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Irradiation Tests 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]. The Korean government decided to obtain the standard design approval on SMART from the Korean licensing authority by 2011.

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 target of fast neutron fluence of Alloy 690 was determined to be $1x10^{18}$ n/cm^2, $1x10^{19}$ n/cm^2, and $1x10^{20}$ n/cm^2 (E>1.0 MeV), considering the maximum lifetime neutron fluence of $1.1x10^{18}$ n/cm^2 [3] of the SMART steam generator. To obtain these neutron fluences, three different irradiation capsules were scheduled and successfully irradiated in the OR5 and CT test holes of the HANARO. The target of irradiation temperature of the specimens was determined as 250 ± 10°C, considering the operating temperature of 247°C~282°C [4] of the steam generator tube having the highest neutron fluence. Generally, the neutron irradiation degradation effect appears more clearly in a lower temperature.

The obtained material properties of the irradiated Alloy 690 specimens will be very valuable to acquire the standard design approval of SMART from the Korean licensing authority.

2. Material and Specimens

To obtain the post-irradiation properties of the Alloy 690 specimens at different neutron fluences, three different heat Alloy 690 were prepared. Various specimens including the standard and sub-size plate tensile specimens, 0.4T compact tension (CT) specimens, hardness, microstructure (Optical and TEM), and thermal diffusivity (TD) specimens were prepared, as shown in Figure 1 and 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.

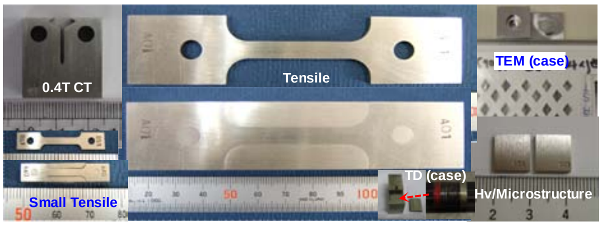

Figure 1. The specimens of Alloy 690

Table 1. Specimens in the SMART irradiation capsules

Specimen	Size(mm)	Specimen (Heat)		
		1st Capsule (09M-02K)	2nd Capsule (10M-01K)	3rd Capsule (11M-03K)
0.4T CT	24x25x10	20	11	20
Plate tensile	108x25x2.5	14	14	14
Small tensile	26x5x0.5	40	40	40
Hardness	10x10x2	28	17	28
TEM	ø3x0.1	30	30	30
TD	ø9x1.0	-	40	16
Total		132	152	148

3. Irradiation Tests

Three irradiation capsules were designed, fabricated and irradiated for an evaluation of the neutron irradiation properties of Alloy 690 as shown in Figure 2.

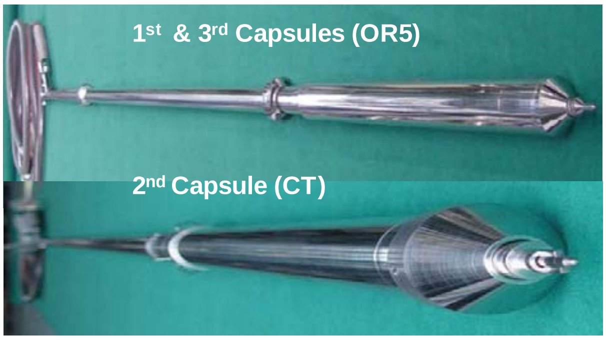

Figure 2. Irradiation capsules of OR5 and CT test hole

The first irradiation capsule of 09M-02K was irradiated in the OR5 test hole of the HANARO at a 30MW thermal power of 250±10℃ up to a fast neutron fluence of 3.76×10^{19} n/cm^2 (E>1.0MeV) as shown in Figure 3 [4]. The second irradiation capsule of 10M-01K was irradiated in the CT test hole of the HANARO at a 30MW thermal power of 250±10℃ up to a fast neutron fluence of 3.17×10^{20} n/cm^2 (E>1.0MeV) as shown in Figure 4 [5]. The third irradiation capsule of 11M-03K was irradiated in the OR5 test hole of 250±10℃

up to a fast neutron fluence of 4.28×10^{18} n/cm^2 (E>1.0MeV).

