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Development of High-temperature Irradiation Capsule (15M-03K) for Testing of VHTR Reactor Core Structural Materials

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1. Introduction

As the nuclear reactors planned in the Gen-IV program will be operated at high temperature and under a high neutron flux, the requirements for irradiation of materials at high temperature are recently being gradually increased. Among them, VHTR will be operated at about 1,000 ℃, and thus a new capsule enduring a very high temperature needs to be developed. The irradiation tests of the materials in HANARO up to the present have usually been performed at temperatures below 300℃ at which the PWR is being operated. Accordingly, the specimen holders of the capsule are made of Al, which has a good thermal conductivity and is easy to process. Al might melt easily at high temperature. To overcome the restriction for high-temperature use of Al thermal media of the existing standard capsule, a new capsule with double thermal media of Ti-Fe material was developed as a more advanced capsule than the single thermal media capsule. This double-layered thermal media will enable testing at a higher temperature than a capsule with thermal media including Al material [1].

2. Design of Capsule

2.1 Design

A new capsule aims to be irradiated at temperatures higher than 1,000 ℃. Ti and Fe were selected as materials for the thermal media in this capsule. Fig. 1 shows a schematic view of the capsule. It has a double-layered structure, the outer portion of which is made of Fe, and the inner portion is made of Ti. The gap between the holder and specimen is 0.1 mm, while that between the inner and outer thermal media is 0.2 mm, and between the outer thermal media and outer tube the gap is 0.26-0.29 mm, which was designed to effectively control the temperature of each stage. All gaps are filled with He gas of 101kPa.

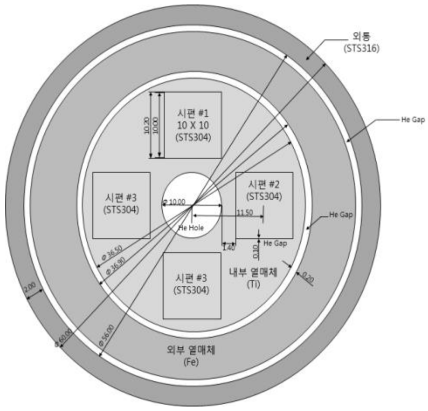

Fig. 1. Schematic view of double thermal media capsule

The capsule is composed of only one stage at the center position to investigate the soundness of the instruments and the inner parts during the irradiation at high temperature. One electric heater and 3 thermocouples were installed around the outer thermal media. The thermal media has 4 holes to contain the specimens of STS 304 material with a dimension of 10x10x100 mm, as shown in Fig. 2.

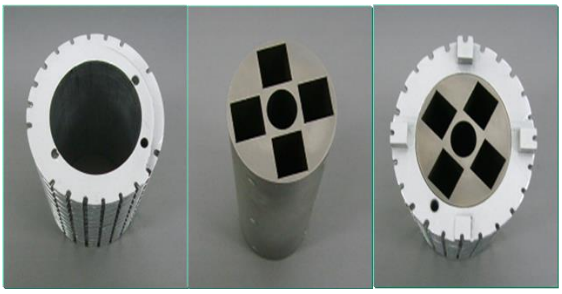

Fig. 2. Double-layered thermal media

2.2 Nuclear and thermal analysis

As the thermal media consisting of Ti and Fe were first used in HANARO, the nuclear characteristics were evaluated for safe irradiation. The reactivity was calculated to be 9.6 mk when the thermal media are all Ti, and 9.2 mk when mixed with Ti and Fe. Accordingly, the irradiation test was proved to be safe because it is less than the limit value of +12.5

mk required at HANARO [2]. Fig. 3 shows the neutron spectrum at the CT hole, which is the average value at all specimens.

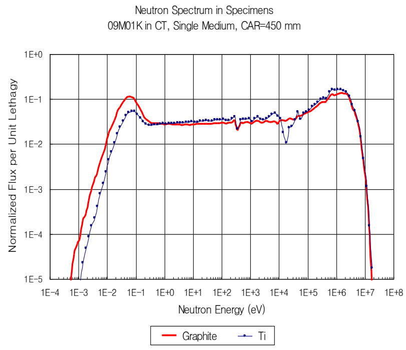

Fig. 3. Neutron Spectrum in CT hole

The heat generation rates were determined by referring to the data recently calculated for a safety analysis. In this calculation, the values at a 450mm height of the control rod were used. The heat generation rates are listed in Table 1.

