Hydride Effect on the Burst Properties of HANA-4 and HANA-6 Cladding Tubes

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1. Introduction

Zirconium alloys have been used as nuclear fuel cladding material because they have satisfactory mechanical strength and corrosion resistance. As new alloys for high burn-up fuel in reactors is being required, KAERI has developed some Zr-based new alloys, called HANA alloys, for high burn-up fuel cladding material. The sample specimens of HANA-4 (Zr-1.5Nb-0.4Sn-0.2Fe-0.1Cr) cladding tube material showed good performance in both corrosion and creep at the irradiation test up to 10GW/MtU in Halden test reactor [1]. In addition to good creep performance, the other mechanical properties such as tensile, burst, fatigue are also required for the cladding to show the good performance in reactor. When a zirconium alloy is used in a nuclear reactor, hydrides form in it from not only external hydrogen sources such as waterside corrosion, dissolved hydrogen in coolant, water radiolysis but also internal sources such as hydrogen content in fuel pellets and moisture absorbed by the uranium dioxide fuel pellet [2]. The terminal solubility of hydrogen in Zircaloy is about 150 ppm at 350℃ which is near the coolant temperature of power reactor [3]. But the local hydrogen content in the irradiated Zircaloy-4 cladding tube can be over 1000 ppm [4]. Thus, hydrogen embrittlement of zirconium alloys has been extensively studied because hydrides may act as a sudden failure [5]. The tensile strength of the HANA-4 cladding tube increased and tensile elongation decreased with the increase of hydrogen in it up to 500 ppm [6]. To know the effect of hydrogen on the burst properties of HANA-4 and HANA-6(Zr-1.1Nb-0.05Cu) the cladding tubes at reactor operation temperature, the burst tests at 350±1℃ were attempted on HANA-4 and HANA-6 as well as Zircaloy-4 (Zr-1.26Sn-0.23Fe-0.12Cr) and A (Zr-1.0Nb-0.99Sn-0.11Fe) sample cladding tubes which have about 500 to 1200 ppm hydrogen.

2. Methods and Results

The cladding tube specimens with 150mm in length were charged with hydrogen gas at 400℃. After being hydrogen charged, the specimens were heat-treated for 30 minutes at 410℃ in order to homogenize the hydrogen content in the specimens. HANA-4 and HANA-6 tube specimens were finally heat-treated at 510℃ for 2.5 hours and it was known that the heat treatment of Zircaloy-4(Zry-4) and A tube specimens were done at about 470℃. It was found by gas analysis that actual hydrogen content of the hydrided specimens 457 ppm to 1181 ppm. The burst tests of the specimens were carried out at 350℃ according to the requirements of ASTM B811-97 pressurizing Ar gas with 50 bars per minute. After the tests, the ultimate hoop stress (UHS) and total circumferential elongation (TCE) of the specimens were calculated with the methods presented in the ASTM B811-97.

2.1 Hydrides on the specimens

Fig. 1 shows that the thicker and the longer hydride platelets precipitated as the hydrogen content of the specimens increased.
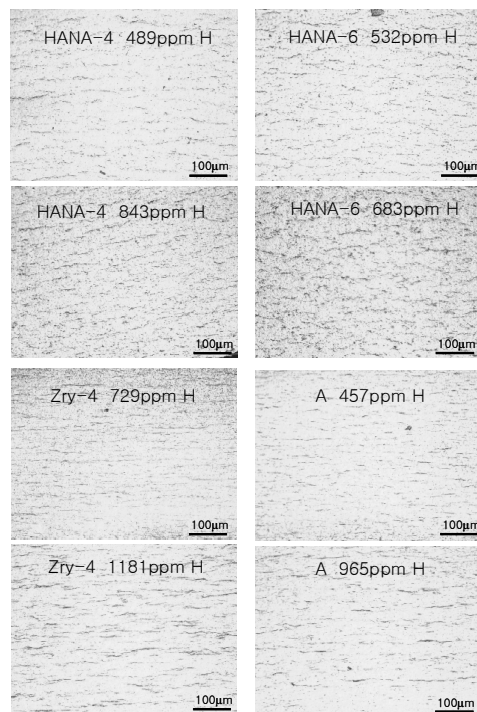

