Hydrogen Content Effects on Delayed Hydride Cracking in Zircaloy-4 Cladding

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1. Introduction

Since Delayed Hydride Cracking (DHC) is observed from pressure tubes of Zr-2.5Nb alloy, there have been lots of studies of DHC. Recently, spent nuclear fuel dry storage period is getting longer in many countries. So, DHC is re-considered as a possible mechanism for the degradation of zirconium alloy fuel cladding. Also, because of long period operation, burn-up of spent nuclear fuel and hydrogen contents of cladding is getting higher. For that reason, the relation between hydride content in zircaloy-4 cladding and delayed hydride cracking was evaluated experimentally in this paper.

2. Delayed Hydride Cracking Experiment

2.1 Specimen

Zircaloy-4 tube was used as a specimen. For hydrogen charging, 150 mm Zircaloy-4 tubes were located in an electric furnace and heated up to 400℃ with hydrogen gas. After hydrogen charging, the specimens were sealed in vacuumed quartz and treated at 400 ℃ for 24 hours to homogenize hydrogen distribution in the specimens. To confirm hydrogen content, hot vacuum extraction method was used and the hydrogen content of each specimens are shown in Table 1.

Table 1. Hydrogen content of specimens

	S1	S2	S3	S4
Hydrogen content (wppm)	173.3	247.0	304.0	599.3

2.2 Experiment equipment

Experiment was conducted by Pin Loading Test method developed in Studsvik. Pin loading fixture, shown in Fig. 1, was prepared and located at the center of equipment. To control the temperature of specimen, heater was set up, surrounding the specimen. At the bottom of the bar, connected to PLT fixture, weight disk was hanged.

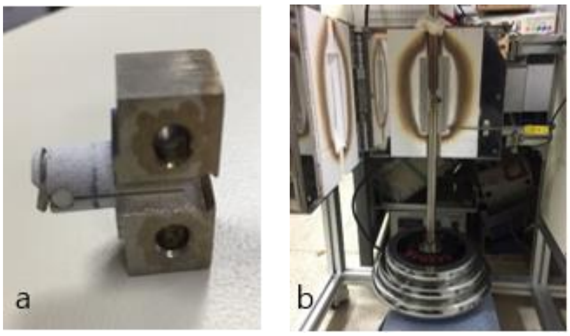

Fig. 1. (a) Pin Loading Test fixture, (b) Heater and Tensioning Tester.

2.3 Experimental condition

Experimental condition is described in Fig. 2. The temperature was increased from room temperature to 400℃. After an hour holding 400℃, the temperature decreased to test temperature which was 250℃. To minimize temperature fluctuation, the temperature was held for 30 minutes before loading. After loading weight, the condition of experiment was maintained for 20 hours. Different hydrogen content specimens were experimented same as above.

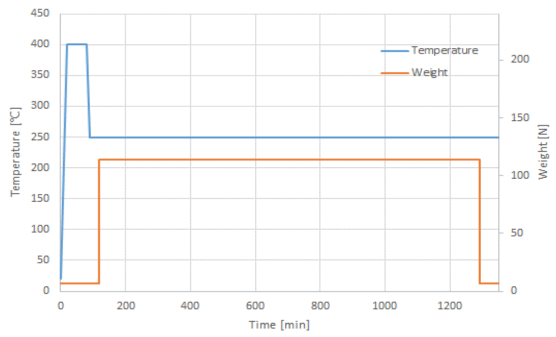

Fig. 2. The experimental condition of temperature and weight.

2.4 Experiment result

Firstly, relation between hydrogen content and delayed hydride crack initiation weight was tested. When the loading weight was 89.2 N, DHC wasn't occurred at S1 specimen but DHC was occurred at S2 and S3 specimens. Even, when S4 specimen was tested, DHC was occurred with lower weight which was 79.4 N. It means that DHC occurring weight was lower when hydrogen content was higher.

Also, DHC crack growth rate was tested when the loading weight was increased. The result showed that DHC growth rate was faster when the loading weight was increased.

Table 2 shows the result of crack growth rate and stress intensity factor at the different hydrogen content specimens. From the result, it is possible to estimate K_I threshold range for each hydrogen content specimens.

Table 2. DHC crack growth rate and stress intensity factor of different hydrogen content specimens depending on loading weight

	Weight [N]	Crack growth [mm]	Crack growth rate [m/s]	K_I [$MPam^{1/2}$]
S1	89.2	0	0	6.12
	113.7	0.18	2.50E-09	8.83
	138.2	0.583	8.10E-09	
S2	79.4	0	0	5.58
	89.2	0.059	8.19E-10	6.27
	113.7	0.478	6.64E-09	
	138.2	0.611	8.49E-09	
S3	79.4	0	0	5.41
	89.2	0.088	1.22E-09	6.07
	113.7	0.611	8.49E-09	
	138.2	0.644	8.94E-09	
S4	69.6	0	0	5.06
	79.4	0.18	2.5E-09	5.17
	89.2	1.15	1.6E-08	
	113.7	1.05	1.46E-08	
	138.2	1.06	1.47E-08	

3. Conclusion

In this study, hydrogen content effects on DHC was estimated by using PLT specimen. According to experiment result, when the hydrogen content was higher, DHC occurring load was lower and when the loading weight was increased, DHC growth rate was faster. It means that high burn-up spent nuclear fuel is less safe from DHC than low burn-up spent nuclear fuel during spent nuclear fuel dry storage.

REFERENCES

[1] IAEA, "Delayed Hydride Cracking of Zirconium Alloy Fuel Cladding", IAEA-TECDOC-1649, 2010.