

Study of Hydride Re-orientation and Mechanical Property to evaluate Spent Fuel Integrity During Interim Dry Storage

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1. Introduction

The operating condition of modern PWRs is getting severer for the nuclear fuel cladding to meet the needs for an economical power generation. As the operating condition, oxide and the subsequent hydrogen caused by the waterside corrosion are generated in the cladding, which decreases the initial ductility of the cladding. Such an oxide and hydrogen act as a negative effect on the cladding safety under the Back-End Fuel Cycle.

In Korea, 23 nuclear power plants are in operation and lots of spent fuels are on the onsite storage. The onsite storage capacity in Korea is supposed to be full around at the year of 2016 and interim storage facilities could be considered to be constructed before 2016 [1].

Therefore, the dry storage concept is becoming a major technical consideration for intermediate spent fuel storage at present [2]. In relation to this, studies on the effects of interim dry storage conditions to spent fuel integrity have recently been initiated in Korea.

During the interim dry storage condition, the fuel cladding failure is affected by oxide thickness, hydride content and hydride re-orientation, among that the most important factor of the fuel cladding failure is the hydride reorientation, because the hydride reorientation behavior is shown by decrease cladding temperature in dry storage. However, the hydride reorientation mechanism was not clearly defined.

To achieve this, it should be secured that the base technology for integrity assessment in dry storage. In this study, the hydride re-orientation and its effect on the mechanical property of fuel cladding was studied.

2. Methods and Results

2.1 Material Preparation

The fuel cladding used in the study was supplied by the Kepco Nuclear Fuel Company. The fuel cladding was finally heat treated at 465 °C for 2.5h to have a stress-relieved microstructure, which is known to bear a good corrosion resistance. The outer diameter and the thickness of the fuel cladding was 9.5mm and 570 μm, respectively. The chemical composition of the Cladding was Zr-1.0Sn-0.1Fe-1.0Nb in weight percentage.

The fuel cladding was cut into the desired length and charged by the vacuum furnace at a level up to 600ppm to simulate the effect of hydrogen. In order to stabilize

hydrogen in the specimens as hydride form, vacuum annealing was carried out at 400 °C for 24h after chemically cleaning of the specimen surface with ethanol and acetone. After annealing the fuel cladding was cooled in air. The hydrogen content was measured using the inert gas fusion thermal conductivity detection method by LECO hydrogen analyzer RH404. As the absorbed hydrogen contents can be varied in spite of the same charging conditions, all of the specimens were analyzed for their hydrogen content.

2.2 Ring Tensile Test

Hydrogen-charged fuel cladding tubes were cut across their diameter then machined as a ring tension specimen which has a 2mm width and 2mm gauge length. Fig. 1 shows the schematic configuration of the ring tension test.

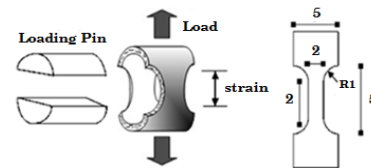


Fig. 1. Schematic configuration of ring tensile test specimen

The ring tensile tests were carried out between RT and 400 °C which lower than the in-service temperature of the cladding in a dry storage cask.

Table. 1 : Test matrix in this study

Specimen ID	Hcontent (ppm)	Test start point	Test start Temp.
D-RT	600	①	RT
D-T2		②	200
D-T3		③	300
D-T4		④	400
D-T4H2		⑤	400
P-T43FC		⑥	300
P-T32FC		⑦	200
P-T2H2		⑧	200

*D : Dissolution, P : Precipitate, FC : Furnace Cooling

The specimens of D-RT, D-T2, D-T3, D-T4 were heated to a peak temperature (RT, 200, 300, 400 °C) at a heating rate of 1 °C/min, after ring tensile testing. In P-

