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Irradiation Tests of High-Temperature Materials for the Gen IV VHTR Program in HANARO

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1. Introduction

The Generation IV (GEN-IV) International Forum, or GIF, was chartered in July 2001 to lead the collaborative efforts of the world's leading nuclear technology nations to develop next-generation nuclear energy systems to meet the world's future energy needs.

Among the six GEN-IV systems, the VHTR (Very-High-Temperature Reactor System) is one of the leading reactor designs participated in by South Korea and the U.S.. The VHTR (Very High Temperature Reactor) is the next step in the evolutionary development of high-temperature reactors. The VHTR technology addresses the advanced concepts for a helium gas-cooled, graphite-moderated, thermal neutron spectrum reactor with a core outlet temperature greater than 900℃. The VHTR environment is unique, and little data exists on the behavior of materials under irradiation and in the temperature and pressure ranges of interest. At present, no candidate alloy has been confirmed for use as either the cladding or structural material in VHTR's. To meet these challenges, a Generation IV R&D plan for the structural materials in VHTR's was initiated as an International Nuclear Energy Research Initiative (I-NERI) Project, which is a bilateral research agreement between the Ministry of Science and Technology (MOST) of Korea and the Department of Energy of the U.S. [1].

To obtain the proposed test condition by the Joint U.S./ROK I-NERI Project of 'VHTR Environmental and Irradiation Effects on High-Temperature Materials', the development of new instrumented capsule technologies for an IP/OR irradiation test and a high-temperature irradiation test have been successfully performed in HANARO [2].

9Cr-1Mo and 9Cr-1Mo-1W steels were selected as candidate materials of a reactor pressure vessel of the VHTR, and the OR 5 test hole in HANARO was selected as the irradiation test hole. Two HANARO irradiation capsules of the high temperature materials were successfully designed and irradiated in the OR5 test hole of HANARO at a 30MW thermal power of 390±10℃ up to a fast neutron fluence of 4.4×10^{19} n/cm^2 (E>1.0MeV).

2. Irradiation of High Temperature Materials

2.1 Materials and Specimens

As a reactor pressure vessel material of the VHTR, modified 9Cr-1Mo steel manufactured by USINOR INDUSTEEL (Belgium) and forged 9Cr-1Mo-1W steel manufactured by Doosan Heavy Industry (DHI) were procured. Various specimens such as standard and 1/2-size Charpy and plate tensile specimens of the matrix, welded, and HAZ(heat-affected zone) parts made of the steels were prepared, as shown in Table 1 and Figure 1.

Table 1. Specimens of the irradiation capsules

Capsule	Specimen	Size (mm)	Location	No
07M-21K (9Cr-1Mo)	Charpy	10x10x55	M, W	29
	1/2-size Charpy	5x5x27.5	M, W	32
	Plate tensile	1x15x76	M, W, HAZ	30
08M-09K (9Cr-1Mo-1W)	Charpy	10x10x55	M, W, HAZ	32
	1/2-size Charpy	5x5x27.5	M, W	40
	Plate tensile	1x15x76	M, W	20

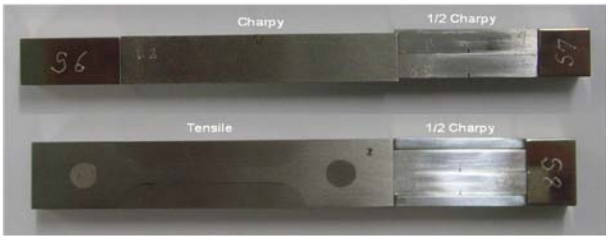

Figure 1. The specimens stacked with spacers in the irradiation capsules

2.2 HANARO Irradiation Capsule

HANARO irradiation capsules of 07M-21K and 08M-09K was designed and fabricated for an evaluation of the neutron irradiation properties of high temperature materials, as shown in Figure 2. These instrumented irradiation material capsules were newly designed to be irradiated in the OR5 test hole of HANARO for the first time. The capsule with an outer diameter of 56 mm 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. The capsule was manufactured as shown in Figure 2 by the S&T Daewoo Co., which has expert skills in manufacturing capsules.

