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Test Technique Development on the Irradiated Reconstituted PCVN Specimen in Hot Cell

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1. Introduction

The degradation of fracture toughness is the important factor to restrict the life of nuclear pressure vessel in PWR reactors. A pressure vessel is operated in conformity with the fracture analysis based on ASME codes to ensure safety margins from the unstable fracture. A fracture analysis is performed based on the result from the Charpy impact tests in PWR reactor, but it has the questions to be exact solutions because the test results give indirect and excessively conservative values. Therefore the research to find an exact toughness parameter is undergoing to use the pre-cracked Charpy v-notch (PCVN). As results the master curve method is proposed in ASTM E1921 to be supposed an appropriate tool to evaluate the fracture toughness for the irradiated, or the operated pressure vessel materials.

The surveillance test program to evaluate toughness degradation on existing commercial PWR reactor is performed through the impact test on Charpy specimens. It gives the lack of the specimen to evaluate the safety in toughness for on-going operation beyond design life. To overcome the shortage of specimen, the test method to use a reconstituted PCVN specimen fabricated from the broken half of Charpy specimen is proposed and adopted in foreign reactors. In this paper techniques developed for the reconstituted specimen from the domestic commercial PWR reactor in hot cell are described.

2. Specimen Fabrication in Hot Cell

In this section the fabrication techniques on the reconstituted PCVN specimen in hot cell are described. The procedures are in turns of cutting and face cleaning of broke half specimen, welding end studs, removing the excessive welding bids, notch machining.

2.1 Machining the Broken Half Specimen

Dimensions of broken half specimen are about 10mm in width, 10mm in thickness, and 27.5mm in length. Furthermore the broken side is deformed to irregular shape during breakage from impact force as shown in Fig. 1 from the domestic commercial reactor. The broken half should be machined to the dimensions of 10 mm x10 mm x 14 mm in width, depth, length to use the insert in PCVN specimen. The insert is fabricated using the CNC milling machine shown in a hot cell as Fig. 2. Both pre-stressed regions from an impact test are cut out, and the whole surface is finally grinded to be 10 ㎛ in roughness and cleaned.

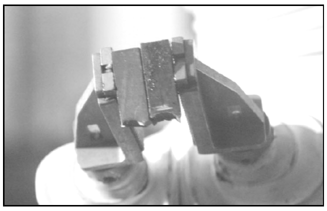

Fig. 1 Broken Charpy specimen

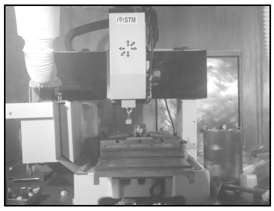

Fig. 2 CNC milling machine in hot cell.

2.2 Specimen Welding and Verifications

The both ends in the insert are electronically arc-welded between the studs. A specially designed welding machine to use in hot cell is invented. The atmosphere near the welding area is controlled by argon gas to protect oxidation. The welding conditions decided from the trial error method are 1,200 A in supplying current, 0.06 seconds in time, 6 bar in loading pressure to studs. The area temperature apart 1 mm from the welding spot rises over 300 ℃, and the notch area apart 7 mm is about 129 ℃ in temperature as shown in Fig. 3. It means that the effect of welding heat can be ignored to compare the metallurgical transformation temperature of the insert. The micro-hardness test is performed to inspect the recovering effects of the neutron irradiation damage from welding heats. The change of mechanical properties in the notch area can be assumed not to happen from the result of hardness distributions as shown in Fig. 4.

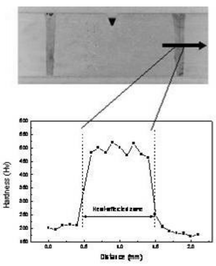

Fig. 3 Hardness distribution in welding area.

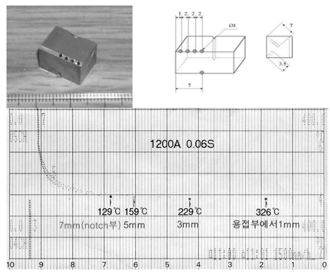

Fig. 4 Tempeature distribution in welding area..

2.3 Notch Cutting Procedures

After welding between the insert and studs, a notch is cut in the longitudinal center of specimen and machined to fit the dimensions. The cutter having the shape of notch in the code of ASTM E1921 is prepared in the CNC milling machine. Finally the welded specimen is machined the outer dimensions of 10 mm x 10mm x 55 mm.

3. Test Procedure Developments

In this section the developed equipments and procedures to measure fracture toughness in hot cell are described.

