Evaluation of the Crack Initiation of Curved Compact Tension Specimens of a Zr-2.5Nb Pressure Tube using the Unloading Compliance and Direct Current Potential Drop Methods

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1. Introduction

Zr-2.5Nb pressure tubes, carrying fuel bundles and heavy water coolant inside, degrade due to neutron irradiation and hydrogen embrittlement during their operation in heavy water reactors. The safety criterion for the Zr-2.5Nb tubes to meet is a leak-before-break (LBB) requirement. To evaluate a safety margin related to the LBB criterion, facture toughness of the pressure tubes are to be determined periodically with their operational time. For a reliable evaluation of the LBB safety criterion of the pressure tubes, it is required to precisely determine their fracture toughness.

Since the fracture toughness or J of the pressure tubes is determined only by the extended crack length, it is important to reliably and precisely evaluate the advanced crack length. However, the problem lies with the detection of the crack opening point because prior plastic deformation before a start of the crack makes it difficult. The aim of this work is to evaluate which method can define the crack initiation point in the Zr-2.5Nb compact tension specimens more precisely between the unloading compliance method with a crack opening displacement (COD) gauge and the direct current potential drop (DCPD) methods.

2. Experimental Procedures

Curved compact tension (CCT) specimens of 17 mm long x 20.4 mm wide were cut out of a Zr-2.5Nb tube of 103mm inside diameter x 4.2 mm thick. Fracture toughness tests were conducted at room temperature on the CCT specimens in accordance with ASTM E1820-01 using a single-specimen method [1]. A pre-fatigue crack was introduced into all the CCT specimens with a 0.5^{o} tapered pin using an Instron 8501. The pre-fatigue crack was controlled to grow to the 0.5 a_o/W. The detailed procedures are reported elsewhere [2]. A COD gauge and electrical wires to supply currents and measure a potential drop were connected to the CCT specimens as shown in Fig. 1 so as to record the unloading compliances and the potential drop simultaneously with the load-line displacement. Unloading compliances were determined from the slopes of the load versus load-line displacement obtained at the 15% unloading rate while the dc potential drop was determined at the peak load points. The crack lengths were measured directly on the fractured surfaces using the 9-point method, from which the extended crack length or Δa, determined by the unloading compliance method and the DCPD method, were calibrated.

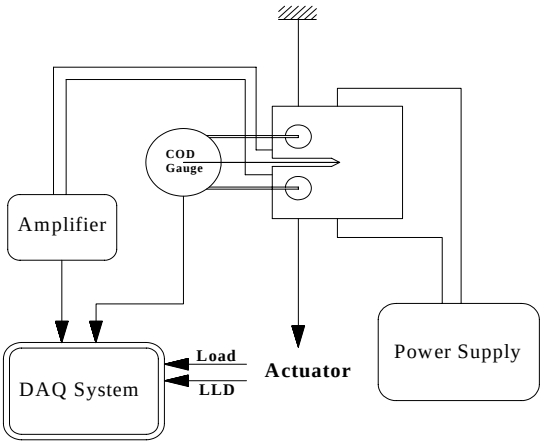

Fig. 1. Schematic diagram of test set-up.

3. Results

Fig. 2 shows the typical records for the load, potential drops and compliances for Zr-2.5Nb CCT specimens with the load-line displacement of up to 4 mm. A change of the potential drop corresponding to the crack opening point ccurred at the load-line displacement lower than 1 mm. In contrast, the minimum of the unloading compliances occurred at around the 1 mm or more load-line displacement. In other words, the unloading compliance method detects the onset of the crack initiation at around the 1 mm displacement while the DCPD method detected it at the displacement lower than 1 mm.

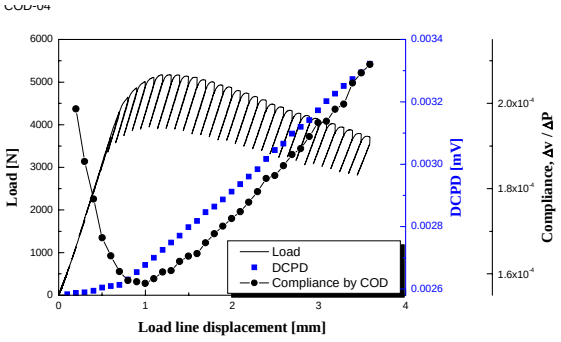

Fig. 2. Change of loads, direct current potential drops and compliances determined by the COD gauge with the load line displacements for the Zr-2.5Nb curved compact tension specimens at RT.

To confirm which method can precisely detect the crack opening point, the fracture surfaces were examined optically with the load-line displacement

closely changing from 0.8 to 1.2 mm. Fig. 3 shows the fractured surfaces of the Zr-2.5Nb CCT specimens loaded to the displacement of 0.8 mm and 1 mm, respectively. The crack was nucleated somewhere at the displacement between 0.8 and 1 mm. Based on this finding, a conclusion is drawn that the DCPD method is more accurate in detecting the onset of the crack opening.

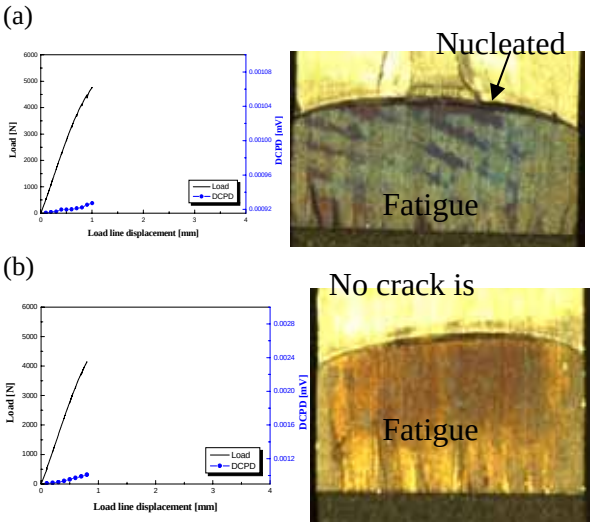

Fig. 3. (a) Direct observation of the crack grown on the fractured surfaces when Zr-2.5Nb compact tension specimen was loaded to the load line displacement of 1.0 mm. (b) No crack appeared on the Zr-2.5Nb CT specimens at the load line displacement of 0.8 mm.

4. Conclusion

The crack opening points for the Zr-2.5Nb CCT specimens were assessed using three different methods: DCPD method, unloading compliance method with a COD gauge and a direct observation on the fractured surfaces with an optical microscope. It was found that the DCPD method detected the crack opening point for the Zr-2.5Nb CCT specimens more precisely and sensitively than the unloading compliances. This was confirmed by the direct observation of the nucleated crack on the fractured surfaces.

REFERENCES

[1] American Society for Testing and Materials, ASTM E 1820-01, “Standard Test Method for Measurement of Fracture Toughness”.

[2] Y.S. Kim, Y.M. Cheong, S.C. Kwon, S.S. Kim and S.B. Ahn, KAERI technical report, KAERI/TR-1329/99, 1999.