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Behavior of HANA Cladding under the Rapid Pressurization

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1. Introduction

Reactivity Initiated Accident (RIA) is considered as the one of the most important accidents in the design of a light water reactor (LWR), which is mainly caused by an inadvertent ejection of the control rod. When the RIA occurs, the reactivity of the cladding rapidly rises so that the cladding integrity is severely damaged by the mechanical impact of the fuel and it even results in a fuel rod failure.

Recognized its severance, many researchers have concentrated on the behavior of a high-burnup cladding in the RIA situation, such as a high-speed ring tension test. However, their works were limited to uniaxial tensile test so that the effect of biaxial stress state on the mechanical property is not fully simulated at present. From the literature, the biaxiality of the cladding under actual RIA is known between 1 and 2 [1], on the other hand, the biaxiality of the ring tension test is zero, to leave a significant discrepancy between them.

The objectives in this study are to construct a rapid pressurization device and to investigate the mechanical property of the HANA-cladding under the rapid pressurization to closely simulate the RIA condition.

2. Experimentals

2.1. Test specimen

The claddings used in this study were the HANA-cladding developed by KAERI. HANA-4 (Zr-1.5Nb-0.4Sn-0.2Fe-0.1Cr), HANA-5 (Zr-0.4Nb-0.8Sn-0.3Fe-0.15Cr-0.07Cu), and HANA-6 (Zr-1.1Nb-0.05Cu) were used. Commercial grade low tin Zircaloy-4 (Zr-1.3Sn-0.2Fe-0.1Cr) was used as a reference cladding. Final heat treatment of the HANA cladding and Zircaloy-4 was conducted at the 470^{o}C so that all claddings had a stress-relieved state.

2.2. Rapid pressurization device

Fig. 1 shows a schematic illustration of the rapid pressurization device. Non-flammable silicon oil was used as a pressure medium. To achieve the high pressurization rate, the oil was initially pressurized at the accumulator up to 60000psi (=414MPa) prior to the test. The test begins by releasing electronic valve which connects between accumulator and the specimen to achieve the pressurization at the rate of 11.9GPa/sec in room temperature and 5.1GPa/sec in 350^{o}C. Length of the specimen is 200mm. In the device, hydraulic crosshead and load cell was equipped so that variation of axial stress was enabled.

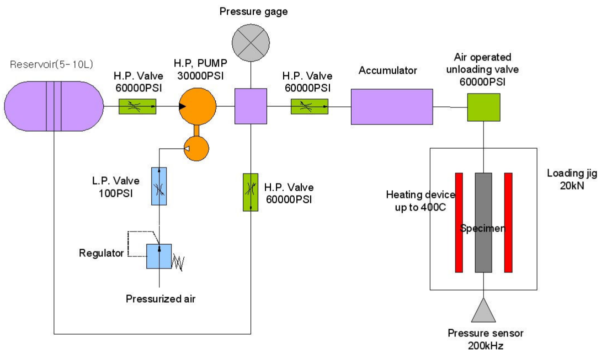

Fig. 1 Schematic illustration of rapid pressurization device for simulating RIA

3. Results and Discussions

3.*1. Mechanical property in as-received condition*

Fig. 2 shows the time-pressure profile of Zircaloy-4 cladding with the test temperature. Rupture time was ranged in 30~40 mili-seconds so that it could closely simulate actual RIA situation whose average pulse width ranged between 20 and 30 mili-seconds. Maximum hoop stress gradually decreases as the test temperature increases. Fig. 3 shows the maximum hoop stress of the as-received HANA-claddings after the rapid pressurization test. In Zircaloy-4, Maximum hoop stress in the rapid burst test increased 25% compared to the conventional burst test, which implies that the mechanical property in the rapid pressurization quite differs from that in conventional burst test. The maximum hoop stress of HANA-claddings increased compared to the Zircaloy-4, which is due to strengthening effect caused by the optimal addition of alloying element, such as tin and niobium [2].

