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Thermal Analysis Study of Irradiation Capsule

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1. Introduction

Capsules have been developed since 1995 and are being utilized for the irradiation test of materials and nuclear fuel in HANARO. In performing a worthy irradiation test, it is essential that the desired specimen temperature be maintained throughout the irradiation period. For that reason, the design of the capsule must be such that the temperature can be continuously monitored, and means must be provided whereby the temperature can be controlled. To predict the temperature distribution in the capsule, the temperature analysis is performed using the Thermal analysis code.

In this study, we investigated to which one gives better results in estimating temperatures of capsule using several thermal analysis codes. To evaluate the correct temperature, the analysis results are compared with the irradiation test data of 10M-01K capsule.

2. Methods and results

2.1 Modeling

The material capsule called 10M-01K was designed and manufactured to evaluate the neutron irradiation properties of the Alloy 690 for 'SMART development' in 2010. The capsule was irradiated in the CT test hole of HANARO at a 30 MW thermal output at 250±10 ℃ up to a fast neutron fluence of 3.17×10^{20} n/cm^2 (E >1.0 MeV) about 25days [1].

Fig. 1 shows the design of 10M-01K. To study for the characterization of temperatures, a part of the capsule (1-stage) was sampled to make the calculation model. Fig. 2 shows the cross section of 10M-01K. The thermal media is a cylinder with rectangular specimen holes.

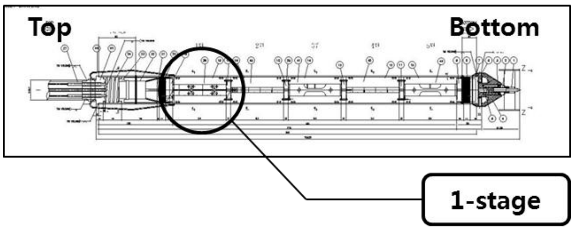

Fig. 1. The full body of 10M-01K capsule. The circle area indicates the 1-stage area.

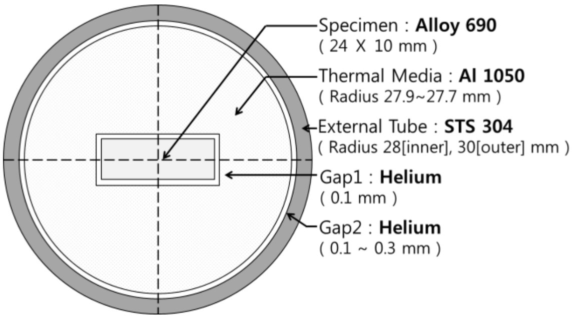

Fig. 2. The cross section of 10M-01K (1-stage).

The gap between the thermal media and the specimens was fixed as 0.1 mm (gap1), and that between the media and the tube is changed between 0.1 ~ 0.3 mm (gap2). The gap is filled with the helium gas. The specimen is made of Alloy 690, the specimen holder is Aluminum 1050, and the external tube is Stainless Steel 304. The thermal properties are listed in Table 1. Table 2 shows the heat generation of the respective materials, which are those in area of 1-stage (167.5 ~ 196 mm).

Table 1: The thermal properties used calculating the temperature.

	Temp. (℃)	**Alloy 690**	**Al 1050**	**Helium**	**STS 304**
conductivity (W/m·℃)	100	13.5	206.3	0.2	16.2
	200	15.4	215.3	0.2	17.5
	300	17.3	230.4	0.2	18.7
	400	19.1	249.7	0.3	20
	500	21	268.6	0.3	21.3
	600	22.9	279.8	0.3	22.6
	700	24.8	273.6	0.3	23.9
	800	26.6	237.6	0.4	25.1
Density (kg/m^3)		8190	2710	0.1786	8030

Table 2: The heat generation of the materials used in the capsule design.

Heat generations (W/g)	**Alloy 690**	**Al 1050**	**STS 304**
	4.06	3.34	3.81

2.2 Analysis

The temperature distribution of the model of 10M-01K capsule is estimated with 1-dimensional heat transfer code, GENGTC [2], 2·3-dimensional finite

Table 3: Temperature distribution in accordance with the gap size and Helium pressure (unit, ℃). 0.5 $K_{He,1atm}$ means the any pressure (about 50-100 torr). These values are calculated using GENGTC, HEATING 7.2f, and ANSYS 14.0.