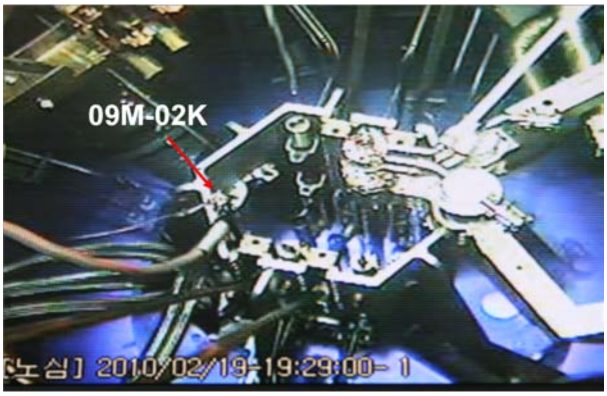

Figure 3. Reactor core during the irradiation test of 09M-02K

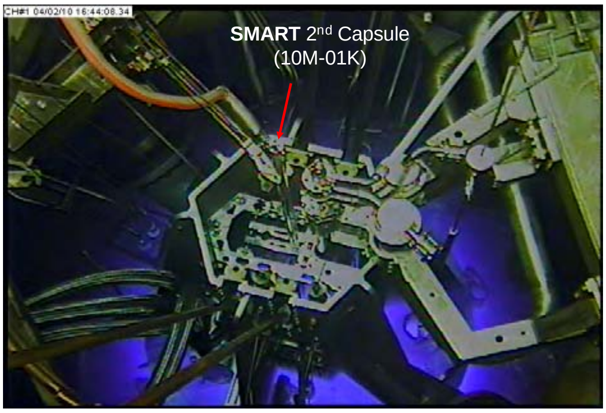

Figure 4. Reactor core during the irradiation test of 10M-01K

During the irradiation tests, the temperatures of the specimens were measured and controlled uniformly with thermocouples and heaters installed in the capsule. The temperatures of the Alloy 690 specimens were consistently maintained in the range of 250±10℃ during the entire irradiation, as shown in Figure 5.

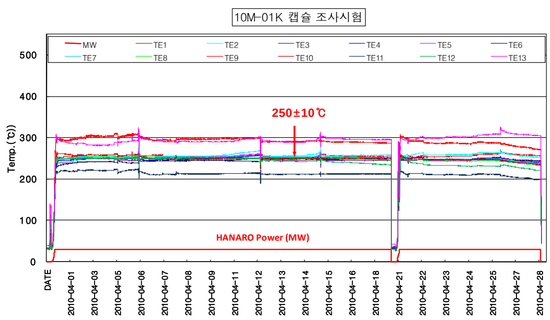

Figure 5. Variation of the temperatures of the 10M-01K (2nd capsule) during the irradiation

4. Post-Irradiation Analysis

After the irradiation tests, the main bodies of the irradiated capsules was cut off at the bottom of the protection tube with the cutting system, and they were transported to the Irradiated Materials Examination Facility (IMEF) by using a HANARO fuel transfer cask. Capsule bodies were dismantled in the hot cell for post-irradiation tests of the irradiated specimens.

The irradiated specimens were tested to evaluate the neutron degradation of the tensile, fracture toughness, hardness and thermal conductivity properties of the Alloy 690 heat exchanger tube material [6].

The obtained test results are being used as useful information to design and evaluate the operation safety on SMART steam generator. The data will be one part of the crucial data to acquire the standard design approval on SMART from the Korean licensing authority by 2011.

5. Conclusion

To obtain the neutron irradiation characteristics of the heat exchanger tube of the SMART steam generator, three irradiation capsules was successfully designed and irradiated in the OR5 and 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℃ up to the fast neutron fluence of $3.17\text{x}10^{20}$ n/cm^2 (E>1.0 MeV). The obtained post irradiation test results are being used as crucial data to acquire the standard design approval on SMART from the Korean licensing authority.

ACKNOWLEDGEMENTS

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