Development of DHCV Test Techniques for the irradiated CANDU Pressure Tube Materials in Hot Cell

Woong-sub Song [a], Sang-bok AHN [a], Young-suk KIM [b]
[a] *Irradiated Material Examination Facility,* [b] *Candu Pressure Tube Development Team*
KAERI, 150 Dukjin Dong, Yuseong Ku, Daejon City 305-353

1. Introduction

The delayed hydride cracking (DHC) phenomenon was first observed in zirconium-niobium material in experiments in 1972.[1] Since many pressure tubes are cracked by DHC during operation in Canada it has been intensively studied.[2,3] Some tubes in domestic CANDU reactors had been found with cracks from DHC during operation. Little attention for the irradiated pressure tube has been given to the DHCV behaviors because of not preparing for the test techniques and equipment in domestic. To perform the DHCV test for the operated pressure tube materials it is necessary that the test techniques are to be developed in hot cell facility. In hot cell usages the equipments are specially designed to be operated by the remote control and endure radiation atmosphere.[4] The electric discharge machine (EDM), dynamic, static universal testing machine, hydrogen charge system and direct current potential drop (DCPD) system are to be adopted to the test and test procedures and data analysis method to determine DHCV will be optimally developed through the study.

2. Techniques development

In this section the developed techniques of DHCV test for the irradiated pressure tubes are fully described. The main techniques are specimen cutting, hydrogen charge, fatigue pre-cracking, crack length measurement and determination of crack velocity.

2.1 Fabrication of the Irradiated Specimen

The EDM has been developed to fabricate the curved compact tension with 17mm wide (17mm-CCT) [5] directly from the irradiated CANDU pressure tube in hot cell. The machine is composed of mainly two parts, which are main body to discharge cutting specimen including filter unit and control part. The whole layout size of main body is 1,000(W) x 905(D) x 800(H) mm. The maximum size for working material is 300(X) x 200(Y) x 100(H) mm and special chucking device to be operated by manipulator is equipped to handle pressure tube. The operation conditions are decided to fabricate specimen through the optimum operation tests. They are 6 Amperes in current and 2 μs on-time in discharging intervals. Under these conditions the specimen are fabricated in the conditions of the 30 ~ 60 μm in surface roughness, ~ 100 μm in heat affected depth, and ~ 90℃ in heat up temperature.

2.2 Fatigue Pre-cracking

Fatigue pre-cracking procedure is performed using the dynamic universal testing machine. To obtain a sharp and uniform crack tip tapered pins to connect the specimen and the jig are adopted considering the curvature of specimen. The taper angle in pin is decided to be 1.5^{o} through the crack slant test. Fatigue pre-cracking is performed in the spirit of ASTM E399 A22 [1]. To initiate the fatigue crack evenly, the initial stress intensity factor range (□*K*) is about 12 $MPa{\cdot}m^{1/2}$ with 0.2 in the load ratio. Once the fatigue crack is initiated ΔK is decreased to 10 $MPa{\cdot}m^{1/2}$ at the final stage and the loading cycle is 3~5 Hz. The final fatigue crack length is to have about 0.5 in a/w ratio. To the end of pre-cracking stage the crack growth is continuously monitored by the DCPD signal.

2.3 Hydrogen Charge and Homogenization

Hydrogen is layered on the surface of specimen using a cathode hydrogen charging method. After the specimen fixed to the anode is submerged into 0.1 mol liquid of sulfuric acid, the direct current is supplied specimen to be layered hydrogen to the specimen surface.[6] To hold irradiation defects and the operating temperature effects in the material the hydrogen soaking temperature is 275°C which doesn't exceed the reactor operating temperature. At this temperature the hydrogen content to soak into specimen is about 50 ppm according to McMinn in the case of the irradiated Zr-2.5Nb materials. [7]