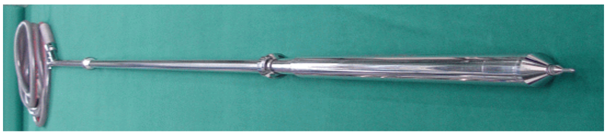

Figure 2. The irradiation capsule for the OR5 test hole

2.3 Irradiation in HANARO

The material capsule irradiation in the OR test hole is the first one done 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 examination, the neutron fluxes and gamma heatings of the specimens located in the OR5 hole of HANARO were theoretically calculated to evaluate the thermal structural safety of the capsule. And the reactor reactivity change by the capsule was checked and proved to be negligible on the reactor safety [3].

Each irradiation capsule was irradiated for 1 cycle (about 24days) in the OR5 test hole (Figure 3) of HANARO with 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.

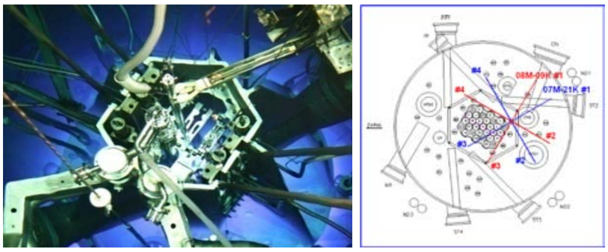

Figure 3. HANARO core and loading orientation of the specimens in the capsules

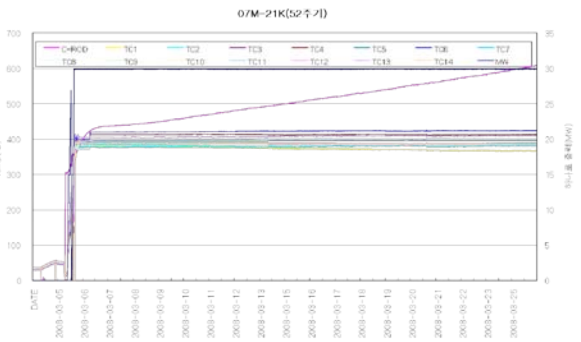

Figure 4. Variation of the temperatures of the 07M-21K capsule specimens during the irradiation test

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 1.1~4.4×10^{19}(n/cm^2) (E>1.0 MeV) depending on the irradiation time and specimen-loading orientation in the reactor core, as shown in Figure 3. The dpa of the irradiated specimens was evaluated to be 0.03～0.07 by using the SPECTOR code [5].

After the irradiation test, the capsules were transported to the IMEF (Irradiated Materials Examination Facility) and dismantled for post-irradiation tests of the irradiated specimens. The calculated values of the neutron fluence were evaluated to be located within a 20% error range of the theoretical values calculated by the MCNP code.

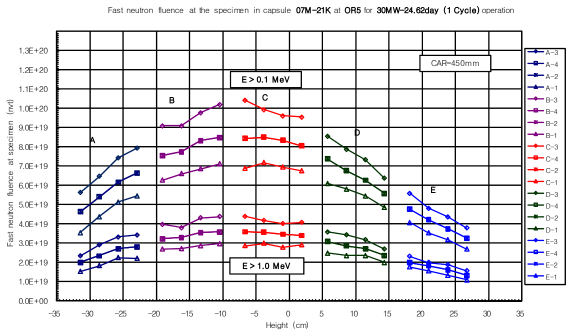

Figure 5. The axial distribution of the fast neutron fluence of the specimens in the 07M-21K capsule

3. Conclusion

The high-temperature materials for the VHTR were successfully irradiated for an evaluation of the neutron irradiation properties for the Joint U.S./ROK I-NERI Projects of 'VHTR Environmental and Irradiation Effects on High-Temperature Materials'. 07M-21K and 08M-09K capsules were irradiated in the OR5 test hole for the first time in HANARO. The specimens were irradiated at 390±10℃ up to a fast neutron fluence of 4.4×10^{19}(n/cm^2) (E>1.0MeV), and the dpa of the specimens was evaluated to be 0.03～0.07.

ACKNOWLEDGEMENTS

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