Irradiation of High Temperature Materials in the OR5 Test Hole in HANARO

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1. Introduction

A material capsule system has been developed for an irradiation test of non-fissile materials in HANARO (High flux Advanced Neutron Application ReactOr) [1]. This capsule system has been actively utilized for the various material irradiation tests requested by users from research institutes, universities, and the industries [2]. The capsules were mainly designed for an irradiation of the RPV (Reactor Pressure Vessel) and reactor core materials, and Zr-based alloys of parts of nuclear fuel assembly.

All of the material irradiation tests of nuclear materials have been performed in the HANARO CT and IR test holes with a relatively higher neutron flux. In an irradiation test using a capsule, the neutron fluence of a specimen is mainly dependent of the reactor operation time. An operation cycle for the HANARO consists of about 24 operation days and 11 maintenance days. Therefore, short time irradiation tests such as RPV materials requiring only a 2 day-irradiation for a life time neutron fluence requires new capsule technology.

Recently, an evaluation of the neutron irradiation properties of high temperature materials was requested by the Joint U.S./ROK I-NERI Projects of 'VHTR Environmental and Irradiation Effects on High-Temperature Materials'. To obtain the proposed fast neutron fluence of $1x10^{19}$ n/cm^2 (E>1.0 MeV), the OR 5 test hole was selected as the candidate test hole.

As a first irradiation material capsule in the OR test hole of HANARO, the 07M-21K capsule was successfully designed and irradiated in the OR5 test hole of HANARO of a 30MW thermal power at 390 ± 10℃ up to a fast neutron fluence of 4.4×10^{19} n/cm^2 (E>1.0MeV).

2. Design and Fabrication

2.1 Specimens

This capsule was designed to evaluate the neutron irradiation properties of high temperature materials for the Joint U.S./ROK I-NERI Projects. 91 specimens such as standard and 1/2-size Charpy and plate tensile specimens of matrix, welded and HAZ(heat-affected zone) parts made of 9Cr-1Mo steel were placed in the capsule as shown in Table 1. Specimens were inserted into an Al thermal media as a square bar shape with spacers of a similar material to simplify the handling and thermal calculation of the capsule as shown in Figure 1.

Table 1. Specimens of the 07M-21K capsule(9Cr-1Mo)

Specimen	Size (mm)	Location	No
Standard Charpy	10x10x55	Matrix, Welded part	29
1/2-size Charpy	5x5x27.5	Matrix, Welded part	32
Plate tensile	1x15x76	Matrix, Welded, HAZ	30

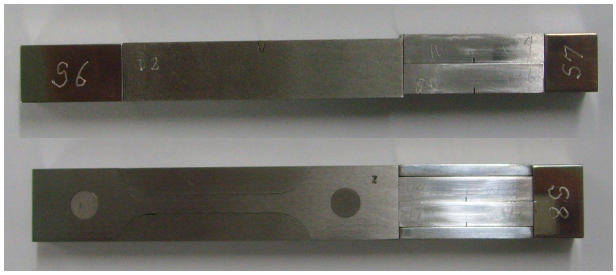

Figure 1. The specimens stacked with spacers of similar materials

2.2 Capsule Design and Fabrication

An instrumented capsule of 07M-21K was designed and fabricated for an evaluation of the neutron irradiation properties of high temperature materials as shown in Figure 2. As a first irradiation material capsule in the OR test hole of HANARO, the basic structure of the 07M-21K capsule was based on the 07M-09K mock-up capsule which was designed and out-pile tested for the development of specific technology and the evaluation of in-reactor safety of the capsule.

The capsule of 56 mm in outer diameter was composed of 5 stages having many kinds of specimens and an independent electric heater at each stage. During the irradiation test, the temperature of the specimens and the fast neutron fluences were measured with 14 thermocouples and 5 sets of Ni-Ti-Fe neutron fluence monitors installed in the capsule. A new 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. The capsule was manufactured as shown in Figure 2 by the S&T Daewoo Co. which has expert skills in manufacturing capsules [3].