2.4 DHCV Test

The static universal testing machine, direct current potential drop device, temperature control furnace, and data acquisition system are set up in hot cell area to perform DHCV test. The input current lines at DCPD system are screwed to the each edge of specimen and the dropped voltage lines are spot welded to the area of crack mouth. After mounting the specimen to jig the thermal heat-up, homogenization and cool-down are started on the route of Fig.2 as shown. The load is applied and the dropped voltage measured after holding the test temperature during 2 hours followed cool-down. The applied load is determined in the compliance with ASTM E 399 by 10~12 $MPa{\cdot}m^{1/2}$ based on the specimen size and the virtually measured crack length. To measure crack increment the input current to the specimen is 6 Ampere and the dropped voltages are 2~3 mV various with the test temperature and crack length. During test the crack increment amount is forecasted the followed equation $\Delta a/W = (1.1 \sim 1.2) \bullet \Delta V / V_0$ that was determined from the calibration test. After advancing the expected crack length the test is finished. To measure the exact DHC crack length, the specimen is heat-tinted during 1 hour on 250℃ in temperature and fractured. The crack length is measured on the fractured surface with x20 magnification using the high-scope system.

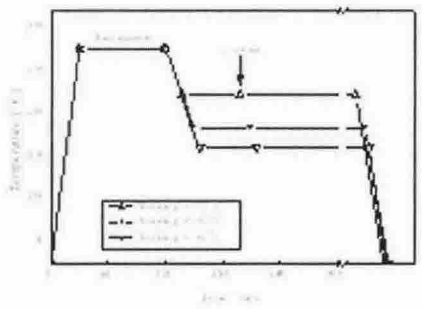

Fig. 1 Thermal routes and loading procedure in the DHCV test

2.4 Determination of DHCV

During the test we can achieve load, load line displacement, dropped voltage according to time. Fig. 2 shows typical test parameters resulted from the test. The DHCV from Fig. 2 and the measured crack length can be calculated using the equation, velocity(V)= (DHC increment crack length)/(total test time-incubation time). In DHCV test, the crack length is increased contrary to the applied load to be constant. It means that the velocity may be varied causing from the K-value increase at the crack tip, which depends on crack length. To get the exact velocity it is noteworthy to survey the velocity variations according to stress intensity factor variation during test. Fig. 3 shows the variation example of DHCV and K-value during 30~60 minutes in the limited time. In figure the DHCV should be decided to the average value in the constant velocity section (stage-II range) extracting from rapid increase sections (stage-I, III range).

3. Conclusion

The DHCV test techniques for the irradiated CANDU pressure tube materials are successfully developed in hot cell. The specially designed equipments for hot cell usages are developed and installed in hot cell to be adopted to the DHCV test. The techniques to fabrication specimen, hydrogen charge, fatigue pre-crack, thermal heating and cooling route and crack advance monitoring are optimized for the test through the study. Furthermore the methodology to decide the exact velocity from the acquired raw data from the test is suggested. The developed techniques will be contributed to the DHC behavior evaluation of the operated pressure tube in domestic CANDU reactors.

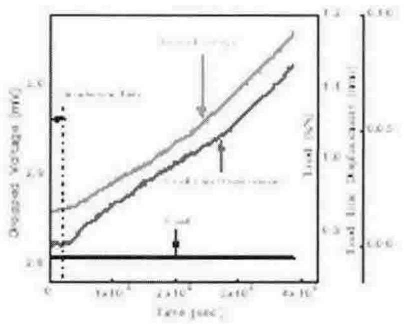

Fig. 2 Typical load, load line displacement and dropped voltage behavior during DHCV test

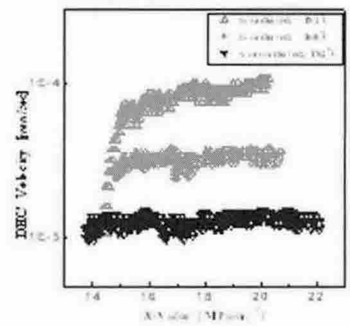

Fig. 3 The variation example of DHCV and K-value during test

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