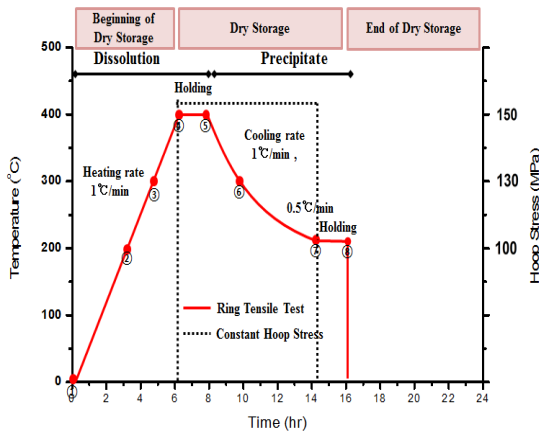


Fig 2. Thermal history which the Zr-Nb specimens were subjected during reorientation test

T43FC, the specimen was heated to 400°C and cooled to 300°C at a cooling rate of 1°C/min under loading and furnace-cooled to 300°C after ring tensile testing when the temperature was lowered to 300°C. The loading was applied up to 150-130MPa. With cooling, the applied stress was continuously decreased in the furnace (from 400 to 300°C in case of P-T43FC). Likewise, In P-T32FC, the specimen was heated to 300°C and cooled to 200°C in the furnace at a cooling rate of 0.5°C/min under loading and furnace-cooled to 200°C after ring tensile testing when the temperature was lowered to 200°C. The loading was applied up to 130-100MPa. With cooling, the applied stress was continuously decreased in the furnace (from 300 to 200°C in case of P-T32FC). In P-T32H2, the specimen was heated to 400°C, cooled to 300-200°C at a cooling under loading, maintained at 200°C for 2h under loading and Furnace-cooled to 200°C after ring tensile testing to examine the time dependent reorientation of hydrides. Strain rates of the ring tensile test were 0.001s⁻¹, in which the crosshead speed was divided into the initial gauge length. As such, the associated crosshead speed was 0.12 mm/min. All tensile tests were performed at three identical times then they were averaged. Strain could be calculated by dividing the crosshead displacement into the initial gauge length. Microstructures of the fractured specimen were observed using an optical microscope (OM) and a scanning electron microscope (SEM).

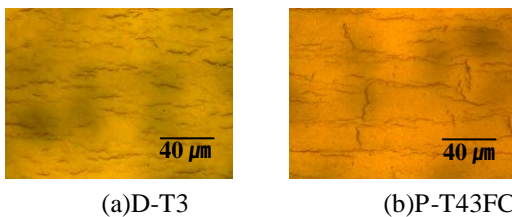


Fig 2. Hydride distribution on radial-circumferential plane of specimens before(a) and after reorientation (b), and show the reorientation of hydrides in P-T43FC

Fig. 2(a) exhibit the hydride distribution on the radial-circumferential plane of D-T3. Fig. 2(b) show the hydride reorientation in P-T43FC. (cooled from 400 to 300°C).

The stress-strain curve of hydride fuel cladding specimen at 300°C before and after reorientation treatment are shown in Fig. 3 The stress-strain curve of as-received (non-hydride) specimen is also shown for comparison. In D-T3 specimen can be slightly strengthened by circumferential hydrides. However, the ductility decreased slightly after formation of circumferential hydrides. The strength and ductility decreased with the formation of radial hydrides in D-T43FC. The strength decreased to 450MPa and the ductility decreased to 35%.

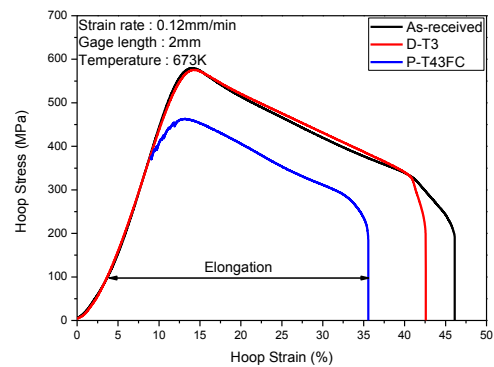


Fig. 3. The Stress-strain curves of hydride Zr-Nb specimens at 300°C before and after reorientation treatment. The stress-strain curves of as-received(non-hydrided) specimen is also shown for comparison.

3. Conclusions

In this study, hydride reorientation in fuel cladding was investigated and the following conclusions were obtained. The reorientation of hydrides was pronounced in P-T43FC specimen, which was cooled from 400 to 300°C under loading. In P-T43FC specimen, the strength decreased to 450MPa and ductility decreased to 35%.

Acknowledgment

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