The First Irradiation (09M-02K Capsule) of Alloy 690 Steam Generator Tube Material of the SMART in HANARO

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1. Introduction

The System-integrated Modular Advanced ReacTor (SMART) is one of the advanced SMRs [1]. The Korean government decided recently to develop the system as one of its new growth engines. At present, preparations are underway to obtain the standard design approval on SMART from the Korean licensing authority by 2011.

In order to fundamentally eliminate the possibility of a large break loss of coolant accidents, major components of the reactor coolant system such as the pressurizer, the reactor coolant pump, and steam generators are located inside the reactor vessel in the SMART system [2].

Alloy 690 was selected as the candidate material for the heat exchanger tube of the steam generator of SMART [2]. The SMART R&D is now facing the stage of so-called ‘engineering verification and approval of standard design’ toward application to DEMO reactors. Therefore, the material performance under the relevant environment is required to be evaluated. One of the important material performance issues is fracture toughness for which the engineering database is necessary to design a steam generator. Because the SMART steam generators are located inside the reactor vessel, the degradation of the fracture toughness of the Alloy 690 heat exchanger tube should be clearly determined for a design lifetime neutron fluence. However, the neutron irradiation characteristics of the alloy are barely known.

Therefore, an irradiation plan of the Alloy 690 materials to obtain the neutron irradiation characteristics of the alloy using HANARO irradiation capsules was planned [3]. Based on the test plan, the first irradiation capsule of 09M-02K was successfully designed and irradiated in the OR5 test hole of HANARO at a 30MW thermal power of 250±10℃ up to a fast neutron fluence of 4.6×10^{19} n/cm^2 (E>1.0MeV).

2. Material and Specimens

Three different heat Alloy 690 were prepared and various specimens such as standard and sub-size plate tensile specimens, 0.4T compact tension specimens, hardness, and microstructure specimens (Optical and TEM) were prepared, as shown in Table 1 and Figure 1. Specimens were inserted into an Al thermal media as a square bar shape with spacers of a same material to simplify the handling and thermal calculation of the capsule as shown in Figure 1.

Table 1. Specimens in the 09M-02K irradiation capsule

Specimen	Size(mm)	Number (Heat)
0.4T Compact Tension	24x25x10	16(A) 2(B) 2(C)
Plate tensile	108x25x2.5	14(A)
Small plate tensile	26x5x0.5	20(A) 10(B) 10(C)
Hardness	10x10x2	10(A) 9(B) 9(C)
TEM	ø3x0.1	10(A) 10(B) 10(C)
3 Heats : Special Metals(A), EPRI(B), UlJin#5(C): Total 132		

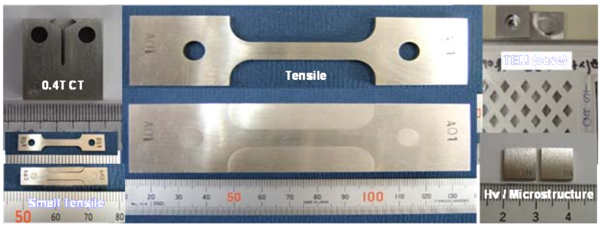

Figure 1. The specimens stacked with spacers in the irradiation capsule of 09M-02K

3. Irradiation Capsule (09M-02K)

The first irradiation capsule of 09M-02K was designed, fabricated and irradiated for an evaluation of the neutron irradiation properties of Alloy 690 as shown in Figure 2. The capsule was designed to be irradiated at 250℃ in the OR5 test hole according to a user’s requirement [4]. In-reactor safety of the capsule was discussed and it was proven to be safe for the irradiation tests of Alloy 690 in the OR5 test hole of HANARO [5]. The irradiation temperature of the specimens is determined by the gamma heating, the He gas pressure, and widths of gaps between the capsule parts. The irradiation temperature of the specimens was preliminarily analyzed by using the GENGTC and ANSYS codes.

