-4

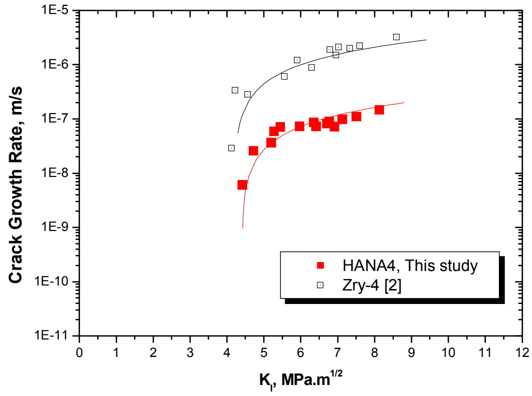

Figure 3 Crack propagation rate versus stress intensity factor for HANA-4 and Zry-4 claddings.

Acknowledgement

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