Evaluation of Fracture Toughness of Zr-2.5Nb Pressure Tubes Using a Load Separation Method

Joong Cheul Park, Young Suk Kim, Hyeon Cheol Jeong, Kyung Soo Im, Yong Moo Cheong
Korea Atomic Energy Research Institut, 150, Dukjin-dong, Daejeon 305-353, Korea, yskim1@kaeri.re.kr

1. Introduction

Zr-2.5Nb pressure tubes are one of the most important components in CANDU nuclear power plants to govern their lifetime [1]. A critical safety criterion in association with pressure tubes is a leak-before-break requirement. To evaluate if this criterion is met, elastic-plastic fracture toughness tests are to be carried out periodically on the Zr-2.Nb pressure tubes operating in reactors.

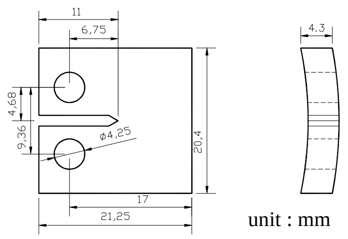
Fracture toughness, *J* of the Zr-2.5Nb tubes has been determined using a burst test method on long tubes in excess of 50 cm, which is rather complicated and difficult to conduct remotely in hot cells. Thus, we need to develop a test method other than the burs test method with a non-standard specimen, which can represent the J of Zr-2.5Nb tubes

The aim of this work is to develop a load separation method (LSM) that can determine the fracture toughness of the Zr-2.5Nb pressure tubes. Initial and final crack lengths were measured on the cross sections of compact tension specimens after testing and instantaneous crack lengths were also determined by a direct current potential drop method to demonstrate the accuracy of estimated crack lengths by the LSM.

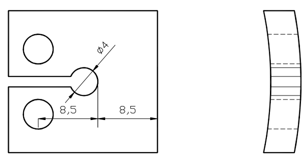
2. Methods

2.1 Materials and Specimen

The material used in this work was cold-worked Zr-2.5Nb pressure tube. A blunt and cracked specimens were curved compact tension(CCT) specimens having a crack to width ratio(a/W) of 0.5, equally. The detail dimension of the CCT specimen was shown in Fig. 1.



(a) Cracked specimen



(b) Blunt notched specimen

Figure 1. Dimension of curved compact tension specimen (W=17mm)

2.2 The Load Separation parameter

The S_{pb} parameter is defined as the load ratio of a pre-cracked and a blunt notched specimen at constant plastic displacement [2]. The subscript, "*p*", corresponds to a pre-cracked specimen that exhibits crack growth during the test and "*b*" corresponds to the blunt notched specimen with constant crack length during the test. Hence,

$$S_{pb} = \left.\frac{P_p(a_p, v_p)}{P_b(a_b, v_p)}\right|_{v_{pl}} = \left.\frac{G_p\left(\frac{a_p}{W}\right)\cdot H\left(\frac{v_{pl}}{W}\right)}{G_b\left(\frac{a_b}{W}\right)\cdot H\left(\frac{v_{pl}}{W}\right)}\right|_{v_{pl}} \qquad (1)$$

where, v_{pl} is the plastic load-line displacement, a_p is the crack length of the pre-cracked specimen, a_b is the crack length of the blunt notched specimen, *G(a/W)* function is geometric function and *H(v/W)* function is deformation function.

The S_{pb} parameter at the beginning of the load displacement record, when no crack propagation is occurring and hence the crack length of the pre-cracked specimen is equal to the initial crack length, is constant provided the separation property holds, then

$$S_{pb} = \left.\frac{P_p(a_p, v_p)}{P_b(a_b, v_p)}\right|_{v_{pl}} = \left.\frac{G_p\left(\frac{a_p}{W}\right)}{G_b\left(\frac{a_b}{W}\right)}\right|_{v_{pl}} = const. \qquad (2)$$

Assuming the validity of the load separability property in the crack length and plastic displacement range the specimen will undergo, the variation of the S_{pb} parameter constancy is related to the onset of crack extension. With independence of the crack tip conditions, it is possible to assume that the geometry function, *G(a/W)* is given by a power law. In this work the function G has been writing in term of the crack length.

$$G\left(\frac{a}{W}\right) = const.\left(\frac{a}{W}\right)^m \qquad (3)$$

Replacing Eq. (3) in Eq. (2) the S_{pb} parameter results.

$$S_{pb} = \left. \frac{P_p(a_p, \nu_p)}{P_b(a_b, \nu_p)} \right|_{\nu_{pl}} = \left. \frac{\left(\frac{a_p}{W}\right)^m}{\left(\frac{a_b}{W}\right)^m} \right|_{\nu_{pl}} = \left. \left(\frac{a_p}{a_b}\right)^m \right|_{\nu_{pl}} \quad (4)$$

Eq. (4) is a relationship between the crack length and load ratio, and rearranging it, it is possible to obtain an expression for the remaining ligament as,

$$a_p = a_b \left(S_{pb} \big|_{\nu_{pl}} \right)^m \quad (5)$$

As a results, the crack length can be estimated for each point of the load line displacement record if "*m*" parameter is known. In this paper, the method of calculating "*m*" parameter is omitted.

