The effect of temperature and stress on hydride reorientations of high burnup claddings under interim dry conditions

Su-Jeong Min [a*], Myeong-Su Kim [a], Chu-Chin Won [a], Kyu-Tea Kim[a]
[a]*Nuclear and Energy Engineering Department, Dongguk Universty*
123, Dongdea-Ro, Gyeongju, Republic Of Korea, 780-714
[*]*Corresponding author: maymsj1118@dongguk.ac.kr*

1. Introduction

Interim dry storage of spent nuclear fuel has been considered as an option for increasing spent fuel storage capacity in Korea. It is generally known that hydride reorientation from the circumferential to radial direction may reduce the critical stress intensity that accelerates radial crack propagation.[1-4] In this work, the integrity of high burnup spent fuel during the interim dry storage was investigated, simulating interim dry storage and high burnup fuel conditions and using unirradiated Zr-Nb alloy claddings. First of all, mechanical property degradations of the hydrogen-charged Zr-Nb alloy claddings were generated at various temperature conditions. Then, the effects of cooling rate under the tensile hoop stress of 150MPa on hydride reorientation were investigated. It is found that the mechanical properties of the Zr-Nb claddings are strongly related to temperature and hydrogen content.

2. Methods and Results

2.1 Methods

Stress-relief annealed Zr-Nb alloy claddings with an outside diameter of 9.5mm and a wall thickness of 0.58mm were employed. Its chemical composition is given in Table 1. Two cladding tubes, cut into 100mm length, were first uniformly hydrogen-charged by a mixed gas of 150torr H_2 and 200torr He at 400^{o}C. The target hydrogen levels ranged from 300 and 600 ppm. Typically hydrides were oriented in the circumferential direction and homogeneously distributed across the cross-section of the cladding specimens.

Table 1. Chemical composition of Zr-Nb alloy cladding (wt%)

Nb	Sn	Fe	Zr
1.0	1.0	0.1	Balance

The first mechanical tests were carried out for the 250ppm and 500ppm hydrogen-charged Zr-Nb alloy cladding specimens at temperatures of room temperature(RT), 200 ^{o}C, 300 ^{o}C and 400^{o}C at a strain rate of 0.12mm/min to examine the effect of temperature and hydrogen content on the cladding mechanical properties. The specimens were heated at a heating rate of 1^{o}C/min with no stress applied. The second mechanical tests, as shown in Fig.1, were done for the hydrogen-charged specimens of 250 and 500ppm at RT, 200^{o}C, 300 ^{o}C after holding for 2hrs at 400^{o}C under a tensile hoop stress of 150MPa and then cooling at RT, 200^{o}C, 300^{o}C at a cooling rate of 25^{o}C/min maintaining the same hoop stress to evaluate the effect of hydrogen content on the amount and morphology of radial hydride formed during the cooling and subsequently on the mechanical property degradation.

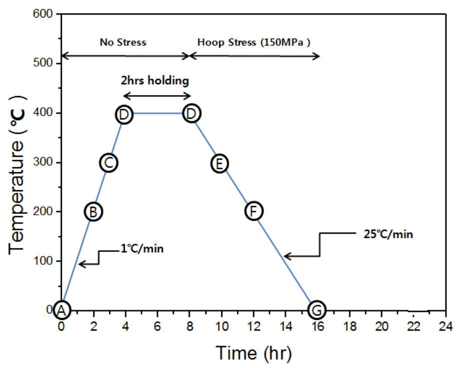

Fig 1.Temperature and Hoop Stress histories for ring specimen cooling tests.

2.2 Results

The first mechanical tests were carried out for the 250ppm and 500ppm hydrogen-charged Zr-Nb alloy cladding specimens at temperatures of RT, 200, 300 and 400^{o}C. The test results are shown in Fig.2 and Fig.3

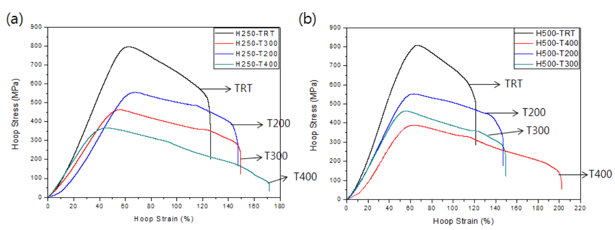

Fig 2.Temperature and Hoop Stress histories for ring specimen cooling tests.