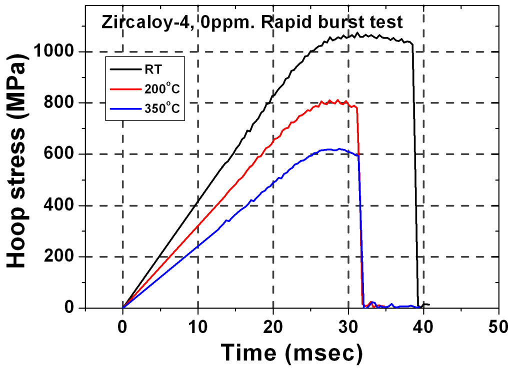

Fig. 2 Time-pressure profile of Zircaloy-4 cladding with the test temperature.

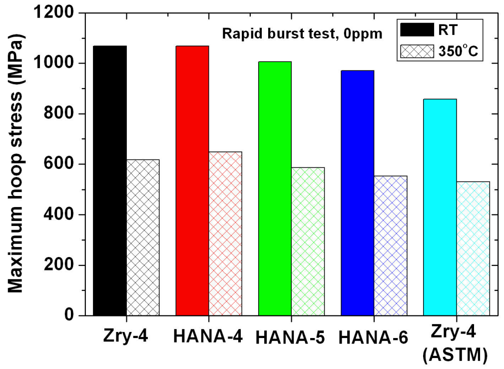

Fig. 3 Maximum burst hoop stress of the as-received HANA cladding under the rapid pressurization test.

3.2. Effect of the hydrogen

Hydrogen absorbs inside the zirconium cladding as the burnup proceeds to decrease the mechanical ductility. To investigate the effect of hydrogen, it was charged into

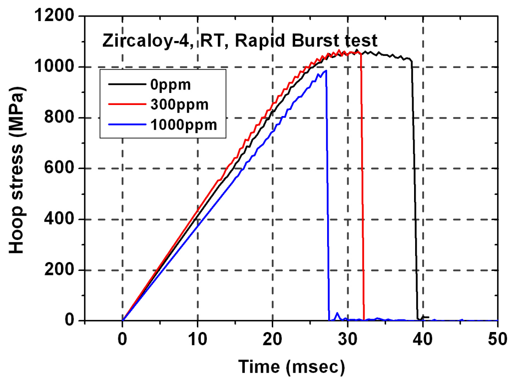

Fig. 4 Time-pressure profile of Zircaloy-4 cladding with the hydrogen content.

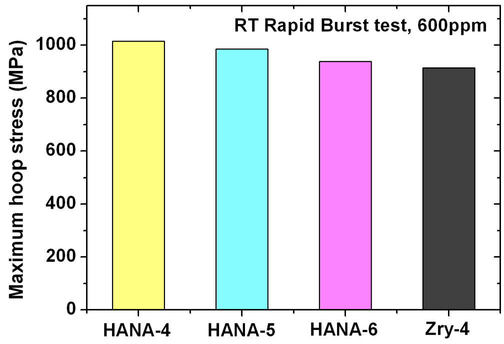

Fig. 5 Maximum burst hoop stress of the hydrided HANA cladding under the rapid pressurization test.

the zirconium cladding up to 1000ppm and rapid burst test was carried out. Fig. 4 shows the time-pressure profile of the Zircaloy-4 cladding with the hydrogen content. As the hydrogen content increases to 300ppm, maximum hoop stress does not much differ from the as-received condition. However, rupture time was reduced because of the brittle failure caused by the hydride. In the case of 1000ppm, the cladding was so brittle that it exhibited an early failure before it reached the maximum hoop stress. Fig. 5 shows the maximum hoop stress of the HANA cladding after hydrogen charged condition. Similar to the as-received condition, the maximum hoop stress of hydrogen-charged HANA claddings showed higher than that of the Zircaloy-4.

4. Conclusions

Mechanical behavior of HANA cladding under the rapid pressurization condition was conducted to simulate the RIA condition. The results showed that the rapid pressurization device could closely simulate the actual power profile during RIA condition. HANA-claddings exhibited the superior RIA resistance to the Zircaloy-4 either as-received or hydrogen-charged condition.

Acknowledgement

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