Development of a Capsule with Double Layered Thermal Media

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As VHTR and SFR projects are being carried ahead as a part of Gen-IV program, a capsule with double layered thermal media was developed for irradiation of high-temperature materials in HANARO. Graphite and Ti materials were used as the thermal media instead of aluminum in this capsule. This capsule was irradiated in the CT hole of HANARO with a 30MW thermal power. The irradiation temperatures and fluence of specimens were in the range of 540~710℃ and 1.0~2.7×10^{20} (n/cm^2) (E>1.0MeV). By the irradiation test at the temperatures higher than 700℃, the structural integrity and irradiation safety of the capsule with double layered structure were confirmed.

1. Introduction

The reactors planned in the Gen-IV program will be operated at a high temperature and flux as shown in Table 1. The outlet temperatures of VHTR and SFR are 1,000℃ and 550℃ respectively [1], which are much higher than the irradiation temperatures of material capsules tested in HANARO up to recently.

The capsule for high-temperature materials was designed as a capsule with double layered thermal media, in which the outer one is aluminum and the inner contains material such as Ti, Mo, Fe, Zr, Gr. This capsule takes aim at irradiation at temperatures up to 1,000℃.

Table 1 Operation conditions of Gen-IV reactors

Type	Temp (℃)		Max. dose (dpa)	Pressure (MPa)	Coolant
	Inlet	Outlet			
PWR	290	320	100	16	Water
VHTR	600	1,000	1~10	7	He
SFR	370	550	200	0.1	Sodium

2. Design and Irradiation of the Capsule

a) Mock-up capsule

A mock-up capsule was designed for performance testing at the out-pile facility to verify the structural and external integrity during irradiation at temperatures higher than 500℃. This capsule has 5 stages of thermal media with double structure, of which the materials are Al/Al, Mo/Al, Zr/Al, Fe/Al and Gr/Al respectively. The inner structure of the capsule is 4 holes scattered type as shown in Fig. 1. The specimens are all made of STS 304 with size of 10x10mmx114mmh and the gap is 0.1mm between specimen hole and specimen. In the center hole, the rod heater was inserted as a substitute of the gamma heating in HANARO.

In calculation, the temperatures were 160~220℃ higher than those of the single thermal media capsule of aluminum material. The temperatures of the specimens maintained 500℃ for 5 hours as shown in Fig. 1, and the thermal media of the double structure capsule was confirmed to maintain the soundness.

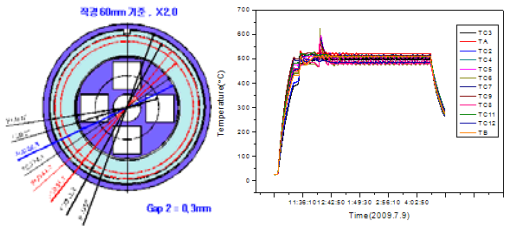

Fig. 1 Section view and integrity test at 500℃

b) Design model

A new capsule targets to be irradiated at temperature higher than 700℃. Ti and Gr were selected as materials for the thermal media in this capsule. Fig. 2 shows the section and the schematic view of the holder. The thermal media has a double layered structure of which the outer was made of aluminum and the inner Ti or Gr. The gap between the holder and specimen is 0.1mm, and between the inner and outer thermal media is 0.15mm, between the outer thermal media and outer tube the gap become 0.16~0.36mm, which was designed effectively to control the temperature of each stage. All gaps were filled with He gas of 101kPa.

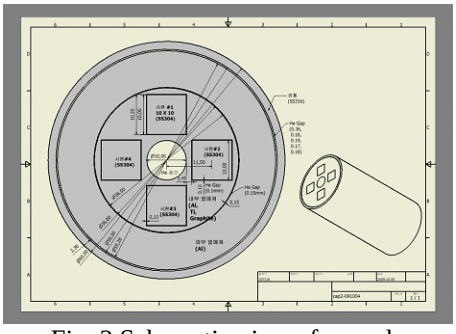

Fig. 2 Schematic view of capsule

c) Nuclear and thermal analysis

As double layered thermal media were new kinds of structure and Gr, Ti were at first irradiated material in HANARO, the evaluation of nuclear characteristics was important in the design of the capsule and the safety of irradiation. The reactivity was calculated to be 9.6 mk even if the thermal media were all Ti, which will make it highest. Therefore, the irradiation test was proved to be safe as it is less than +12.5 mk of the limit value required in HANARO [2]. ANSYS program was used for the thermal analysis. Two-dimensional model for the specimen section was generated. 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 experimentally determined.

Fig 3 shows the irradiation temperatures of the specimen, which were measured using thermocouples. The temperature at stage 4 was highest because the gamma flux is the highest there in HANARO.

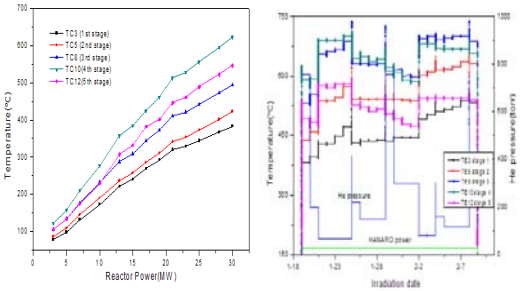

Fig. 3 Irradiation temperatures (before/during normal operation)

Measured and calculated temperatures of the capsule specimens are listed in Table 2. In comparison with the calculated and measured temperatures of the specimens, there was no difference at stage 2, and little at stages 3 and 5. However, the differences are bigger at stage 1 and 4. Especially, the measured temperature at the stage 4 shows about 25 % lower value than the calculated one. The temperatures by calculation generally come out higher than the measured ones. It is inferred from the facts that in the calculation the maximum value is given, and the radiation heat transfer is not considered, and the adiabatic condition at top and bottom is applied in 2-dimensional analysis.

As the method and code of calculation have already been proven, the error by calculation should not be so great and the result should show the same tendency. In this respect, the results of stages 2, 3 and 5 seemed to be acceptable in both calculation and measurement. However, the error in stage 4 was so big and seemed to result from the wrong estimation of neutron flux and gamma heat generation.

Table 2 Comparison of the specimen temperatures at measurement and analysis

Stage	From fuel center (cm)	Gap size (mm)	No heater power at 101kPa		Error (%)
			Calc. (ANSYS)	Measured	
1	22.45	0.36	413	355	16.3
2	10.05	0.16	435	431	0.9
3	0.5	0.19	549	521	5.4
4	-14.75	0.17	691	553	24.9
5	-27.15	0.18	500	458	9.2

Error=(Calculated-Measured)/Measured x 100(%)

3. Conclusions

As SFR and VHTR, which are being developed as a part of the future nuclear systems in Korea, are to be operated at high temperatures, the irradiation tests at high temperatures are required for materials to be used. In accordance with this requirement, a capsule suitable for irradiation test at high temperatures was developed to overcome a restriction on the use of aluminum at high temperature. The new capsule with the thermal media of double layered structure, of which the outer is of aluminum and the inner Ti or graphite, was fabricated. This capsule was applied to the irradiation test up to 700 ℃. The more advanced capsule to be applied to the irradiation test up to 1,000 ℃ will be developed after improving the instrumentations beginning in 2011.

Acknowledgements

This work was supported by the Nuclear Research & Development Program of the National Research Foundation of Korea (NRF) grant funded by the Korean government (MEST).

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