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Effects of hoop stress on the hydride reorientation in spent nuclear fuel cladding

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1. Introduction

Hydride reorientation is one of the fuel rod degradation mechanisms during the long term dry storage condition. Re-oriented hydrides in the radial direction due to hoop stress critically reduce the ductility of fuel cladding. The reduced ductility can threaten the integrity of spent fuel in case of transportation accidents. Moreover, radial hydrides can increase the risk of occurrence of radial-hydride-assisted delayed hydride cracking(RHA-DHC) because radial hydride also reduces fracture toughness.

Threshold hoop stress for the reorientation has been reported to be 90MPa at 400℃[1] and this value is used as limiting criteria in USA[2]. However, there have been other findings that the reorientation can takes place in the hoop stress less than 90 MPa[3-4].

In this study, hydride reorientation experiment was performed to examine the effects of hoop stress. Finite element modeling (FEM) analysis was also carried out to support for experimental results analytically.

2. Experimental

2.1 Specimen preparation

Stress-relieved Zirclaoy-4 cladding with an outside diameter of 9.5 mm and wall thickness of 0.57 mm was used. The specimen was hydrogen-charged by gaseous hydrogen charging method at 400℃. The heat treatment was performed at 400℃ for 5h to ensure uniform distribution of hydride after hydriding. The hydrided specimen was slowly cooled down to room temperature and then cut into 6mm lengths. Hydrogen analysis was carried out using optical microscope and LECO hydrogen analyzer.

2.2 Hydride reorientation treatment

Tensile grip with central piece for ring test was manufactured (Fig. 2). The specimen was heated up to 400℃ in the creep test machine. Once the temperature stabilized, the constant load is applied. The specimen was furnace-cooled to 145℃ at cooling rate of about 1.7 ℃/min. Load is removed and the specimen was furnace-cooled to room temperature. After the test, optical microscope was used to examine the direction of hydrides. In this study, the hydride with ±40° in the radial direction and length longer than 15μm is defined as radial hydride.

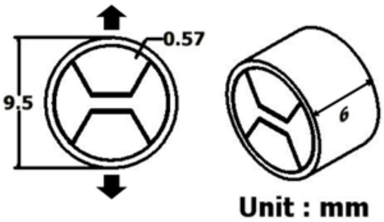

Fig. 2 Dimension of the ring specimen and grip

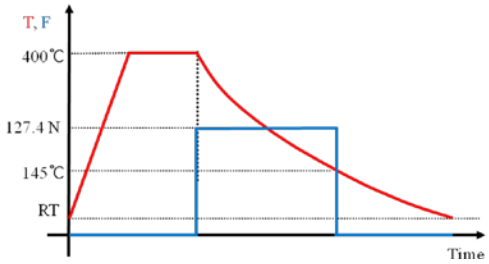

Fig. 3 Load and temperature applied in the specimen

2.3 FEM modeling

In order to support the experiment, FEM analysis was performed with Ansys ver.12. Considering symmetry of system, only 1/8 was modeled including specimen and grip.

Material property at 400℃ was used in the modeling assuming isotropic property.

3. Results and Discussion

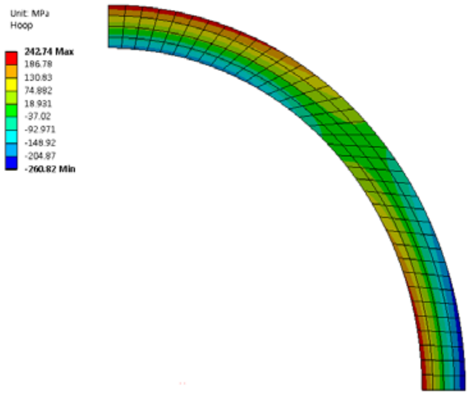

Fig. 4. Hoop stress distribution obtained by FEM analysis

As shown in Fig.4, compressive and tensile stresses are simultaneously created when constant load of 127.4N is applied in the specimen. Stresses built on the outer surface in the 12~1 o'clock direction and on the inner surface in the 2~3 o'clock direction.

