Status of Irradiation Testing of ARAA Material in HANARO

Kee-Nam Choo [a*], Sung-Woo Yang [a], Sung-Jae Park [a] Yoon-Taek Shin [a]
[a]*Korea Atomic Energy Research Institute 111 Daedeok-daero, 989beon-gil, Yuseong-gu, Daejeon 34057, Korea*
[*]*Corresponding author: knchoo@kaeri.re.kr*

1. Introduction

Advanced Reduced-Activation Alloy (ARAA) has been developed since 2011, as a structural material of fusion reactor [1]. A reduced activation ferritic/ martensitic (RAFM) steel is being developed in many countries as a structural material for international thermonuclear experimental reactor (ITER) not only in Korea but also Europe (Eurofer), USA (9Cr-2WVTa), China (CLAM) and Japan (F82H), etc. ARAA, which will be applied to the test-blanket module of ITER, is placed in an environment where 14 MeV high energy neutron irradiation and tritium breeding occur. In case of nuclear structural materials, neutron irradiation can produce the point defect and cluster, which can lead to material degradation and cause problems with integrity of the facility. Therefore, ARAA must be able to endure in these extreme environment and it will be very important to know the information about the defects occurring in the structural materials.

The High Flux Advanced Neutron Application Reactor (HANARO) has been operating as a platform for basic nuclear research in Korea, and the functions of its systems have been improved continuously since its first criticality in February 1995 [2]. Irradiation capsules have been developed and actively utilized for the irradiation tests requested by numerous users to support the national research and development programs on nuclear reactors and nuclear fuel cycle technology in Korea [2,3].

Recently, as part of the fusion reactor development's projects of KAERI and Korea Institute of Fusion Energy (KFE), irradiation testing of ARAA material used as structural materials in a fusion reactor has been required for up to 3 dpa at about 330℃ temperature.

In this paper, the progress and status of the first irradiation testing of the ARRA material in HANARO are described.

2. Design of an Irradiation Capsule

A typical HANARO irradiation material capsule for the ARAA material, as shown in Figure 1, was designed and is being irradiated at HANARO. A 16M-02K capsule was designed for an evaluation of the neutron irradiation properties of the core materials (ARAA) of a fusion reactor [4]. The capsule will be irradiated in the CT test hole at 30MW of maximum thermal power for eight irradiation cycles. The specimens will be irradiated at up to a neutron fluence of $2.5 \times 10^{21} (n/cm^2)$ (E>1MeV) equivalent to 3.0 dpa of radiation damage. To obtain the neutron irradiation properties of the ARAA material, various specimens were placed in the capsule as shown in Table 1. The irradiation specimens are generally located in the center of the standard irradiation capsule. However, multi-hole designs (4 and 6 holes) of the specimens, as shown in Figure 2, were adopted in the capsule to increase an economic efficiency of the volume or to improve the uniformity of specimen temperature at HANARO.

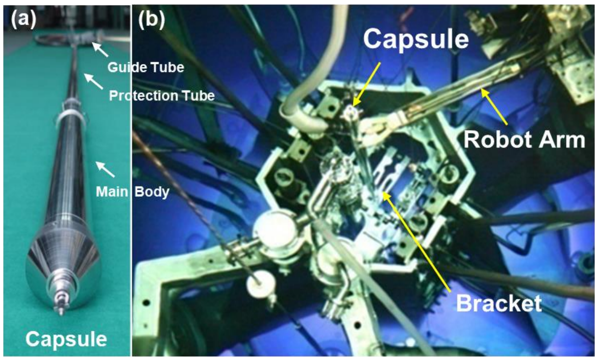

Fig. 1. HANARO irradiation capsule: (a) Irradiation capsule and (b) a capsule system installed in the reactor core.

Table I: ARAA specimens of the 16M-02K capsule

Specimen	Size (mm)	No (ea)	Location
Standard Charpy	10x10x55	42	Stage 2,4,5
Plate tensile	15x1x66	120	Stage 1,3
Hardness/Thermal Conductivity	ϕ10x2	32	Stage 1,3
SEM/EPMA	10x7x4	16	Stage 1,3
TEM	10x10x15	8	Stage 1,3

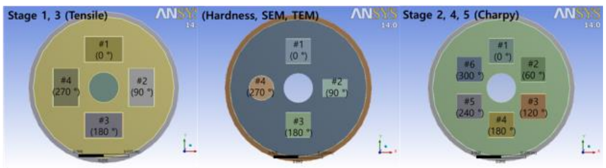

Fig. 2. Cross sections of the 16M-02K irradiation capsule having different specimen-hole designs.

