Hydride reorientation under load condition in Zirconium-2.5Niobium

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1. Introduction

In CANDU (CANada Deuterium Uranium) heavy water reactors, pressure tube is used to carry fuel bundles and primary coolant. Zr-2.5%Nb alloy is used for pressure tube material, since it has excellent corrosion resistance, mechanical properties, and low neutron absorption cross section. In early CANDU reactor, Zircaloy-2 pressure tube was employed. However, after rupture accidents of pressure tube due to delayed hydride cracking (DHC), the pressure tube material has been changed to Zr-2.5Nb alloy. By adding Nb to Zr and performing stress relief heat treatment in roll joint region, the damage due to DHC has been mitigated significantly.

However, pressure tube is oxidized by primary water and it absorbs hydrogen during reactor operation. DHC occurs when the hydrogen concentration exceeds the solubility limit of hydrogen. It is known that the hydride is brittle and easy to fracture at the notches or cracks where stress concentration is occurred.

For the CANDU structure integrity, understanding of hydride formation is very important. In this research, the effect of stress on hydride reorientation is investigated using CB (cantilever beam) specimen.

2. Experimental

2.1. Pressure Tube material (Zr-2.5Nb)

The pressure tube material used in the experiment is Zr-2.5Nb alloy. The chemical composition is shown in Table 1.

Table I: Chemical composition of Zr-2.5Nb (wt%)

Elements	*Zr*	*Nb*	*Fe*	*O*	*N*	*P*
Wt %	*97.4*	*2.5*	*0.05*	*0.097*	*0.007*	*0.003*

2.2. Cantilever Beam (CB) specimen preparation

The Cantilever beam (CB) specimen geometry is a width of 3.2mm, an overall length of 38mm and U-notch size is 0.5mm in depth and 0.05mm in with. The specimen geometry is shown in Fig. 1.

2.3. Formation of Hydride

The CB specimen was heat treated in KAERI hydrogen charging equipment at 400℃ for an hour in hydrogen 150torr and helium 200torr atmosphere. After formation of hydride at the surface of specimen, the specimen is sealed into Pyrex vacuum tubing, and the tubing was heat treated at 400℃ for 24 hours to homogenize the hydrogen. After homogenization hydrogen concentration was measured by LECO RH-404 hydrogen analyzer. It was confirmed as 297ppm.

2.4. Cantilever Beam (CB) Test

CB specimen was fixed on a specimen holder in CB tester. The CB tester is designed to apply a required stress intensity factor (K_I) to a CB specimen.

The specimen was heated up to 350℃ to dissolve hydrogen in Zr-2.5Nb matrix. Applied Max load was K_I: 25 MPa√m. The Load was increased from room temperature and fully applied around at 350℃. Load was sustained for an hours then cooled 250℃for two hours and cooled to room temperature.

2.5. Microstructure characterization

The specimen was etched by a mixture of HNO3:H2O: HF in the ratio 4:4:2. The sample was optimized by optical microscopy VHX-S550E of 200X to 500X. The image was merged for full scale of hydride orientation.

2.6. Stress condition analysis by FEM

Fine Element analysis was conducted to analyze applied stress by CB TEST. The data was compared with hydride orientation image. To understand the relationship of hydride reorientation with applied stress.

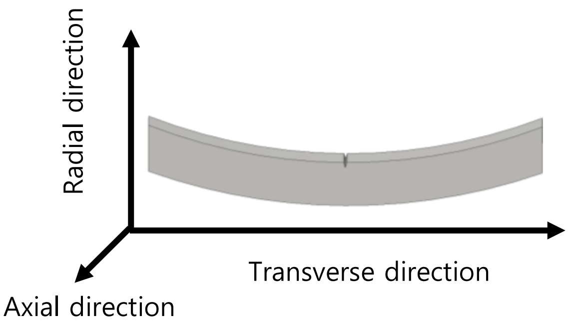

Fig. 1. Geometry of CB specimen machined from Zr-2.5%Nb pressure tube.

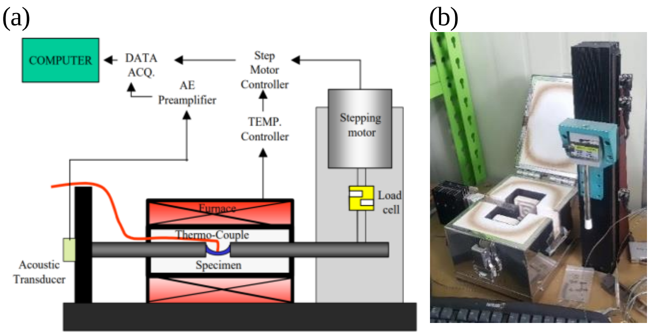

Fig. 2. Schematic illustration of CB tester, (a) integrated computer control system in order to control load and to acquire cracking through acoustic emission (AE) and loading, and (b) photograph of CB testing system.

