Effect of Hoop Stress on the Hydride Reorientation of Non-irradiated Zircaloy-4 Cladding Tube : 90 MPa, 120 MPa & 150 MPa

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1. Introduction

When nuclear fuel is burning, internal rod pressure acts on the inside of the cladding, and the hydride is injected into the radius of the cladding, resulting in a hydride reorientation by hoop stress. At this time, the dissolved circumferential hydride is slowly precipitated from the radial hydride, which makes it more brittle and thus degrading the integrity of the cladding tube. The hydride reorientation occurs by internal rod pressure of the fission gas in cladding tube, and the hoop stress is applied to the outer diameter of the cladding, causing hydrogen to flow in a radial direction [1,2,3].

The effects of hydride reorientation, which may be caused by hoop stress, were evaluated during long-term dry storage of spent fuel cladding.

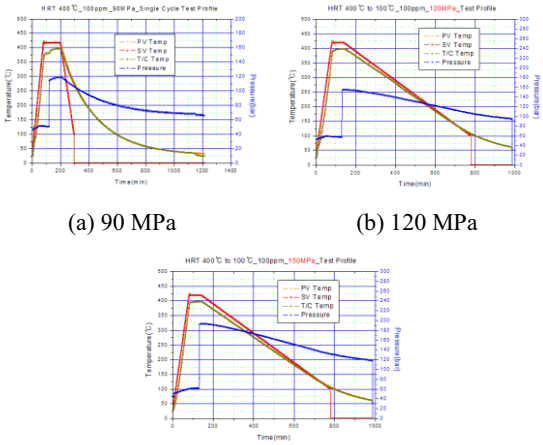
2. Experiment

2.1 Hydride Reorientation Test Method

Using a 100 ppm of the non-irradiated Zircaloy-4 cladding tube, the hydride reorientation test(HRT) from 400℃ of maximum temperature to 100℃ on decreasing 0.5℃/min was performed at the hoop stress 90 MPa, 120 MPa and 150 MPa respectively. At this time, the hoop stress is not constants. Table 1 is HRT temperature program of 0.5℃/min cooling rate. And the Fig. 1 is test profiles of temperature and hoop stress.

Table 1. HRT temperature program

Segment	Target Temperature	Heating(Cooling) Rate	Step Time
1	420℃	+ 5 ℃/min	1.20 hr.min
2	420℃	Holding	1.00 hr.min
3	100℃	- 0.5 ℃/min	10.40 hr.min
4	RT	-	End



(a) 90 MPa (b) 120 MPa

(c) 150 MPa

Fig. 1. HRT profiles of temperature and hoop stress.

2.2 Specimens and Test Condition

The test specimen of non-irradiated Zircaloy-4(cold-worked, stress-relief annealed, CWSRA) cladding was a 100 wppm of the treated homogenization hydrogen, using the vacuum chamber of the volume of a mass system. And each specimen length is 150 mm used fitting at top and bottom. Table 2 lists the specimen and test conditions.

Table 2. Specimen and Test Condition

Specimen				Condition	
Material	Length (mm)	Hydrogen Concentration (ppm)	Diameter (mm)	Hoop Stress (MPa)	IRP (MPa)
Zry-4	150	100	9.5	90	11.54
				120	15.38
				150	19.22

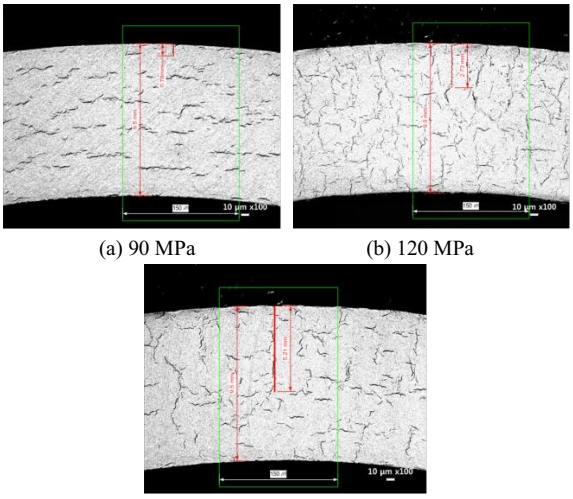
3. Test Results

After hydride reorientation test of non-irradiated Zircaloy-4 cladding tube, the offset strain was assessed from ring compression test at room temperature, 100℃ and 300℃ respectively. And the specimens were reviewed micro-structure of hydride

morphology.

