Mechanical Post Irradiation Examinations for SMART SG Tube Materials in a Hot Cell

Sangbok Ahn*, Seungjai Baik, Dosik Kim, Byungok Yoo, Yanghong Jung, Woongsub Song, Gilsoo Kim, Keenam Choo, Jinseok Park, Wonjae Lee and Woo-seog Ryu

Korea Atomic Energy Research Institute, 1045 Daeduk-daero Yuseong-gu, Daejon, The Republic of Korea
** Corresponding author: sbahn@kaeri.re.kr*

1. Introduction

An advanced integral PWR, SMART (System-Integrated Modular Advanced ReacTor) is being developed in KAERI. It has compact size and a relatively small power rating compared to a conventional reactor. The main components such as the steam generators and main circulation pumps are located in the reactor vessel. In there the neutron irradiations generated from fuel fissions degrade them during operations. The steam generator (SG) tube which is 17 mm in a diameter and 2.5 mm in thickness, is made of Alloy 690 steel. To ensure operation safety, post irradiation examinations (PIE's) is necessary to evaluate the deterioration levels compared to original properties. The change of mechanical properties should be reflected and revised for the design input data.

In this paper the detailed PIE results of SG tube materials are reviewed. Three kinds of test specimen with different shapes are prepared and irradiated in capsules at HANARO. Finally the tests for them are performed in the Irradiated Materials Examination Facility (IMEF) at KAERI.

2. Specimen preparations

The specimens are prepared for tensile, fracture toughness and hardness tests. The specimen dimensions based on the ASTM standards were slightly modified to be fitted to the inner space of a HANARO capsule. The main specifications of specimens are shown in Table 1.

Table 1 Detailed specimen specifications to be irradiated

Tests	Dimensions [mm]	Remarks
Tensile	108 x 25 x 2.5(t)	Plate type
Fracture toughness	24 x 25 x 10 (t)	1/2T CT type
Hardness	10 x 10 x 2 (t)	Plate type

3. Neutron irradiations in HANARO

The fast neutron fluence to irradiate the specimens are required to be $1x10^{19}$ n/cm^2, $1x10^{20}$ n/cm^2, and $1x10^{21}$ n/cm^2 (E>1.0 MeV), considering the lifetime neutron fluence of the SMART steam generator. To obtain these neutron fluences, 2 different capsules are irradiated in the OR5 and CT test holes of HANARO. Irradiation tests has been performed according to the SMART R&D schedule which was decided to be developed by 2010.[1]

4. Mechanical PIE's in IMEF

The irradiated capsule in HANARO shipped into the cask is transported to IMEF. The cask is unloaded in a pool at IMEF and finally the capsule is moved into a hot cell. In hot cells the capsule is dismantled and the specimens were classified into test types. All mechanical PIE's are executed in the hot cells where the test machines are operating. [2~3]

4.1 Capsule unloading and dismantling

After the cask is transported to the entrance of IMEF on the vehicle, the hoist lifts it up and loads it into the transfer cart to the nearest area of the unloading pool. In a pool the cask is opened to pull out the capsule. The capsule is lifted up to a M1 hot cell by the bucket elevator from a pool to a hot cell.

In a M2 hot cell the capsule is dismantled to take the specimens from its inside. The capsule cutting machine is used to do it. It has 1,100 (W) x 1,000 (D) x 400 (H) mm in the external dimensions. The abrasive wheel is cut to the radial direction with the speed of 150 rpm across the capsule and 0.5 ~ 3 mm/min in a cutting speed. The specimens installed in the inner center area are pulled out by the manipulators. Figure 1 shows a capsule and the arranged specimen after dismantling.

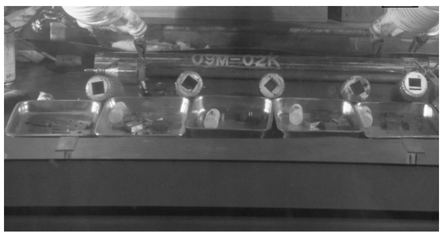

Fig. 1 The cutting machine in a hot cell

4.2 Tensile test

The tensile tests [4] are performed using the static universal testing machine (UTM) in a hot cell. It has 5 ton in a loading capacity and 75 mm in a displacement stroke. The specially designed furnace controls the temperature of a specimen.

Fig. 2 shows the load and displacement curve from the test, and the fractured specimen pieces. In figure the specimen reflects to be steadily elongated and fractured. Figure 3 shows all load displacement curves in the irradiated specimens and the variations of yield strength with temperature. Figure shows the yield strength in the irradiated is decreased about 25~40% than in the unirradiated

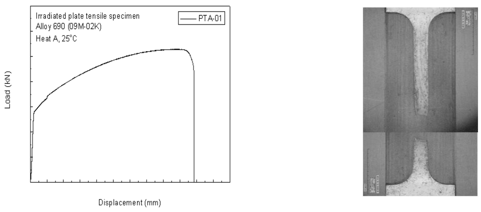

Figure 2 The load and displacement curve and the fractured specimen pieces after test.

