High Burnup Effects on the Burst Behavior of Zr-based Alloy Claddings under LOCA Conditions

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1. Introduction

A current loss-of-coolant accident (LOCA) criterion is based on the results obtained from non pressurized claddings specimens under simulated LOCA condition. However, integrity of fuel cladding can be significantly affected by ballooning and rupture that caused by pressure difference between inner and outer cladding during LOCA. 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 whole process during LOCA 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, burst behavior of several kinds of zirconium based alloys was investigated by integral LOCA test and high burnup effects on the burst behavior of fuel cladding were also examined using H charged cladding sample.

2. Methods and Results

In this section some of the techniques and experimental apparatus used to simulate the LOCA situation are described. Then, the highlight data will be shown with detailed explanation.

2.1 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 introduced through the bottom. Steam flow was initiated at a test chamber temperature of ≈30ºC. Following introduction of steam into the chamber, furnace heating started for a pre-test hold temperature of 300℃. Steam flow and 300℃ of sample temperature were stabilized within 180 s. Heating rates were 1, 14, and 28 ℃ /s from 300℃ to 1200℃. After occurrence of ballooning and rupture opening, the tube was cooled down.

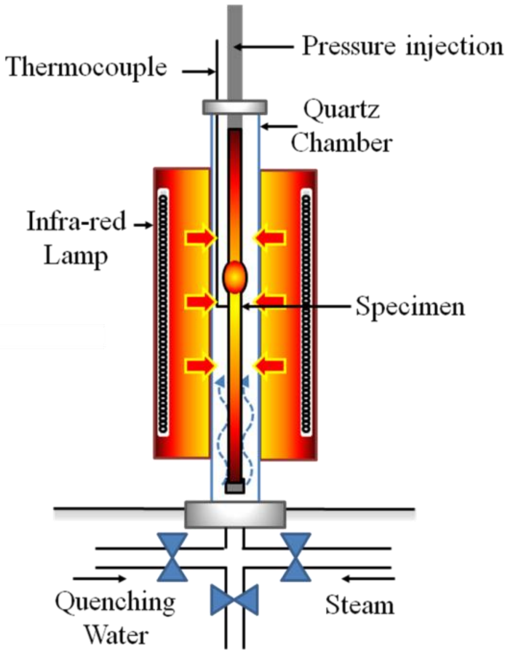

Fig.1. Schematic illustration for the integral LOCA facility

2.2 Results

Fig.2 shows rupture temperature data as a function of internal pressure for a range from 1 to 8 MPa. Integral LOCA test was performed using Zircaloy-4 and HANA4 cladding samples. This result shows general trend. Rupture temperature decreases with increasing internal pressure in both cases. Rupture temperature of HANA4 cladding was similar or slightly higher than that of Zircaloy-4.

Cross-sectional images of the test samples of HANA4 alloy were obtained at burst midplane and shown in Fig. 3. Figs. 3 (a) and (b) show a burst behavior of HANA4 claddings with heating rate of 28C/s. As received and prehydrided (300 wppm) sample shows similar circumferential strain at burst midplane. On the other hand, HANA4 claddings with heating rate of 1C/s show a significant difference in circumferential strain. Prehydrided (300 wppm) HANA4 cladding shows a

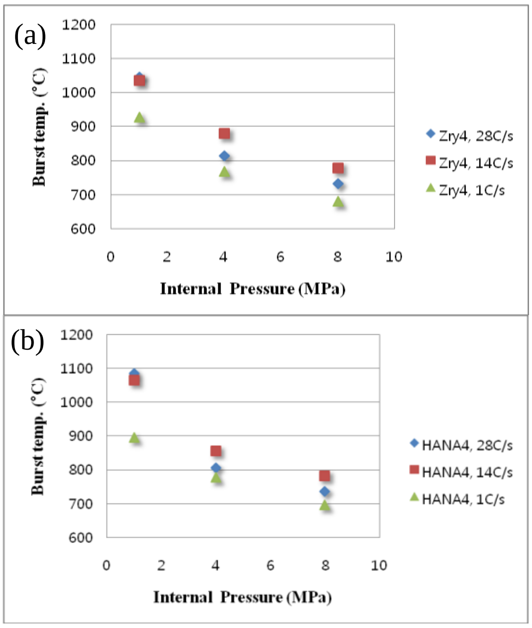

Fig.2. Burst temperature of (a) Zircaloy-4 and (b) HANA4 samples after integral LOCA test

lower circumferential strain than that of as-received sample. Rupture size of as-received cladding was smaller than that of prehydrided cladding.

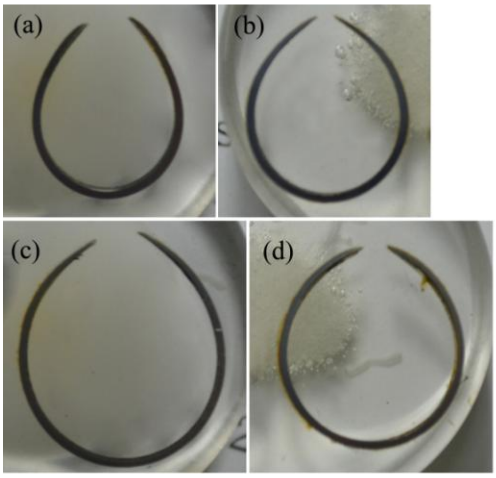

Fig.3. Cross-sectional optical micrographic images at burst midplane for (a) as-received HANA 4 cladding with heating rate of 28C/s, (b) prehydrided (300 wppm) HANA4 cladding with heating rate of 28C/s, (c) as-received HANA 4 cladding with heating rate of 1C/s, and (d) prehydrided (300 wppm) HANA4 cladding with heating rate of 1C/s.

Fig. 4 Shows Burst temperature and maximum circumferential strain of as-received and H charged HANA4 samples after integral LOCA test. H precharged cladding samples shows much lower burst temperature regardless of their heating rate. Burst strain at the location of rupture generally depends on temperature, internal pressure, and heating rate. Fig. 4 (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.

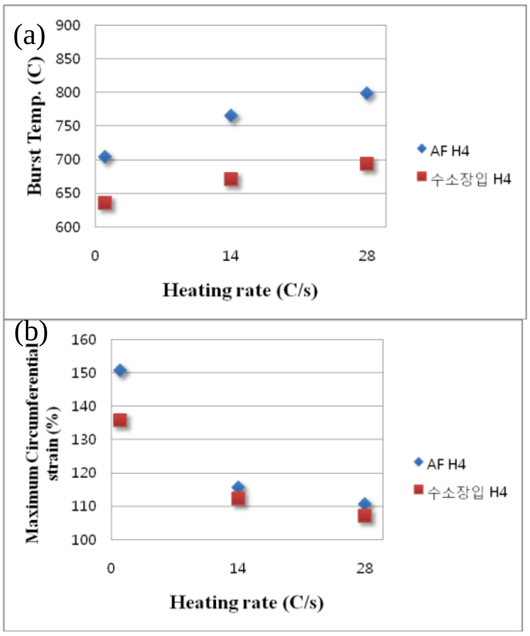

Fig.4. (a) Burst temperature and (b) maximum circumferential strain of as-received and H charged HANA4 samples after integral LOCA test

3. Conclusions

To investigate the high burnup effects on rupture behavior of fuel cladding during the LOCA, H charged claddings were examined. Prehydrided HANA4 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 during LOCA condition.

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)