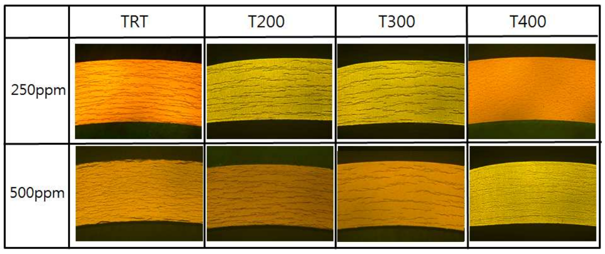

Fig 3. Temperature-dependent microstructure of 250ppm-H and 500ppm-H Zr-Nb claddings

The second mechanical tests were done for the hydrogen-charged specimens of 250, 500ppm at RT, 200°C, 300 °C after holding for 2hrs at 400°C under a tensile hoop stress of 150MPa and cooling rate of 25°C/min maintaining the same hoop stress in order to evaluate the effect of hydrogen content on the amount and morphology of radial hydride formed during the cooling and subsequently on the mechanical property degradation. The test results are shown in Figs. 4 and summarized in Table 2.

From this figure, it can be seen that effect of cooling temperature on the ultimate tensile strengths and strain is considerable. It was reported that hoop strain will decrease as cooling temperature in the cladding decrease. However, the hoop strain of the 250ppm hydrogen-charged specimens are a little less than those of the 500ppm-H specimens during the cooling.

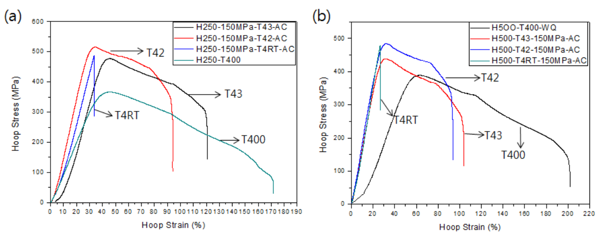

Fig 4. Hoop stress-strain curves of 250ppm-H and 500ppm-H Zr-Nb claddings

Table 2. Cooling temperature-dependent Hoop stress and Hoop strain of Zr-Nb claddings.

수소함량(ppm)	온도 (℃)	Hoop stress(MPa)	Hoop strain (%)
250	TRT	796.7	85
	T200	555.5	100
	T300	462.2	117
	T400	366.7	165
	T43AC	476.8	90
	T42AC	515.5	71
	T4RTAC	336.7	0
500	TRT	807.7	75
	T200	552.8	95
	T300	463.2	112
	T400	388.7	170
	T43AC	438.6	85
	T42AC	484.7	75
	T4RTAC	477.9	0

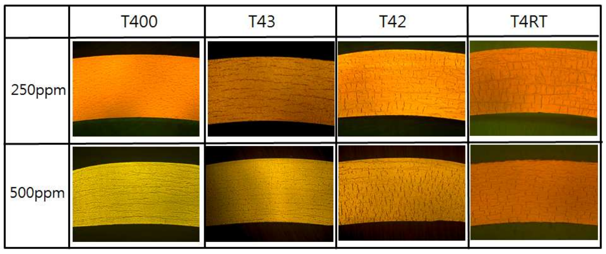

Fig 5. Cooling Temperature-dependent microstructure of 250ppm-H and 500ppm-H Zr-Nb claddings.(x100)

This can be explained by the morphologies of the specimens, as shown in Fig. 5. This figure indicates that the fraction of the radial hydrides is largest for the 250ppm specimen during the cooling from 400 to RT. It is noteworthy that the larger fraction and length of the radial hydrides may generate the more brittle cladding materials. Therefore, the 250ppm specimen generated the least elongation.

3. Conclusions

- The effect of cooling temperature in the cladding are considerable. The elongation of the specimens during the cooling from 400 to RT are a little less than those of the elongation of the specimens during the cooling from 400 to 200~300, which may be explaned by a relatively longer radial hydride plates reprecipitated from the dissolved hydrogen at each temperature.
- The effect of initial hydrogen content in the cladding on the amount and morphology of radial hydrides are significant. The 250ppm hydrogen-charged cladding specimens generated larger fraction when cooling from 400 to RT under a tensile hoop stress of 150MPa, compared to the 500ppm specimens.
- Ring tensile tests for the specimens cooled down under the 150MPa hoop stress condition show that there is little effect of hydrogen contents on ultimate tensile strengths, while the 250ppm-H specimen generated less plastic elongation than the 500ppm-H specimen which may be explained by a relatively longer radial hydride plates in the 250ppm-H specimen.

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