Effect of Cooling Rate on the Hydride Reorientation of Non-irradiated Zircaloy-4 Cladding Tube : 0.5℃/min vs. 0.5℃/hr

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1. Introduction

In a dry storage environment, the spent fuel will have a long period of cooling time at high temperatures. 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]

The effects of cooling rate of hydride reorientation, which could occur during long-term dry storage process in the spent fuel cladding, were evaluated.

2. Experiment

2.1 Hydride Reorientation Test Method

Using a 400 ppm and 600 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 and 0.5℃/hr were performed at hoop stress 90 MPa respectively. Table 1 and 2 is HRT temperature program of 0.5℃/min and 0.5℃/hr. And the Fig. 1 is test profiles of temperature and hoop stress.

Table 1. HRT temperature program of short-term [2]

0.5℃/min Cooling Rate HRT 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

Table 2. HRT temperature program of long-term [3]

0.5℃/hr Cooling Rate HRT Program			
Segment	Target Temperature	Heating(Cooling) Rate	Step Time
1	418 ℃	+ 2 ℃/min	3.29 hr.min
2	418 ℃	Holding	1.00 hr.min
3	100 ℃	- 0.5 ℃/hr	636.00 hr.min
4	RT	-	End

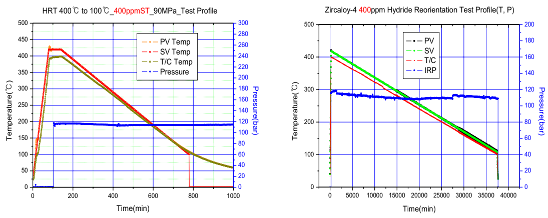

Fig. 1. HRT profiles of temperature and hoop stress.

2.2 Specimens and Test Condition

The test specimen of non-irradiated Zircaloy-4(cold-worked, stress-relief annealed, CWSRA) cladding were 400 ppm and 600 ppm of the treated homogenization hydrogen respectively, using the injection chamber of the volume of a mass system. And each specimen length is 150 mm used fitting at top and bottom. Table 3 lists the specimen and test conditions.

Table 3. Specimen and Test Condition

Specimen				Condition	
Material	Length (mm)	Hydrogen Concentration (ppm)	Diameter (mm)	Hoop Stress (MPa)	IRP (MPa)
Zry-4	150	400	9.5	90	11.536
		600			

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 after HRT

Fig. 2 is a micro-structure of 400ppm and 600ppm specimen after HRT. Through the visualized review, it is difficult to observe the change in radial hydride.

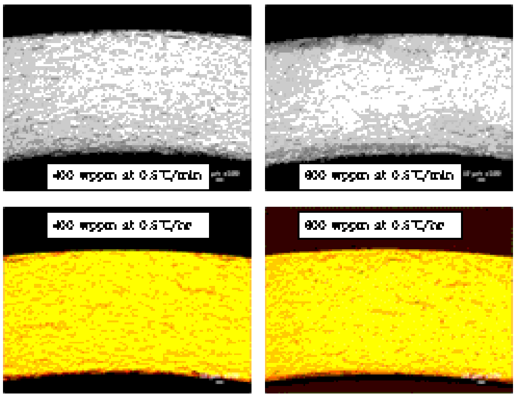

Fig. 2. Morphology after HRT.

3.2 RCT Results at RT

Table 4 and Fig. 3&4 are ring compression test results at room temperature. At result of offset strain, the 600wppm specimen of long-term cooling speed was assessed the brittle by radial hydride.

Table 4. Results of RCT and Offset Strain

RCT at RT	Hydrogen Concentration (ppm)	Diameter (mm)	Length (mm)	Max. Load (N)	Offset Dis (mm)	Offset Strain (%)
Non-HRT	400	9.50	10.01	907.9	2.53	26.65
	600	9.50	10.00	867.2	2.025	21.32
Short-term	400	9.51	10.01	925.4	2.51	26.40
	600	9.50	10.01	694.4	0.50	5.26
Long-term	400	9.51	9.18	744.9	1.70	17.88
	600	9.50	10.01	655.8	0.23	2.42

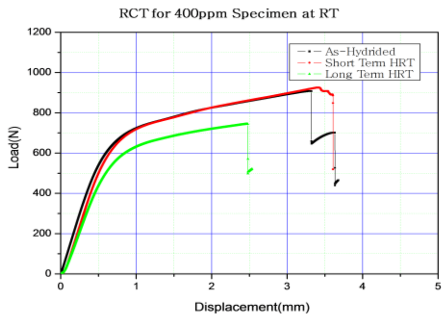

Fig. 3. Results of 400 ppm RCT at RT.

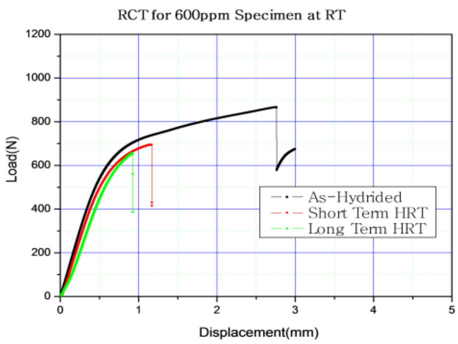

Fig. 4. Results of 600 ppm RCT at RT.

4. Conclusion

Using a 400 ppm and 600 ppm non-irradiated Zircaloy-4 cladding tube, the hydride reorientation test (HRT) from 400℃ of maximum temperature to 100℃ on decreasing 0.5℃/min and 0.5℃/hr respectively were performed at hoop stress 90 MPa. The test results of offset strain of the 400 ppm specimen at the short-term cooling rate of 0.5℃/min were 26.65%, 26.4% and 17.88% respectively. And the results of offset strain of the 600 ppm specimen at the long-term cooling speed of 0.5℃/hr were 21.32%, 5.264% and 2.42% respectively. In order to assess the effect of the cooling speed on the hydride reorientation, a repetition test is required in various conditions.

ACKNOWLEDGEMENT

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