3.1 Hot Cell Equipment

The fracture test is performed in IMEF at KAERI. A universal testing machine (UTM) is used to test, which is modeled in Instron-8502 as shown in Fig. 5. To control test temperature the heating/cooling chamber is used to heat up to 300 ℃ and cool down to -150 ℃. The temperature on the specimen is directly measured with the thermocouple attached to the specimen to avoid the difference between the temperature displayed on the controller and in the specimen. A displacement during test is measured using a LVDT in the UTM, it was corrected by the results of pre-comparing test to the certified other LVDT system. A test jig is designed to be easily adopted to hot cell usages as shown in Fig. 6. The center of specimen in a longitudinal direction is aligned to the load line by the moving position device in jig. The high-scope system having the maximum magnification of 100X, and the conventional commercial camera system are equipped in hot cell to measure crack length and investigate fracture surface after test.

Fig. 5 Universal testing machine in hot cell.

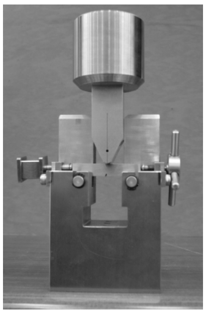

Fig. 6 Jig for PCVN specimen.

3.2 Fatigue Pre-cracking and Fracture Test

After the fabrication of specimen reconstruction a pre-cracking is performed. A pre-cracking is started with *25* MPa•m$^{1/2}$ in the magnitude of an initial stress intensity factor (*Ki*) and finished *19* MPa•m$^{1/2}$ in a final stress intensity factor (*Kf*) until a crack grows to 1 mm in length. A total cycles during pre-cracking is averagely up to 100,000 under 30 Hz in frequency. Before start to load the specimen, a specimen is cooled down to the designated temperature and hold up the temperature during minimum 1 hr in the chamber. The fracture test speed is 0.15 mm/min in displacement, the data of load and displacement are recorded during loading as shown in Fig. 7.

After fracture test a specimen is broken into two pieces after holding 30 min. under – 100 ℃ in the chamber. The lengths of pre-cracking and ductile fracture region are measured using high scope system. A fig. 8 is shown in the shape of fractured surface.

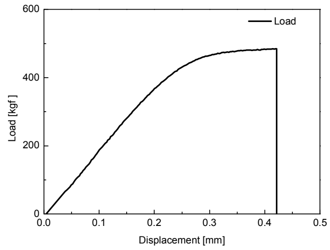

Fig. 7 Example of load-displacement curve from test.

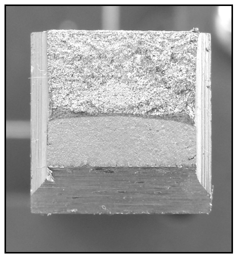

Fig. 8 Shape of fractured surface.

3.3 Determination of Toughness Value

From the load-displacement curve the J-integral at onset of cleavage fracture is calculated in the sum of elastic and plastic components according to ASTM E1921-03 as $J_c = J_e + J_p$. The elastic component of *J* is calculated as $J_e = (1-\nu^2) \bullet K_e/E$ and the plastic component of J is calculated $J_p = (\eta \bullet A_p) / (B_n \bullet b_0)$. Finally K_{Jc} is determined for each datum from *J* at onset of cleavage fracture as $K_{Jc} = (Jc \bullet E/(1-\nu^2))^{1/2}$. Fig. 9 shows the example of K_{Jc} according to temperature resulted from the developed techniques in this paper.

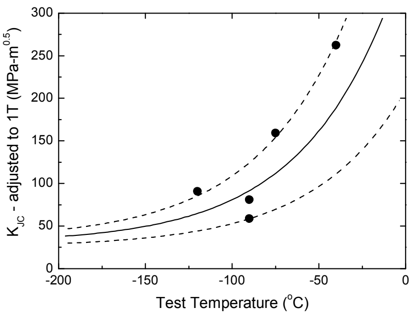

Fig. 9 Example of facture toughness according to temperature

4. Conclusion

Test techniques in hot cell on the reconstituted PCVN specimen are developed after using impact test from PWR surveillance test program. The developed equipments and procedures are developed to weld, cut notch, pre-crack, fracture, measure crack length, and the most suitable conditions to operate equipments are decided. Developed techniques are successfully applied to evaluate fracture toughness in transition region for judging the on-going operation safety evaluation after design life in domestic PWR reactor. These techniques will be useful to measure fracture toughness for the irradiated reactor materials in future.

REFERENCES

[1] ASTM E 1921-03, Standard Test Method for Determination of Reference Temperature, T_0, for Ferritic Steels in the Transition Range, 2003.

[2] Wallin, K,, Master Curve Analysis of Ductile to Brittle Transition Region Fracture Toughness Round Robin Data (The Euro Fracture Toughness Curve), 1998.