Irradiation Capsule (24M-05K) Design for TP 304H Stainless Steel in HANARO

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1. Introduction

HANARO has been actively used for fuel and material irradiation testing to support national R&D projects relevant to nuclear systems [1, 2].

Recently, to support the development of fracture mechanics-based damage assessment technology for reactor core structural components under complex neutron loading environments, conducted by the Korea Atomic Energy Research Institute (KAERI), and the evaluation of neutron irradiation characteristics for advanced reactor steels under research by Ulsan National Institute of Science and Technology (UNIST), neutron irradiation tests for relevant materials using the HANARO research reactor were planned.

An optimized design of the irradiation capsule (24M-05K) was made for the irradiation test of thermal embrittlement-resistant stainless steel (TP 304H and weld materials) in HANARO. Various specimens of the matrix and welding materials of the steel, were required to be irradiated. The specimens will be irradiated at about 340℃ in the CT test hole of HANARO up to a neutron fluence of $4.2x10^{21}(n/cm^2)$ (E>1MeV) equivalent to 5.0 dpa of radiation damage. It will provide essential data proving the safety of reactor vessel internal (RVI) components that are exposed to a high neutron irradiation and high-temperature in nuclear power reactors.

2. Basic Design of Capsule

An instrumented capsule (24M-05K), as shown in Fig. 1, was designed for irradiation tests of TP 304H steel and weld materials in HANARO. A nominal chemical composition of TP 304H steel and weld materials is shown in Table I compared with a standard 304 stainless steel. Various specimens, such as Compact Tensions (CT), Charpy, plate tensile and small microstructural specimens of the matrix and welding materials of the steel, were required to be irradiated. The capsule is composed of 5 stages with a specimen holder, an independent electric heater and some thermocouples and specimens at each stage. During the irradiation test, the temperature of the specimens and the fast neutron fluence will be measured by 14 thermocouples and neutron detectors installed in the capsule.

The capsule will be irradiated in the CT hole of HANARO for 308 days (11 HANARO operation cycles) at the specimen temperature of 340±10°C. The specimens will be irradiated at up to a neutron fluence of 4.2×10^{21} (n/cm^2) (E>1.0 MeV) equivalent to 5 dpa of radiation damage.

Table I: Nominal chemical composition of TP 304H steel and weld materials compared with a standard 304 stainless steel

Type	Composition (wt%, Fe=bal.)								
	C	Mn	Si	P	S	Cu	Ni	Cr	Mo
304H-Base	0.051	1.09	0.42	0.017	0.002	0.02	8.03	18.15	0.01
E308L-SMAW weld	0.029	0.84	0.83	0.027	0.004	0.10	9.42	19.54	0.12
ER308L-GTAW weld	0.022	1.92	0.43	0.013	0.010	0.06	10.79	19.85	0.13
STS304	≤0.08	≤2.00	≤1.00	≤0.04	≤0.03		8-10.5	18-20	

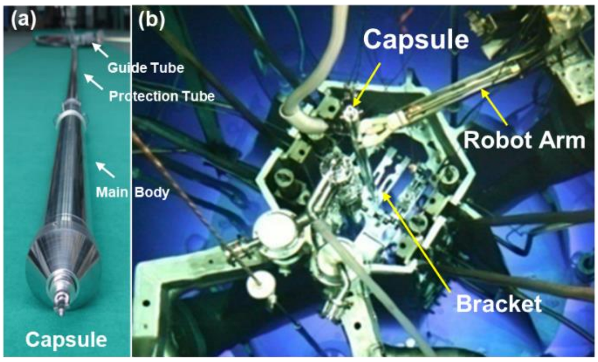

Fig. 1. HANARO irradiation capsule: (a) Irradiation capsule and (b) a capsule system installed in the reactor core.

3. Nuclear / Thermal Analysis and Final Design

Based on the basic design of the capsule, nuclear characteristics and thermal design of the capsule were performed for a safe irradiation test in HANARO. Due to a complicated 6-hole design and CT specimens with large dimensional sizes, resulting in higher specimen temperatures, the final design of the capsule was optimized in three revision steps.

To satisfy the required irradiation temperature of the CT specimens having relatively larger areas, a new specimen allocation design was applied in the capsule. The CT specimens were inserted in cases of same material and vertically allocated in 4 holes, as shown in Fig. 2 and 3. Charpy and other specimens were allocated in 4 or 6 holes in the capsule.

Based on the specimen allocation design, nuclear characteristics of the capsule parts were evaluated using the Monte Carlo transport analysis method [3]. The irradiation temperature of the specimens was analyzed by using the GENGTC code [4]. Compared to a conventional central allocation of the CT specimens, the temperature of the specimens decreased by 30-40℃ and the difference of temperature between the surface and center regions was also decreased from 67℃ to 39℃ by the new vertical allocation.