Figure 2. The 07M-21K irradiation capsule

2.3 Safety Analysis of the Irradiation

The material capsule irradiation in the OR test hole is the first time in HANARO. It might affect the safety of a reactor itself. Therefore, the irradiation of the 07M-21K capsule was examined to attain an admission of the 'Reactor Safety Review Committee of HANARO' based on the capsule design and safety analysis. In the exanimation, the neutron fluxes and gamma heatings of the specimens located in the OR5 hole of HANARO was theoretically calculated to evaluate the thermal structural safety of the capsule. And the reactor reactivity change by the capsule were checked and proved to be negligible on the reactor safety [3].

3. Irradiation in HANARO

The high temperature materials' specimens were irradiated for 24.62days (1 cycle) in the OR5 test hole (Figure 3) of the HANARO of a 30MW thermal output. During the entire irradiation, the measured temperatures of the specimens were consistently maintained in the range of 390±10℃ as shown in Figure 4.

The amount of neutron fluence of the specimens was calculated by the MCNP code [4] as shown in Figure 5. A fast neutron fluence of the specimens was obtained in the range of $1.10\sim4.40\times10^{19}$(n/cm^2) (E>1.0 MeV) and $0.27\sim1.04\times10^{20}$(n/cm^2) (E>0.1 MeV), respectively. The dpa of the irradiated specimens was evaluated to be 0.034～0.07 by using the SPECTOR code [5].

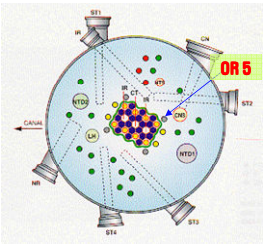

Figure 3. Core configuration of the HANARO

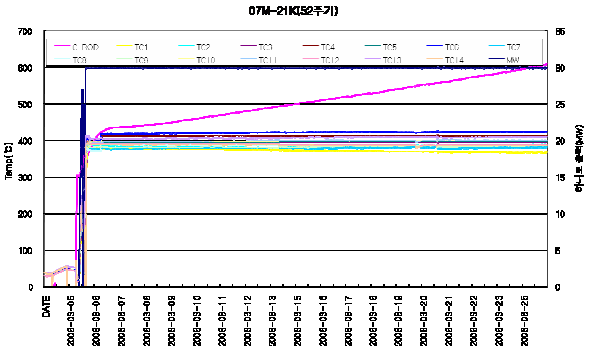

Figure 4. Variation of the temperatures of the 07M-21K capsule specimens during the irradiation test

After the irradiation test, 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 capsule were dismantled for post irradiation tests of the irradiated specimens. The calculated values of the neutron fluence will be compared with the measured values of the neutron fluence monitors.

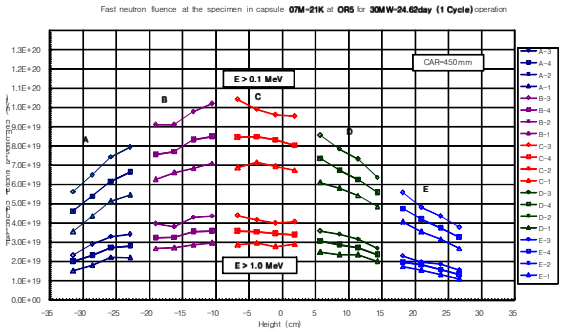

Figure 5. The axial distribution of the fast neutron fluence of the specimens in the 07M-21K capsule

4. Conclusion

The first instrumented capsule of 07M-21K for the irradiation in the OR test hole of HANARO was successfully designed and irradiated for an evaluation of the neutron irradiation properties of high temperature materials for the Joint U.S./ROK I-NERI Projects of 'VHTR Environmental and Irradiation Effects on High-Temperature Materials'. The high temperature materials were irradiated in the OR5 test hole of HANARO of a 30MW thermal power at 390±10℃ up to a fast neutron fluence of 4.4×1019(n/cm2) (E>1.0MeV) and the dpa of the specimens was evaluated to be 0.034～0.07.

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