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Design and Test of the Capsule for Long-term Irradiation of the RPV Material in HANARO

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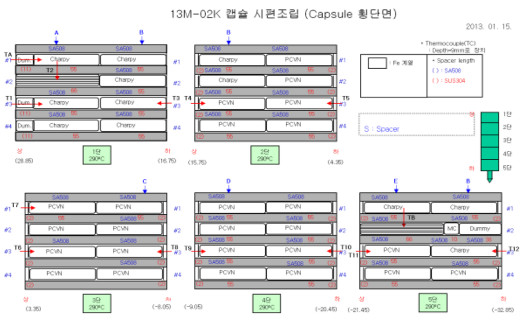
1. Introduction

An instrumented capsule (13M-02K) for long-term irradiation of the RPV material was designed, fabricated and irradiated for an evaluation of the neutron irradiation properties of the reactor pressure vessel model alloys [1]. The basic structure of the capsule was based on the previously fabricated capsule 08M-02K [2] which was successfully irradiated in the OR5 test hole of HANARO. 58 specimens such as PCVN, 1/2 PCVN, Charpy, small tensile and TEM specimens of SA508 RPV model alloys were placed in the capsule. The capsule 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 fluence were measured by 14 thermocouples and 5 sets of Ni-Ti-Fe neutron fluence monitors installed in it. A friction welded tube between STS304 and Al1050 alloys was introduced in the capsule to prevent a coolant soak into the capsule during the cutting process in HANARO. The capsule was irradiated in the OR5 test hole of HANARO of a 30MW thermal output at 290±10℃ up to a fast neutron fluence upto10.0×10^{19}(n/cm^2) (E>1.0 MeV).

2. Material and Specimens

The specimens were inserted into the specimen holder of the Al square bar shape with spacers of the same material to simplify the handling and thermal calculation of the capsule. The 25 ST-PCVN and 12 Charpy (Cv) specimens were simply inserted into the Al holder, and 20 small plate tensile specimens were stacked 10 into the holder of the stage 1 and 5 as shown in Figure 1. And 5 MC specimens, which are for micro-compressor and ϕ3 x 0.1 mmt each, were put in the case of size 10 x 10x 15mm and placed in the second hole of the stage 5..



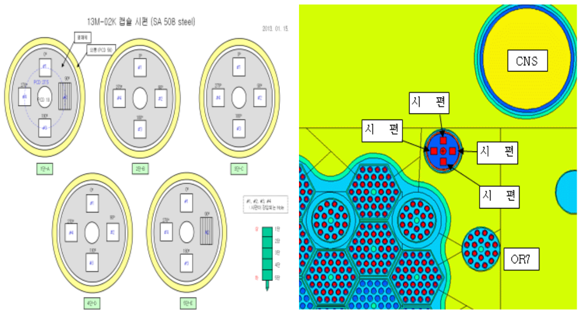


Figure 1. Arrangement of specimens in the capsule

3. Irradiation Capsule

The irradiation capsule 13M-02K was designed, fabricated and tested for an evaluation of the long-term irradiation properties of the RPV SA 508 Gr 3 steel at the higher neutron fluence. The capsule was designed to be irradiated at the temperature of 290±10℃ in the OR5 test hole according to a user's requirements as shown in Figure 2. The irradiation test of the capsule was proven to be safe for the irradiation tests of SA 508 steel through the previous irradiation test in HANARO. The irradiation temperature of the specimen is determined by the gamma heating, the He gas pressure, and widths of gaps between the capsule parts. The irradiation temperature of the specimens was preliminarily analyzed by using the GENGTC and ANSYS codes. The capsule was divided into 5 stages with an independent electric heater at each stage. 14 thermocouples and 5 sets of Ni-Ti-Fe neutron fluence monitors were installed in it to measure the irradiation temperatures and the fast neutron fluences of the specimens, respectively.

Figure 2. Irradiation capsule in the OR test hole

4. Thermal analysis

The reactivity is calculated to be +0.96 mk on the basis that the control rod is 450mm and the capsule is fully inserted at OR5 [3]. The irradiation test is proved to be safe because it is less than +12.5 mk of the limited value required at HANARO. Fig. 3 shows the neutron spectrum distribution at the hole, which is the average values at all specimen.