In performing a worthy irradiation test, it is essential that the desired specimen temperature is maintained throughout the irradiation period. To predict the temperature distribution in the capsule, the temperature analysis is performed using thermal analysis codes. The capsule was designed that the inserted specimens will be irradiated at about 330℃ in the CT test hole of HANARO at 30 MW thermal output. The temperature distribution of the irradiation test capsule was estimated using 1-dimensional heat transfer code GENGTC [5], and 3-dimensional finite element analysis program ANSYS 14.0 [6].

3. Irradiation Testing of the 16M-02K Capsule

A new capsule (16M-02K) having a 4 and 6-hole specimen allocation was designed, fabricated, and irradiated for an evaluation of the neutron irradiation properties of the Advanced Reduced Activation Alloy (ARRA) of a fusion reactor. The measured irradiation temperature of the specimens was compared to the analyzed results by using the GENGTC and ANSYS codes, as shown in Table 2.

Table II: Temperatures of the 16M-02K capsule at 30 MW power (100th cycle)

Stage	TC	GENGTC		ANSYS		Measured*	
		He 1atm	0.4K He	He 1atm	0.4K He	He 1atm	He 40torr
1	TC1	201	281	198	<370	222	338
	TC2	201	281	198	<370	214	332
	TC3	230	312	204	<370	220	324
	TC4	230	312	204	<370	215	310
2	TC5	226	296	206	<441	218	312
	TC6	243	305	220	<441	224	313
3	TC7	245	303	282	369	230	334
	TC8	245	303	282	369	232	337
	TC9	265	329	274	369	231	311
	TC11	265	329	274	369	225	288
4	TC10	251	311	235	<369	242	315
	TC13	241	303	217	<370	239	299
5	TC12	233	300	211	<370	227	302
	TC14	206	282	187	<370	221	300

* Heater power 0, control rod at 468mm

Figure 3 shows the variation of temperature of the ARAA specimens of the 16M-02K capsule measured by inserted thermocouples during an irradiation cycle (102-2 cycle). The temperature was stably controlled in the range of 295-337℃ during a reactor operation cycle at HANARO of 30MW thermal power.

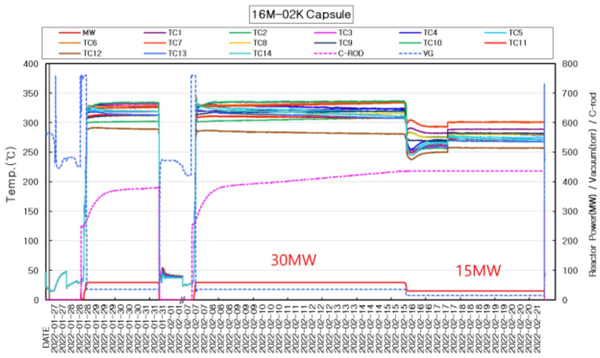

Fig. 3. Temperature variation of specimens during an irradiation testing of the 16M-02K capsule (102-2 cycle).

Although the integrity of the 6-hole structured capsule was preliminarily proved [7], the safety of the capsule was not proven in HANARO. Considering the stable behavior of the specimen temperatures and design experience of the capsule, the 6-hole design could be safely applicable for an irradiation testing of the most Fe and Zr-based nuclear materials at HANARO.

During the irradiation testing of the 16M-02K capsule, abnormal reactor power drop occurred, as shown in Figure 3. The reactor power drop from 30MW to 15MW resulted in a decrease of the specimen temperature to the range of 246-301℃. Considering a complicated recovery process of the irradiated materials [8], the effect of the temperature decrease on the irradiation properties of the ARAA should be carefully discussed later.

The irradiation results of this capsule will be very useful in design of subsequent irradiation capsules for welded ARAA materials.

4. Summary

The progress and status of an irradiation capsule for ARAA material were summarized. The 4 and 6-hole structured capsule of the 16M-02K was designed, fabricated, and successfully irradiated for an evaluation of the neutron irradiation properties of the Advanced Reduced Activation Alloy (ARRA) of a fusion reactor. Considering the stable behavior of the specimen temperatures and design experience of the capsule, the 6-hole design could be safely applicable for an irradiation testing of the most Fe and Zr-based nuclear materials at HANARO. During the irradiation testing of the 16M-02K capsule, abnormal reactor power drop from 30MW to 15MW occurred and resulted in a decrease of the specimen temperature. The temperature of the specimen in the range of 295-337℃ was changed to the range of 246-301℃. The effect of the temperature decrease on the irradiation properties of the ARAA should be carefully discussed later.

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