Effect of Hydrogen on Mechanical Behavior of Zr-based Alloy Fuel Cladding at High Temperature

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1. Introduction

The nuclear fuel cladding should maintain good performance without serious degradation under not only normal operating conditions, but also various accident condition. Therefore, it is very important to investigate the behavior or performance of fuel cladding under various range of temperature. At the present, however, most of research results have been obtained from non-pressurized claddings specimens. However, integrity of fuel cladding can be significantly affected by ballooning and rupture that caused by pressure difference between inner and outer cladding. Ballooning may cause the fuel relocation or fuel dispersal due to its rupture opening during accidents. In addition, wall thickness of cladding can be reduced and local regions near the rupture open would become heavily oxidized and hydrided [1]. Therefore, integral test that can simulate pressure difference should be carried out for comprehensive safety analysis. Although a number of researches have been conducted, most investigations of them were performed using as-received cladding specimens.

In this study, mechanical behavior of zirconium based alloys cladding was investigated by high temperature test and high burnup effects on the ballooning behavior of fuel cladding were also examined using H charged cladding sample..

2. Experimental Procedure

Figure 1 shows the schematic illustration of integral LOCA test apparatus used in this study. For integral LOCA tests, 400 mm long cladding sample was used and filled with 10 mm-long alumina pellets to simulate the heat capacity of the fuel. The stack length of these pellets was about 360 mm long. The pressure was injected through stainless tube at the top and the cladding specimen was supported at the top to minimize specimen bowing. For comparison study, as-received and prehydrided (300 wppm) cladding sample were used. The Specimen temperature was measured by type-R thermocouple located near the sample center and the quartz tube provides an enclosed volume for steam flow and water quench, both of which are into the chamber, furnace heating started for a pre-test hold temperature of 300°C.

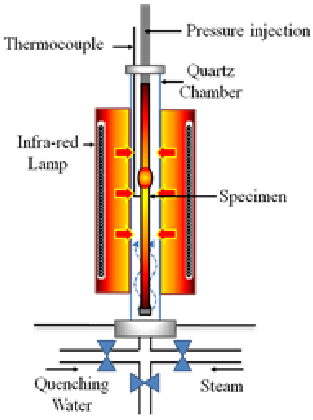

Fig. 1. Schematic illustration for the integral LOCA apparatus.

Steam flow and 300°C of sample temperature were stabilized within 180 s. Heating rate was 28°C/s from 300°C to 1200°C. After oxidation at 1200°C with hold time of 300s, the tube was cooled slowly and quenched at ≈800°C by bottom flooding..

3. Results and discussion

Cross-sectional images of the test samples of Zr alloy cladding were obtained at burst midplane and shown in Fig. 2. Figs. 2 (a) and (b) show a burst behavior with heating rate of 28 C/s. As received and prehydrided (300 wppm) sample shows similar circumferential strain at burst midplane. On the other hand, Zr alloy claddings with heating rate of 1 C/s show a significant difference in circumferential strain. Prehydrided (300 wppm) sample shows a lower circumferential strain than that of as-received sample. Fig. 3 shows burst temperature and maximum circumferential strain of as-received and H charged samples after the test. H precharged cladding samples shows much lower burst temperature regardless of their heating rate [Fig. 3(a)].

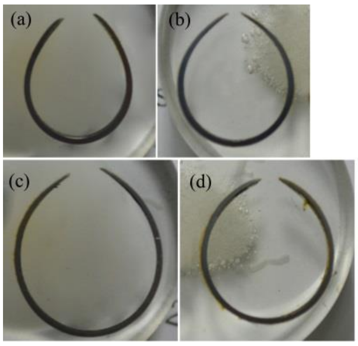

Fig. 2. Cross-sectional optical micrographic images at burst midplane for (a) as-received cladding with heating rate of 28 C/s, (b) prehydrided (300 wppm) cladding with heating rate of 28 C/s, (c) as-received cladding with heating rate of 1 C/s, and (d) prehydrided (300 wppm) cladding with heating rate of 1 C/s.

Burst strain at the location of rupture generally depends on temperature, internal pressure, and heating rate. Fig. 3 (b) shows burst strain as a function of heating rate. Internal pressure was fixed as 8 MPa. Difference in maximum circumferential strain of as-received and prehydrided cladding was increased with decreasing heating rate.

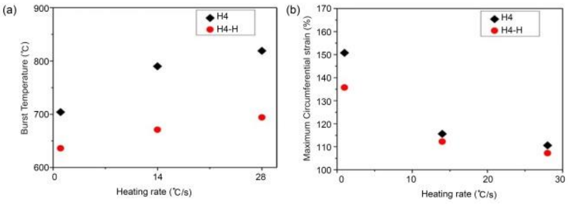

Fig. 3. (a) Burst temperature and (b) maximum circumferential strain as a function of heating rate for H4 and H4 cladding specimens.

4. Conclusion

To investigate the high burnup effects on rupture behavior of fuel cladding at high temperature, H charged claddings were examined. Prehydrided cladding shows the lower burst temperature and circumferential strain than that of as-received cladding. These results indicate that hydrogen uptake in high burnup fuel cladding may affect significantly on the burst behavior at high temperature.

ACKNOWLEDGEMENT

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REFERENCES

[1] M. Billone, Y. Yan, T. Burtseva, and R. Daum, Cladding Embrittlement during Postulated Loss-of-Coolant Accidents, NUREG/CR-6967, 2008 (available online in NRC ADAMS as ML082130389 at http://www.nrc.gov/NRC/reading-rm/adams.html.