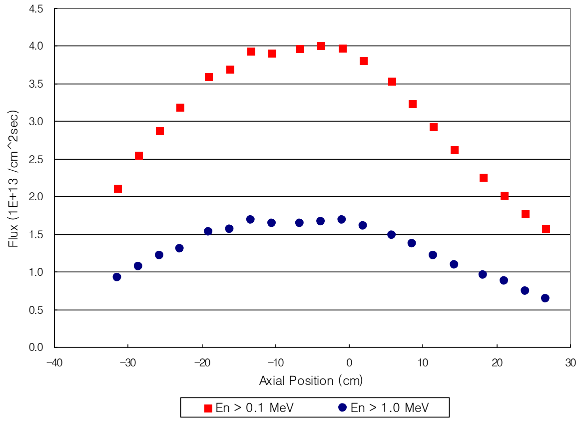


Fig. 3. Average fast neutron spectrum distribution

The GENGTC program was used for the thermal analysis. A one-dimensional model for the specimen section was generated and used for the code calculation. The temperature of the cooling water in the reactor in-core is about 33 ℃, and the heat transfer coefficient at the outer surface of the external tube is 30.3 x 10^3 W/m^2℃, which was determined experimentally [4].

Table 1 shows the temperature analysis results by GENGTC code and the measured values during irradiation test. The analysis was performed repeatedly until the calculated values converged adjusting the gap on the target temperatures between the outer tube and the thermal media. The measured temperatures during an irradiation are almost in the range of the calculated values.

Table 1. Results of irradiation temperatures

Stage	Gap size (mm)	Temperature	
		Target Temp.	Measured Temp.
1	0.5	290~300	272~295
2	0.37	290~310	283~295
3	0.23	290~295	276~295
4	0.28	290~320	283~294
5	0.34	290~315	287~299

5. Irradiation Test in HANARO

The capsule was safely irradiated in the OR5 test hole of the HANARO of a 30MW reactor output power for 2 cycles (about 53.58days) as shown in Figure 3. The temperature of the specimens during an irradiation was initially increased by the gamma heating and then roughly adjusted to an optimum condition by the He gas control system. It was then finally adjusted to a desired value by micro-electric heaters. During an irradiation test, the temperatures of the specimens were measured and monitored with thermocouples installed in the capsule. The irradiation temperature of the specimens was maintained in a range of 290±10℃ except for the MC specimens which reached up to about 310 ℃. The higher irradiation temperature of the MC specimens was attributed to a complicated layer structure in the specimen case.

The fast neutron fluence of the specimens was obtained in the range of 2.7~10.0×10^{19}(n/cm^2) (E>1.0MeV). The amount of neutron fluence of the specimens was calculated by the MCNP code and will be compared to the obtained value from the irradiated fluence monitors.

The irradiated capsule was being maintained in the reactor pool for cooling the radioactivity. After the cooling, 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 irradiated specimens will be tested to evaluate the irradiation performance of the SA508 steel in the IMEF hot cell. The obtained test results will be one part of the data to evaluate the irradiation characteristics of SA508 and improve the performance of the RPV steel in the nuclear power plant.

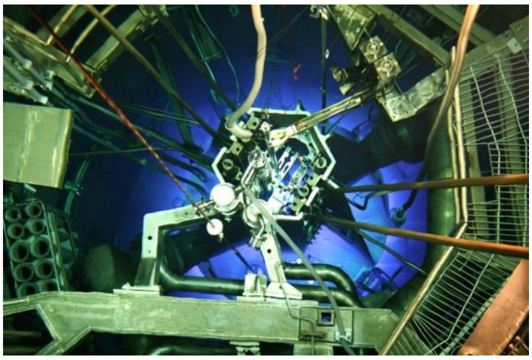


Figure 3. Reactor core during the irradiation test

6. Conclusion

To obtain the long-term irradiation characteristics of the RPV SA508 Gr. 3 steel at the higher neutron fluence, a capsule was successfully designed and irradiated in the OR5 test holes of the HANARO. Various types of specimens such as PCVN, Charpy, plate tensile specimens of SA508 alloys were irradiated at 290±10℃ (at 295±15℃ for the MC specimens) up to a fast neutron fluence of of 2.7~10.0 x 10^{19}(n/cm^2) (E>1.0 MeV). The obtained post irradiation test results will be very valuable for the evaluation on the integrity evaluation of the currently operating nuclear power plant.

ACKNOWLEDGEMENTS

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