Effect of Thermal Cycling on the Hydride Reorientation of Non-irradiated Zircaloy-4 Cladding Tube : 1 Cy, 3 Cy & 10 Cy

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1. Introduction

During long-term dry storage, spent fuel undergoes several thermal cycles. In particular, after charging into spent fuel storage casks, vacuum drying is performed to remove water, and this vacuum drying process undergoes several heat cycles. This heat cycle can affect the hydride reorientation in the fuel cladding. [1]. The United States NRC is an ISG-11, Rev. 3 (2003), it is necessary to confirm the radial hydride reorientation in the conditions related to the dry transfer operation and storage. It is recommended that the heating/cooling cycle be allowed up to 10 times during loading of the fuel in the dry storage cask and the temperature variation width should be less than 65℃(included vacuum drying).[2,3]

The effects of thermal cycling on the hydride reorientation, which could occur during vacuum drying process of the spent fuel cladding in dry storage cask, were evaluated.

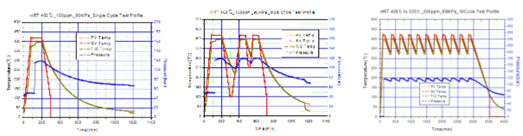
2. Experiment

2.1 Hydride Reorientation Test Method

Using a 100 ppm and 300 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 single cycle, 3 cycles and 10 cycles 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

Thermal Cycling HRT Temperature Program				
Segment	Target Temp.	Heating Rate	Step Time	Remarks
1	420℃	+5℃/min	1.20 hr.min	
2	420℃	Holding	1.00 hr.min	
3	335℃	- 0.5℃/min	2.50 hr.min	
4	335℃	Holding	0.30 hr.min	
5	420℃	+5℃/min	0.17 hr.min	
	Repeat 2~5 segments 10 times			
6	420℃	+5℃/min	0.17 hr.min	
7	420℃	Holding	1.00 hr.min	
8	100℃	- 0.5℃/min	10.40 hr.min	
9	RT	-	-	End



(a) single cycle (b) 3 cycles (c) 10 cycles

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 a 100ppm and 300ppm 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

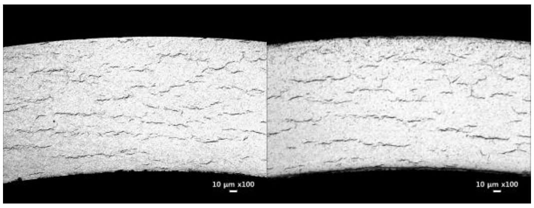
Specimen			Condition			
Hydrogen Concentration (ppm)	Length (mm)	Dia. (mm)	Hoop Stress (MPa)	IRP (MPa)	ΔT (℃)	Cycle
100	150	9.5	90	11.5	300	1
				11.5	180/100	3
300	150	9.5	90	11.5	80	10
			120	15.3	80	10

3. Test Results

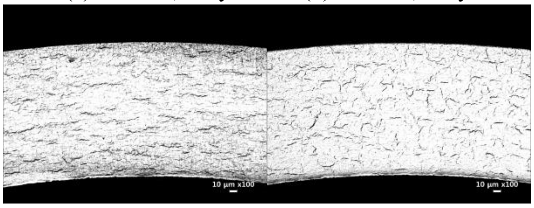
After hydride reorientation test of non-irradiated Zircaloy-4 cladding tube, the offset strain was assessed from ring compression test at room temperature, 100℃ and 300℃ respectively. And the specimens were reviewed micro-structure of hydride morphology.

3.1 Morphology after HRT

Fig. 2 is a micro-structure of specimen after HRT of thermal cycle conditions. It is difficult to observe changes in radial hydrides at 90 MPa hoop stresses through visualized studies. However, radial hydrides were observed in some of the 120 MPa hoop stress specimen in 10 cycles.



(a) 90 MPa, 1 Cy (b) 90 MPa, 3 Cy



(c) 90 MPa, 10 Cy (d) 120 MPa, 10 Cy

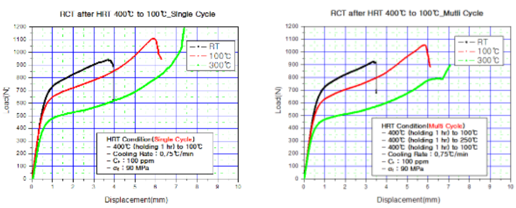
Fig. 2. Morphology after HRT.

3.2 RCT Results at RT

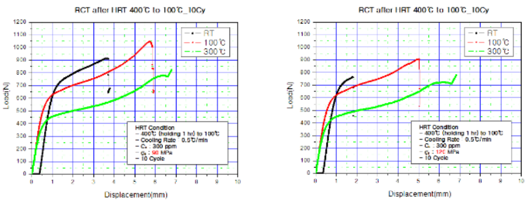
Table 3 and Fig. 3 are ring compression test results at room temperature. In this hydride reorientation test, the offset strain results of 1-cycle, 3-cycle and 10-cycle of 90 MPa hoop stress specimens were assessed 29.82%, 27.05% and 24.65% respectively. The 120 MPa hoop stress specimen was evaluated as susceptible to fracture by radial hydrides. However, it was evaluated as not exceeding the creep limit of less than 2%.

Table 3. Results of RCT and Offset Strain at RT

Specimen	Hydrogen Concentration (ppm)	Diameter (mm)	Length (mm)	Max. Load (N)	Offset Dis (mm)	Offset Strain (%)
90 MPa, 1 Cy	93.8	9.49	10.06	933	2.83	29.82
90 MPa, 3 Cy	135.3	9.50	10.23	916	2.57	27.05
90 MPa, 10 Cy	366.0	9.50	10.01	915	2.34	24.65
120 MPa, 10 Cy	375.6	9.50	9.98	764	0.75	7.86



(a) 90MPa, 1 Cy (b) 90MPa, 3 Cy



(c) 90MPa, 10 Cy (d) 120MPa, 10 Cy

Fig. 3. Results of RCT.

4. Conclusion

This hydride reorientation test was performed at the various thermal cycling conditions for integrity of cladding. In this hydride reorientation test, the offset strain results of 1-cycle, 3-cycle and 10-cycle of 90MPa hoop stress specimens were assessed 29.82%, 27.05% and 24.65% respectively. The 120 MPa hoop stress specimen was evaluated as susceptible to fracture by radial hydrides. However, it was evaluated as not exceeding the creep limit of less than 2%.

This results of offset strain at the 10-cycle was similar to other hydride reorientation test cases. It is difficult to assess that a thermal cycle effect is affecting the hydride reorientation. However it has a significant impact on the thermal degradation of the spent fuel cladding.

ACKNOWLEDGEMENT

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