3. Result and discussion

3.1. Orientation of hydride after reorientation Test

The reoriented hydride in CB specimen was observed by optical microscope. This is shown in Fig. 3. The hydride around the notch was reoriented to radial direction (Fig. 3. (b)). However, the hydride opposite side of the notch was remained to transverse direction (Fig. 3 (c)). The reorientation occurred in the tensile stress region along the transverse direction (upper half region), whereas not reoriented in the compressive stress region along the transverse direction (lower half region).

(a)

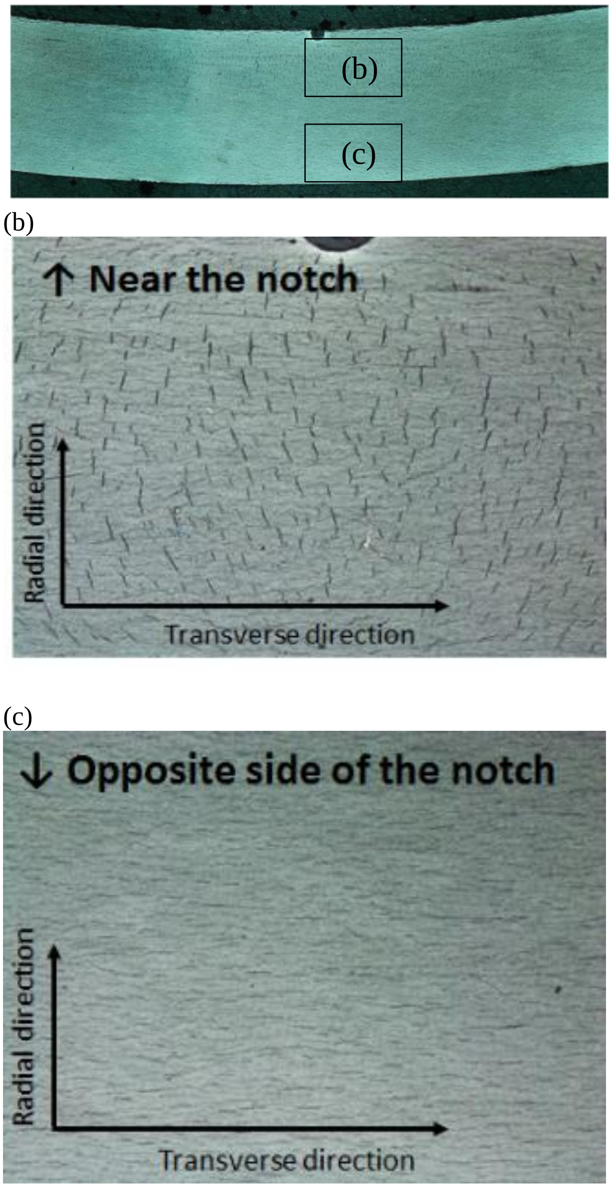

Fig.3. Hydride distribution after reorientation experiment at 350ºC under 25 MPa√m.

3.2. FEM Analysis of CB Test specimen

Applied stress is analyzed by FEM method, as shown in Fig. 4. Tensile stress was applied near the notch at upper half region. However, compression stress was applied opposite side of the notch at the lower half region.

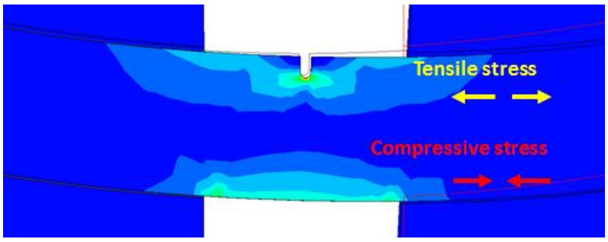

Fig. 4. The schematic illustration of applied stress in CB specimen during reorientation experiment.

4. Conclusions

This research shows the stress and hydride reorientation relationship. Tensile stress in the transverse direction is contribute to form a radial direction hydride, whereas compression stress in the transverse direction is contribute to form a transverse direction hydride.

Acknowledgments

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REFERENCES

[1] Jun Chi. et al. J.Pressure Vessel Technol. Aug 2009, 131(4): 041407 (12page)

[2] Young Suk Kim, etc. Journal of Alloys and Compounds, Volume 429, 21 February 2007, Pages 221-226