The capsule was composed of 5 stages having many kinds of specimens and an independent electric heater at each stage. 14 thermocouples and 5 sets of Ni-Ti-Fe neutron fluence monitors were installed in the capsule to measure the irradiation test temperature and the fast neutron fluence of the specimens, respectively. A friction welded tube between STS304 and Al1050 alloys was also introduced in the capsule to prevent a coolant leakage into a capsule during a capsule cutting process in HANARO.

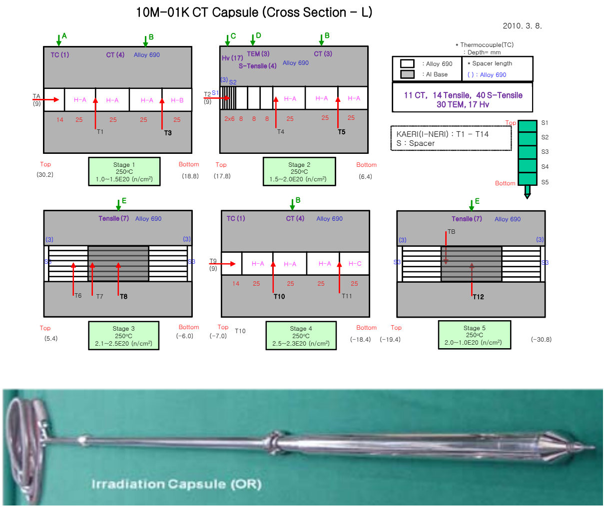

Figure 2. Irradiation capsule of OR5 test hole

4. Irradiation Test in HANARO

The capsule was safely irradiated in the OR5 test hole of the HANARO of a 30MW reactor output power for one cycle (about 28days) as shown in Figure 3. The temperature of the specimens during an irradiation was initially increased by the gamma heating and then roughly adjusted to an optimum condition by the He gas control system. It was then finally adjusted to a desired value by micro-electric heaters. During an irradiation test, the temperatures of the specimens were measured and monitored with thermocouples installed in the capsule. The irradiation temperature of the specimens was maintained in a range of 250±10℃ except for a part of specimens for short period during the irradiation (The specimens in the stage 4 of the capsule reached up to 270 ℃).

A fast neutron fluence of the specimens was obtained in the range of 1.23~4.58×10^{19}(n/cm^2) (E>1.0MeV). The amount of neutron fluence of the specimens was calculated by the MCNP code and will be compared to the obtained value from the irradiated fluence monitors.

The irradiated capsule is being maintained in the reactor water pool for radioactivity cooling. After the cooling, the main body of the capsule will be cut off at the bottom of the protection tube with a cutting system and it was transported to the IMEF (Irradiated Materials Examination Facility). The irradiated specimens will be tested to evaluate the irradiation performance of the Alloy 690 in the IMEF hot cell.

The fast neutron fluence of Alloy 690 was required to be 1×10^{19} n/cm^2, 1×10^{20} n/cm^2, and 1×10^{21} n/cm^2 (E>1.0 MeV) [4], considering the lifetime neutron fluence (1.56×10^{19} n/cm^2) of the SMART steam generator. To obtain these neutron fluences, two different irradiation capsules will be irradiated in the CT test hole of HANARO. Irradiation tests will be performed according to the SMART R&D schedule which was decided by the Korean government to be developed by 2011.

Figure 3. Reactor core during the irradiation test of 09M-02K

3. Conclusion

To obtain the neutron irradiation characteristics of the heat exchanger tube of the SMART steam generator, the first irradiation capsule of 09M-02K was successfully designed and irradiated in the OR5 test holes of HANARO. Various types of specimens such as 0.4T compact tension, tensile, microstructure and hardness made of Alloy 690 were irradiated at 250±10℃ up to a fast neutron fluence of 4.58×10^{19}(n/cm^2) (E>1.0MeV). After the first irradiation, two different irradiation capsules are being scheduled to be irradiated in the CT hole of HANARO for higher neutron fluence.

ACKNOWLEDGEMENTS

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