Effect of Creep Deformation on Ductility of Simulated Spent Fuel Cladding

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1. Introduction

At present, the only licensed method for storing domestic commercial PWR spent fuel is wet storage (or pool storage). But the saturation of pool is imminent, and dry storage process is essential before disposal. Dry storage is considered as well-developed technology for spent fuel management with no critical problems. Meanwhile, one of potential degradation mechanism for spent fuel cladding during dry storage is creep, although it does not degrade the cladding integrity.

Creep will deform the cladding, but the effect of creep deformation on ductility has yet to be reported. In this regards, cladding ductility before and after creep deformation were evaluated by ring compression test (RCT). In addition, hydride distribution was observed by optical microscope to confirm the changes of microstructure.

2. Experimental

2.1 Test material

The test material used in this study was unirradiated CWSR Zircaloy-4 cladding, which has been widely used in PWR fuel cladding. The initial cladding thickness (t) and outer diameter (OD) are 0.57 mm and 9.5 mm (Westinghouse 17X17 type). To simulate the behavior of spent fuel cladding, hydrogen is charged using the Sievert method under mixed argon/hydrogen condition at 400°C.

2.2 Test condition [1]

Creep tests were performed in a muffle furnace by internally pressurization method using 150mm long specimens, because that method is only available to apply stress uniformly without stress concentration at specific points. Assembled specimens constantly pressurized by argon gas to achieve the target hoop stresses. Temperature was continuously monitored and maintained with an accuracy of ± 4°C. The creep strain was calculated from average outer diameter measurement which was performed 10 times (axially 5 points and circumferentially 2 points per specimen). The schematic illustration of the sample and fixtures for the creep test are shown in Fig. 1.

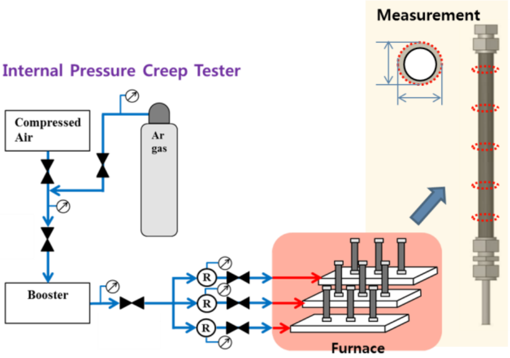


Fig. 1. Creep test method [1].

RCT at RT, 100°C, and 300°C was performed to compare the ductility before and after creep test. Also, microstructural analysis was performed to confirm hydride distribution.

3. Results and Discussion

3.1 Creep deformation

Creep strain as a function of time at 400°C, 120 MPa with various hydrogen contained specimens are shown in Fig. 2. After short primary creep, secondary creep behaviors were maintained during test time. Fresh (As-received) and 100 ppm H specimen shows 1% strain in 120 hours, and creep strain decreases as hydrogen content in specimen increases. 600 ppm H specimen reaches to 1% strain about 1500 hours. Because hydrogen leads to a significant creep strengthening and precipitated hydrides act as obstacles to dislocation glide [2,3].

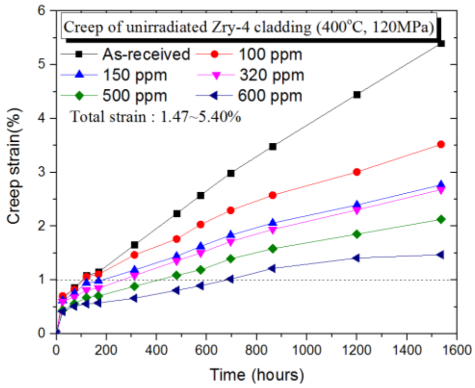
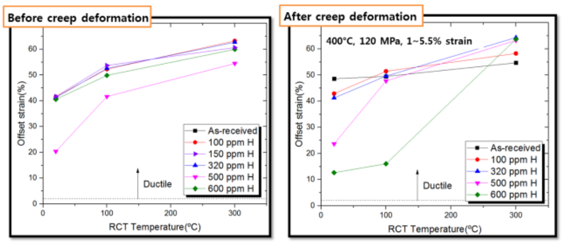


Fig. 2. Creep strain of unirradiated Zircaloy-4 cladding at 400°C, 120MPa.

3.2 Effect of creep deformation on ductility

Fig. 3 shows the measured offset strain by RCT at RT, 100°C, and 300°C. Regardless of creep deformation the ductility decreases as temperature decrease (Fig. 4). The offset strain decreases for specimens having high hydrogen content over 500 ppm, but the offset strain even at RT is enough to maintain ductile property within the all tested ranges of hydrogen contents. The trends of offset strain after creep deformation is identical with that no deformation condition. It implies that creep deformation does not have a significant effect on the ductility.



(a) (b)

Fig. 3. Results of ring compression test (a) before creep deformation (b) after creep deformation.

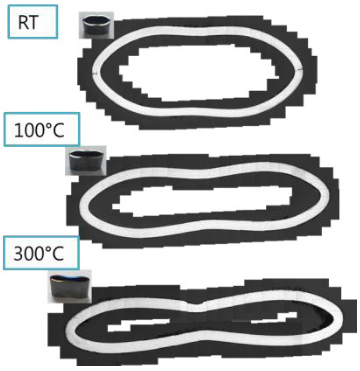


Fig. 4. Microstructure of Zircaloy-4 after creep deformation and RCT (400°C, 120MPa, 320ppm).

Meanwhile, as shown in Fig. 5, microstructure after creep deformation is same as that before deformation. Circumferential hydrides distribute uniformly and its amounts increases as charged hydrogen contents.

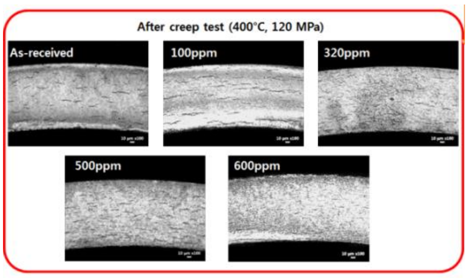


Fig. 5. Microstructure of Zircaloy-4 after creep deformation.

4. Conclusion

To clarify the effect of creep deformation on ductility, creep tests of unirradiated Zircaloy-4 cladding were performed below practical dry storage condition. To compare ductility before and after creep deformation, RCT at various temperatures were performed. That result implies that creep deformation does not have a significant effect on the ductility.

ACKNOWLEGMENTS

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