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The Second Irradiation (10M-01K 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 most advanced SMRs [1]. There has also been a growing interest in small- and medium-sized reactors in developed countries that have deregulated their electricity market, calling for flexibility in power generation. 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.

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 most 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 the HANARO irradiation capsules was planned [2]. The fast neutron fluence of Alloy 690 was required to be $1x10^{19}$ n/cm^2, $1x10^{20}$ n/cm^2, and $1x10^{21}$ n/cm^2 (E>1.0 MeV) [3], considering the lifetime neutron fluence ($1.56x10^{19}$ n/cm^2) of the SMART steam generator. To obtain these neutron fluences, three different irradiation capsules were scheduled to be irradiated in the OR5 and CT test hole of the HANARO. Irradiation tests have to be performed by 2011 according to the SMART R&D schedule which was decided by the South Korean government.

The first irradiation capsule of 09M-02K was successfully designed and irradiated in the OR5 test hole of the 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) [4]. Based on the successful irradiation of the first capsule, the second irradiation capsule of 10M-01K was prepared to obtain the neutron irradiation characteristics of the heat exchanger tube of the SMART steam generator at a higher neutron fluence.

2. Material and Specimens

In addition to the Alloy 690 specimens of the first capsule such as the standard and sub-size plate tensile specimens, 0.4T compact tension (CT) specimens, hardness, and microstructure specimens (Optical and TEM), thermal diffusivity (TD) specimens were prepared, as shown in Table 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 SMART irradiation capsules

Specimen	Size(mm)	Specimen (Heat)	
		1st Capsule (09M-02K)	2nd Capsule (10M-01K)
0.4T CT	24x25x10	16	9
Plate tensile	108x25x2.5	14	14
Small plate tensile	26x5x0.5	20	20
Hardness	10x10x2	10	5
TEM	ø3x0.1	10	10
TD	ø9x1.0	-	16
Total		70	74
Material Heats : Special Metals			

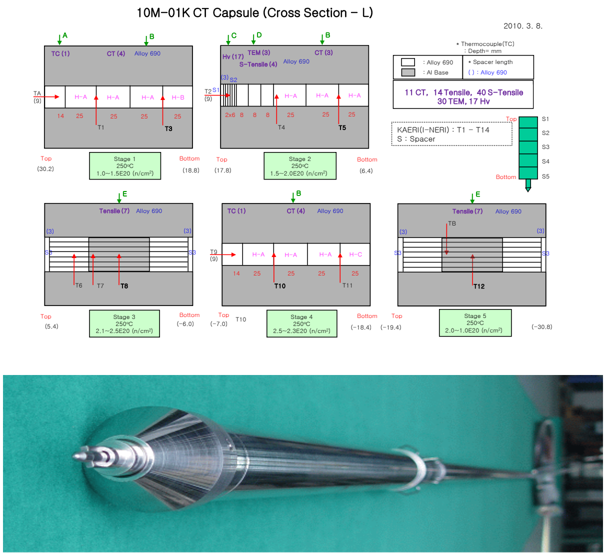

Figure 1. Irradiation capsule of CT test hole

3. Irradiation Capsule (10M-01K)

The second irradiation capsule of 10M-01K was designed, fabricated and irradiated for an evaluation of the neutron irradiation properties of Alloy 690 at a higher neutron fluence as shown in Figure 1. The capsule was designed to be irradiated at the same temperature of 250℃ to the first capsule, in the CT test hole according to a user's requirements [3]. Because of the higher gamma heating in the CT hole than in the OR hole, the number of CT specimens in the second capsule was strictly limited as shown in Table 1 and Figure 1. In-reactor safety of the capsule was discussed and it was proven to be safe for the irradiation tests of Alloy 690 in the CT test hole of HANARO [5]. The irradiation temperature of the specimen 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 basic design of the second capsule is almost the same as that of the first capsule except for the specimens' part. 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 the capsule cutting process in HANARO.

4. Irradiation Test in HANARO

The capsule was safely irradiated in the CT test hole of the HANARO of a 30MW reactor output power for one cycle (about 25.49days) as shown in Figure 2. 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 the TD specimens which reached up to about 310 ℃. The higher irradiation temperature of the TD specimens was attributed to a complicated layer structure of the specimen case.

A fast neutron fluence of the specimens was obtained in the range of $1.10 \sim 3.17 \times 10^{20}$(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 was being maintained in the reactor water pool for radioactivity cooling. After the cooling, the main body of the capsule was 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 obtained test results will be one part of the crucial data to acquire the standard design approval on SMART from the Korean licensing authority by 2011. Based on the obtained results from the first and second irradiation capsules, the design criteria for the final third capsule will be determined.

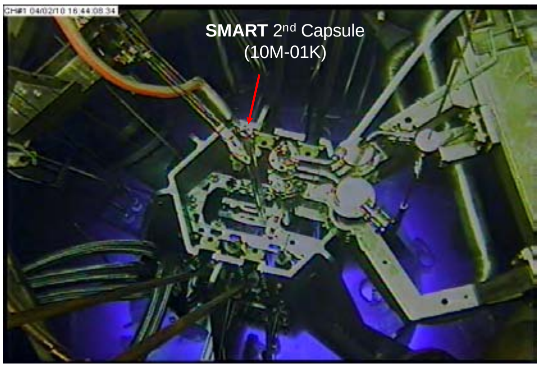

Figure 2. Reactor core during the irradiation test of 10M-01K

3. Conclusion

To obtain the neutron irradiation characteristics of the heat exchanger tube of the SMART steam generator at a higher neutron fluence, the second irradiation capsule of 10M-01K was successfully designed and irradiated in the CT test holes of the HANARO. Various types of specimens such as 0.4T compact tension, tensile, microstructure, hardness and thermal diffusivity made of Alloy 690 were irradiated at 250±10℃(at 295±15℃ for the TD specimens) up to a fast neutron fluence of 3.17×10^{20}(n/cm^2) (E>1.0MeV). The obtained post irradiation test results will be one part of the crucial data to acquire the standard design approval on SMART from the Korean licensing authority by 2011.

ACKNOWLEDGEMENTS

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