Because the gamma heating rate varies along the vertical position of the reactor core, a gap adjustment between the capsule parts is very important to maintain a uniform temperature of the specimens over the region. Final gap adjustment between the capsule parts was performed based on the expected temperatures obtained by the GENGTC code.

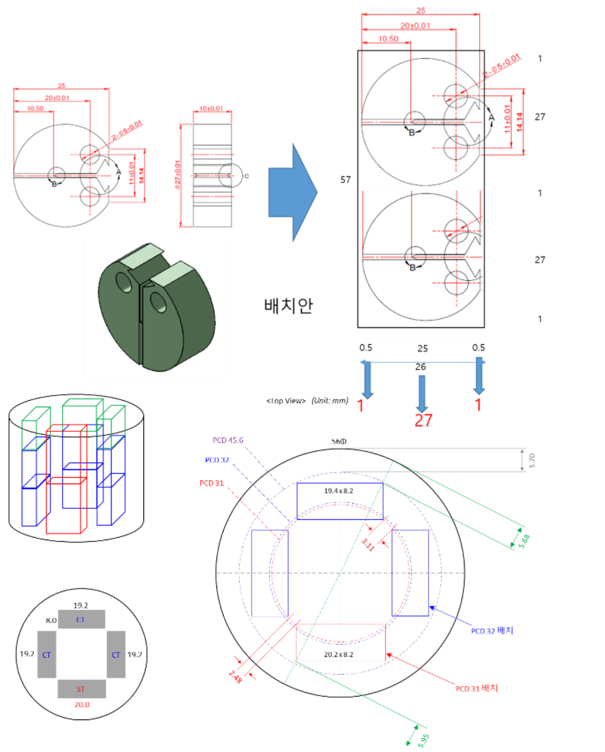

Fig. 2. Schematic view of allocation design of CT specimens

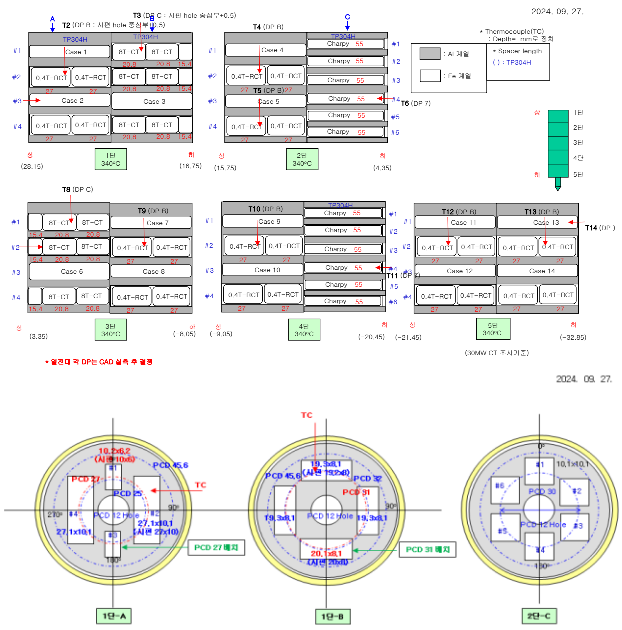

Fig. 3. Schematic cross section of the 24M-05K capsule

4. Future Works

The 24M-05K capsule will be fabricated and irradiated in the CT hole of HANARO up to a neutron fluence of 4.2x10^{21}(n/cm^{2}) (E>1 MeV) equivalent to 5.0 dpa of radiation damage. The irradiated capsule will be moved to IMEF accordance with the accepted procedure after cooling for about 2 months in the HANARO working pool. The capsule will be disintegrated and the irradiated specimens will be taken out and post irradiation tests will be performed in IMEF. The data and experience obtained at design, fabrication of the capsule and irradiation test, will be valuable for design of the capsule which will be tested next at HANARO. The obtained results from the post irradiation tests at IMEF will be useful for the property evaluation of the new structural material for future nuclear power plants.

5. Summary

An optimized design of the irradiation capsule (24M-05K) was made for the irradiation test of thermal embrittlement-resistant stainless steel (TP 304H and weld material) in HANARO. Various specimens, such as Compact Tensions, Charpy, plate tensile and small microstructural specimens of the matrix and welding materials of the steel, were required to be irradiated. The specimens were optimally located in the capsule. A new vertical specimen allocation design was applied to satisfy the required and uniform irradiation temperature of the specimens. Based on the basic design of the capsule, nuclear characteristics and thermal design of the capsule were performed for a safe irradiation test in HANARO. The specimens will be irradiated at about 340℃ in the CT test hole of HANARO up to a neutron fluence of 4.2x10^{21}(n/cm^{2}) (E>1 MeV) equivalent to 5.0 dpa of radiation damage. It will provide essential data proving the safety of reactor vessel internal (RVI) components that are exposed to a high neutron irradiation and high-temperature in nuclear power reactors.

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