3. Results

Fig. 2 shows the S_{pb} parameter versus plastic load line displacement. The S_{pb} parameter was obtained using Eq. (2) taking as the reference for pre-cracked specimen by the load of the stationary test record at different values of plastic load line displacement.

The S_{pb} parameter vs. plastic load line displacement plot shows three distinct zones. There is an inseparable region at the early plastic behavior as notched in stationary crack, a region where the separation parameter maintains an almost constant value. Then the S_{pb} parameter starts to decrease, this is because the load for the pre-cracked specimen starts fall when the crack starts to grow, while the blunt notched specimen remains with a stationary crack length for a long period.

Fig. 3 shows the value of "*m*" parameter obtained using a regression line through the three calibration points. In this case, the "*m*" parameter is about 2.06

Fig. 4 shows the crack length obtained by the S_{pb} method and by DCPD method was plotted against the plastic load line displacement. And the initial and final crack lengths measured on the fracture surface were included. The agreement from initial to final crack length is apparent.

4. Conclusion

In this study, the S_{pb} parameter was introduced to estimate the crack length from a load line displacement record obtained from CCT specimen of Zr-2.5Nb pressure tube. The continues of crack length estimated for every point on the load line displacement record by S_{pb} method shows good agreement with the obtained by DCPD method and measured initial and final crack length.

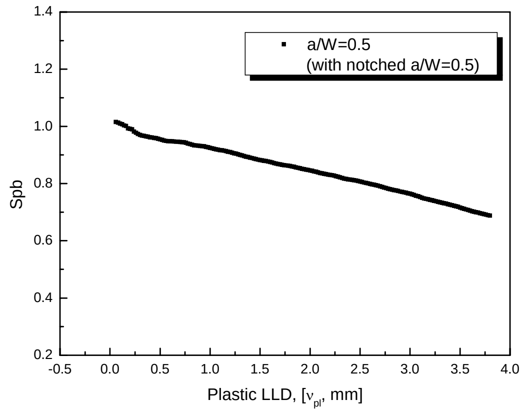


Figure 2. S_{pb} parameter *vs.* plastic load line displacement

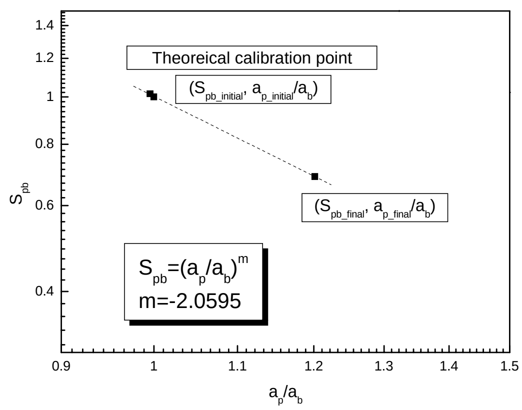


Figure 3. Plot of S_{pb} parameter *vs.* a_p/a_b

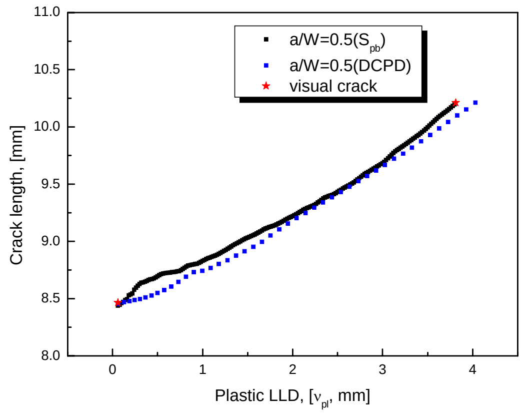


Figure 4. Crack length obtained from S_{pb} parameter, DCPD and measured visual crack

REFERENCES

[1] Y. S. Kim, Driving Force for Delayed Hydride Cracking of Zirconium Alloys, METAL AND MATERIALS International, Vol. 11, No. 1, p. 29-38, 2005.

[2] P. C. Paris, H. A. Ernst and C. E. Turner, A *J* Integral Approach to Development of η_{pl} Factors, ASTM STP 700, p. 338-351, 1980.