Table 1. Heat generation rate

Lay-ers	y-coord. (cm)	γ-Heating rate(W/g)			
		Speci-men SS304	Inner holder Ti	Outer holder Fe	Outer tube STS316
3-1	-8.05 to -5.20	5.6	4.9	5.4	5.7
3-2	-5.20 to -2.35	5.8	5.2	5.8	5.6
3-3	-2.35 to -0.50	6.1	5.4	5.9	5.6
3-4	0.50 to 3.35	6.2	5.5	6.1	5.5

2.3 Thermal analysis

A thermal analysis was performed using the GENGTC program and another 2-dimensional code. The 2-dimensional model for the specimen section is shown in Fig. 1. 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.

Fig. 4 shows the calculated temperatures of the specimen and thermal media at each stage. Because the temperature of the thermal media when the specimen reaches around 1000℃ becomes over 600℃, Al might not be suitable as the material for thermal media. If the reactor power or gap due to thermal expansion during operation changes, the temperature of thermal media may increase over the melting point of Al.

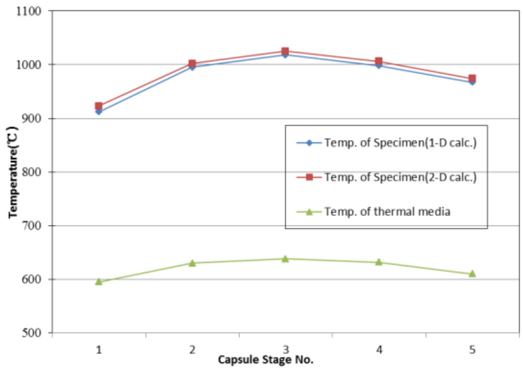

Fig. 4. Temperatures of each stages

Table 2 shows the temperature analysis results of the 15M-03K capsule. An analysis was performed repeatedly until the calculated values converged to the target temperatures by adjusting the He gap between the outer tube and the thermal media.

Table 2. Results of temperature analysis

Stage	Cold gap (mm)	He pressure	Temperature		
			Speci-men	Inner holder	Outer holder
3-1	0.26	0.4K	1004	943	506
		1 atm	679	625	322
3-2	0.26	0.4K	997	936	501
		1 atm	669	621	319
3-3	0.29	0.4K	1020	958	543
		1 atm	678	630	339
3-4	0.28	0.4K	1003	944	530
		1 atm	668	620	331

It is necessary to measure the temperature at 1 atm without any heater input and to compare it with the calculated value. The calculation code in the design does not consider a thermal expansion. The change in the gap by thermal expansion was obtained in advance and put into the calculation code to obtain a more exact value. This process was iterated several times to obtain a converged value. The temperature of the specimen through this process will finally converge to 679℃, as shown in Fig 5. In the future, the temperatures of the specimen and the capsule parts need to be compared with the measured values to confirm the accuracy of the prediction by the calculation code when the irradiation test is starting at the reactor.

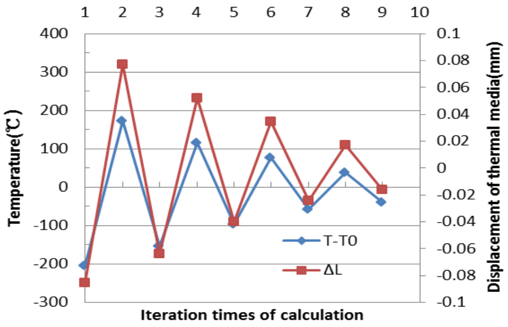

Fig. 5. Temperatures of specimen at 1 atm

3. Conclusions

Because a VHTR is to be operated at a very high temperature, the irradiation tests at a very high temperature are required. In accordance with this requirement, a capsule suitable for an irradiation test at high temperatures was developed. The new capsule has a double layered structure, the outer portion of which is Fe, and the inner portion is Ti, to overcome a restriction regarding the use of aluminum at a very high temperature. The temperature of the specimen in this capsule will increase to 1,000 ℃. During the irradiation test, the integrity of the parts and instruments will be investigated.

Acknowledgements

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