3.1 Morphology and RHCF after HRT

Fig. 2 is a micro-structure of 100 ppm specimen after HRT. It is difficult to observe changes in radial hydrides at 90 MPa hoop stresses through visualized studies. However, radial hydrides were observed at 120 MPa and 150 MPa specimens. Result of RHCF analysis showed 8.21%, 28.77% and 54.79% at 90 MPa, 120 MPa and 150 MPa hoop stress, respectively.



(a) 90 MPa (b) 120 MPa

(c) 150 MPa

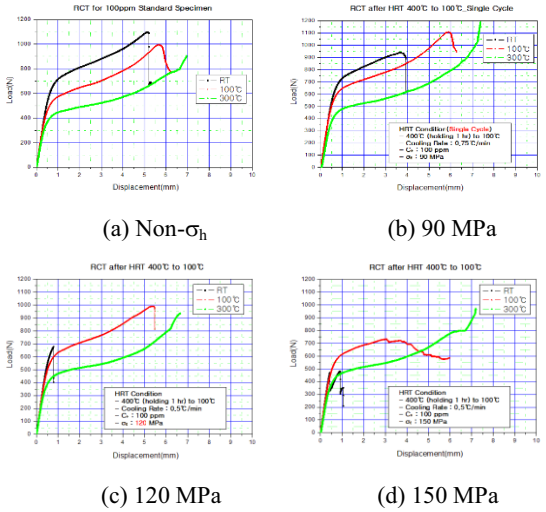
Fig. 2. Morphology and RHCF after HRT.

3.2 RCT Results at RT

Table 3 and Fig. 3 are ring compression test results at room temperature. The 100 ppm specimens were assessed the brittle by radial hydride. At result of offset strain evaluated 29.82%, 2.84% and 0.63% at 90 MPa, 120 MPa and 150 MPa hoop stress respectively. The 150 MPa specimen is very brittle and rated at creep limits of less than 2%.

Table 3. Results of RCT and Offset Strain at RT

Hoop Stress (σ_h)	Hydrogen Concentration (ppm)	Diameter (mm)	Length (mm)	Max. Load (N)	Offset Dis (mm)	Offset Strain (%)
Non-σ_h	100	9.50	10.05	1098	4.114	43.31
90 MPa	93.8	9.49	10.06	933	2.83	29.82
120 MPa	99.5	9.51	10.06	677	0.27	2.84
150 MPa	110.5	9.49	10.02	481	0.06	0.63



(a) Non-σ_h (b) 90 MPa

(c) 120 MPa (d) 150 MPa

Fig. 3. Results of 100 ppm RCT.

4. Conclusion

Using a 100 ppm non-irradiated Zircaloy-4 cladding tube, the hydride reorientation test (HRT) from 400℃ of maximum temperature to 100 ℃ on decreasing 0.5℃/min were performed at each other hoop stresses. Using the morphology, result of RHCF analysis showed 8.21%, 28.77% and 54.79% at 90 MPa, 120 MPa and 150 MPa hoop stress, respectively. The test results of offset strain at 90 MPa, 120 MPa and 150 MPa of the 100 ppm specimens were 29.82%, 2.84% and 0.63% respectively. The 150 MPa specimen is very brittle and rated at creep limits of less than 2%.

ACKNOWLEDGEMENT

This work was supported by the Korea Institute of Energy Technology Evaluation and Planning (KETEP) granted financial resource from the Ministry of Trade, Industry and Energy, Republic of Korea (No. 2014171020166A).

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