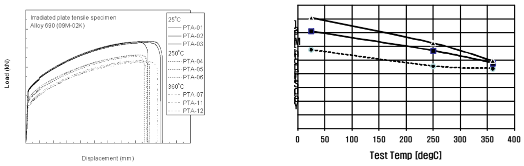

Figure 3 The load and displacement curves and the variations of yield strength

4.3 Fracture test

The fracture tests are performed using dynamic UTM in a hot cell. It has 2.5 tons in loading capacity and 100 mm in a displacement stroke. The chamber controls the temperature of a specimen. Because the specimen dimensions are non standard compared to an ASTM standard the jig was specially designed to attach the specimen to the load. The load to the specimen is forced the uniform displacement speed. During the test the amount of a load and displacement are stored to the control computer simultaneously. Figure 3 shows the load and displacement curve and the fractured surface of the specimen after testing. From figure the crack is suggested to be steadily propagated during loading. The fracture toughness from the load and displacement curve, is decided by the load ratio normalization method which is widely used for a hot cell test.[5] Figure 4 shows the J-R curve and the variations of JQ values in the unirradiated and the irradiated ones with the temperature. The JQ values in the irradiated are lower than the unirradiated ones, and abruptly decreased in the high temperature regions.

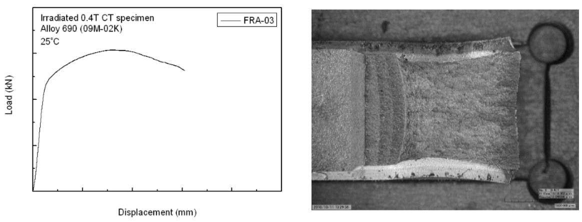

Figure 4 The load and displacement curve and the fractured surface after test.

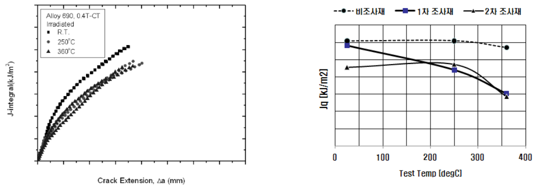

Figure 5 J-R curves and the variation of JQ values with temperature

4.4 Hardness test

The hardness test is performed using the micr hardness tester attached to the microscope, TELATOM-III LEICA. The model of the tester is MICRO DUROMAT 7 which has the load range 0.05 ~ 200 gram and 500 micron in a diagonal size, and a VICKERS type indenter. Before testing, the specimen is prepared to the surface grounding and molded in the resin device. Figure 6 shows the Vickers marks on the specimen and the compared hardness values between the unirradiated and the irradiated ones. The hardness values of the irradiated ones are increased about 30~40% than the unirradiated.

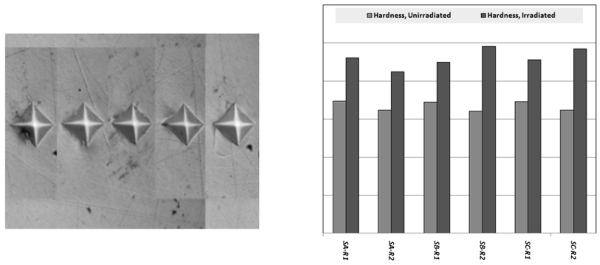

Figure 6 The VICKERS indentation marks, and the hardness variations between the unirradiated and the irradiated.

5. Conclusion

The mechanical PIE's for SMART SG tube materials after neutron irradiations in HANARO is performed. The collected data through the examinations are reviewed to apply to the design of SMART. The neutron irradiation changes the mechanical properties of tube materials into to be brittle and hard. The PIE data from this study will be useful information to design and evaluate the operation safety on SMART steam generator.

REFERENCES

[1] K. N. Choo, M. S. Cho, J. S. Park, W. J. Lee and Y. K. Kim Transaction of KNS Autumn Meeting, 2009.

[2] Brochure Introduction of Irradiated Material Examination Facility, Korea Atomic Research Institute.

[3] S. B. Ahn et al Transaction of KNS Spring Meeting, 2010.

[4] ASTM E8M "Standard Test Method of Tension Testing of Metallic Materials"

[5] Xiaoguang Chen et al. Special Application and Advanced techniques for Crack Size Determination ASTM STP 1251, 1995, pp 83-103