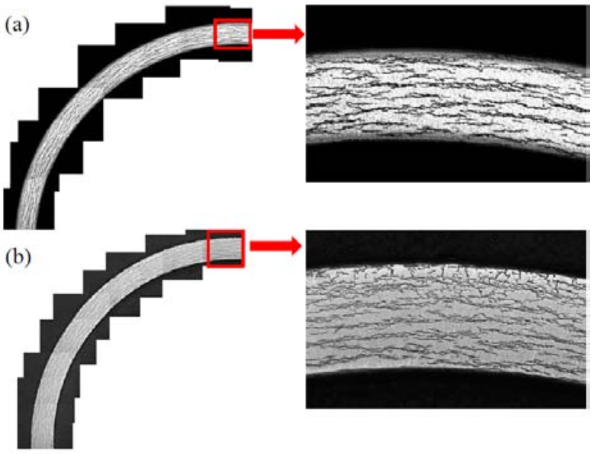

Fig. 5. Morphology of the hydrided specimen (a) before (b) after hydride reorientation treatment

Fig.5 shows the morphologies of the hydrided specimen before and after hydride reorientation treatment. They show that hydride reorientation took place in the region applied high tensile hoop stress.

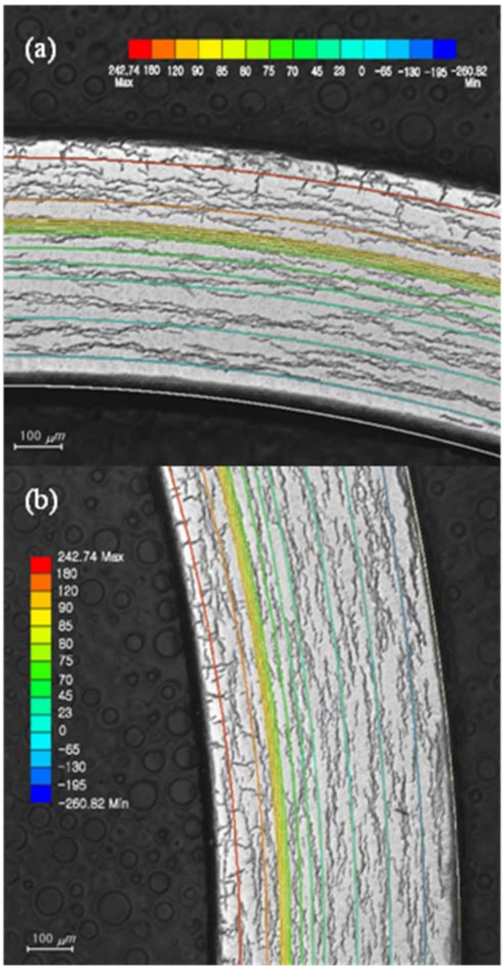

Fig. 5 Morphology of the specimen after the hydride reorientation process and stress distribution obtained by FEM (a) 12 o' clock position (b) 3 o' clock position

To evaluate threshold stress of hydride reorientation, the distribution of hoop stress obtained by FEM was shown by contour lines. And morphology of the specimen after the test was compared with results of FEM analysis(Fig.5). The analysis reveals that hydride reorientation mainly occurred in the region where applied stress is higher than 120 MPa. Some of reoriented radial hydride was observed in the region where the stress is lower than 120 MPa, not exceeding 90 MPa. Therefore it seems that 90 MPa is reasonable value as threshold hoop stress. In the following study, more experimental data will be generated and fundamental analysis will be carried out.

4. Conclusions

In this study, hydride reorientation treatment was performed using creep machine. Also, FEM modeling was performed to support the experimental results analytically. By comparing the morphology of specimen after the test and result of FEM modeling, effects of hoop stress on the hydride reorientation was evaluated. The results reveal that 90MPa is reasonable value as threshold hoop stress. In the following study, more experimental data will be generated and fundamental analysis will be carried out.

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