Fig. 1. Hydrides in axial direction of the cladding tubes with different hydrogen content

2.2 Burst properties of the hydrided specimens

Fig. 2 indicates that the UTS change of specimens is a little but the TCE decreases with the increase of hydrogen content. HANA-4 and 6 specimens have less TCE change than Zry-4 and A specimens. The HANA specimens also

have lower UHS and higher TCE than the other specimens. The difference of burst properties between HANA specimens and the other ones may be from the difference of final heat treatment because the heat treatment temperature of Zry-4 and A was known to be lower about 40 to 60℃ than that of HANA. Since circumferential hydride does not act as a fatal crack-initiating site [7], the UHS of the tube specimens does not seem to decrease with the increase of hydrogen content. As the volume fraction of hydrides increases, the number of void nucleation site increase [4], the increase of hydrogen content in the tube specimens would lead to the TCE reduction.
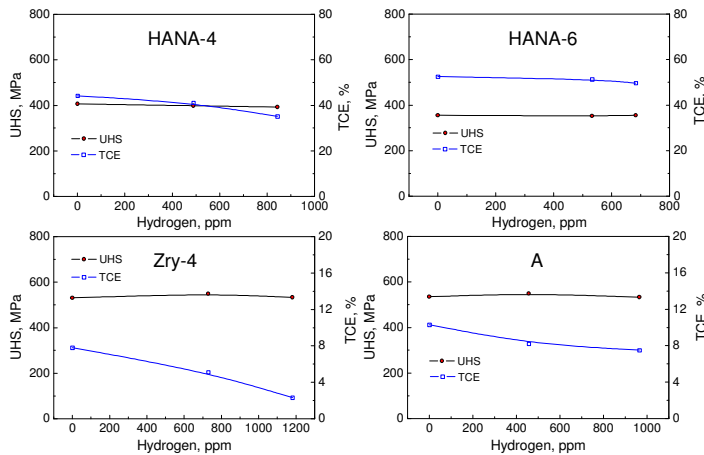

Fig. 2. Burst properties of the cladding tubes at 350℃

2.3 Fracture Surfaces of the Specimens

Fig. 3 shows the fracture surfaces in axial direction of specimens when the specimens were burst at 350℃. HANA specimens have less crack cleavage than Zry-4 and A specimens. Because crack goes along the length of hydride platelet when it is normal to the applied stress direction [8], it seemed that the crack of Zry-4 and A specimens tried to go along the axial direction. By the way, the crack openings of HANA specimens are not severe like Zry-4 and A specimens. The macroscopic burst openings of HANA specimens also do show less axial running. The large matrix ductility of HANA specimens might prevent the crack from easy propagation even though the specimens were hydrided.

3. Conclusion

To study the effect of hydrogen on the burst properties of HANA-4 and HANA-6 cladding tubes which had been finally heat-treated at 510℃, the burst tests were done at 350℃ for the HANA cladding tube specimens as well as Zry-4 and A specimens after they were hydrided 457 to 1181 ppm with the hydrogen content. The test results can be summarized as follows;
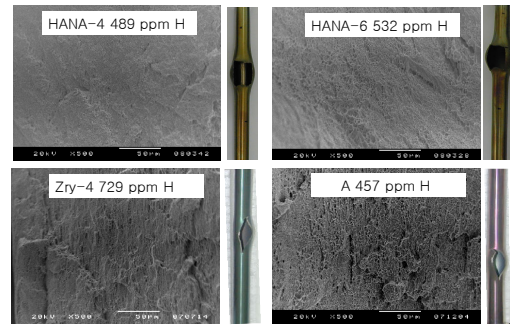

Fig. 3. Fractographs of the hydrided specimens (x500)

(1) As hydrogen content increases, the thicker and the longer hydride platelets precipitate.
(2) Like Zry-4 and A cladding tubes, HANA-4 and HANA-6 cladding tubes have little UHS change but their TCEs decrease with the increase of hydrogen content.
(3) HANA-4 and HANA-6 cladding tubes have less axial burst split than Zry-4 or A cladding tubes when the HANA cladding tubes were finally heat treated at 510℃.

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