CODE	He / gap (mm)	0.1	0.15	0.2	0.25	0.3
GENGTC	**1 atm**	211.51	230.78	247.44	263.34	278.41
HEATING 7.2f		252.80	284.81	315.19	344.23	372.10
ANSYS 14.0		254.17	290.02	324.16	354.94	385.70
GENGTC	**0.5 $K_{He,1atm}$**	288.83	320.69	345.64	369.38	392.56
HEATING 7.2f		363.36	418.02	469.15	517.53	563.65
ANSYS 14.0		374.68	433.70	489.47	544.54	595.63

element analysis program, HEATING 7.2f [3], and ANSYS 14.0 [4]. The temperatures by GENTC and HEATING 7.2f are calculated as the specimen area approximated to the circular having the same area. The temperature of a cooling water in the reactor in-core is about 32 ℃, and the heat transfer coefficient at the outer surface of the external tube is 3.03×10^3 W/m^2.

3. Results

The temperature distribution for the center of specimen in capsule is given in Table 3 and Fig. 3 shows Temperature profile of the values in Table 3. The temperature is greatly influenced by the gap sizes and pressure between the thermal media and the external tube. The temperature is increased with increasing gap size and decreasing helium pressure. The temperature by GENGTC code is lower than those of the other codes and the temperatures by HEATING 7.2f and ANSYS 14.0 code are nearly similar.

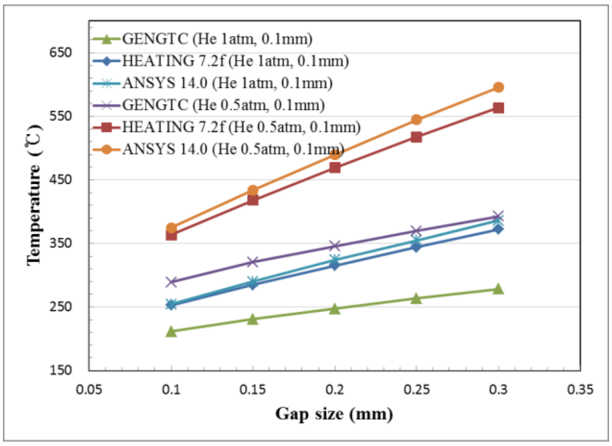

Fig. 3. Effects of the helium gap size and pressure between the thermal media and external tube.

Fig. 4 shows the temperature profile of the capsule in the radial direction. The temperature of the specimen region are higher about 70-80 ℃ than those of the holder region made of aluminum. The temperature of the helium gap region is decreased rapidly along the radial direction since the thermal conductivity of the helium gap is lower than other materials. The temperature by GENGTC isn't observed the down effect of temperature between thermal media and external tube. The surface temperature outside of external tube is similar all (38 ℃).

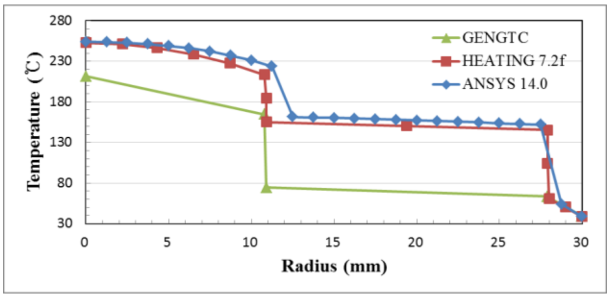

Fig. 4. Temperature profile of the capsule cross section model used in GENGTC, HEATING 7.2f and ANSYS 14.0.

The actual production standard of the bottom part of 1-stage area in 10M-01K capsule is different from capsule model. The gap1 is 0.065 mm and gas2 is 0.06 mm respectively. Table 4 shows the Temperature distribution calculated using three codes and the result values is compared with experimental. The temperature by ANSYS 14.0 code has the error rate of 5.35% and it is the most good consistent with experimental data.

Table 4: Temperature distribution calculated using GENGTC, HEATING 7.2f and ANSYS 14.0. The gap used in the calculation is the actual production standard (Gap1: 0.065 mm, Gap2: 0.06 mm).

	Center temp. (℃)	Surface temp. (℃)	Difference (%)
GENGTC	165.32	38.82	14.34
HEATING 7.2f	210.49	38.84	9.06
ANSYS 14.0	203.32	38.78	5.35
Experimental	193		

4. Conclusions

Ideal analysis method for thermal analysis is investigated to using several thermal analysis codes. To evaluate the correct temperature, the analysis results are compared with the irradiation test data of 10M-01K capsule. The temperature distribution for the center of specimen in capsule is influenced the gap between the thermal media and external tube and the helium pressure. At position of helium gap, the temperature of the capsule in the radial direction is rapidly decreased.

The temperatures by HEATING 7.2f and ANSYS 14.0 using finite element model are similar to each other. The temperature by ANSYS 14.0 code has the error rate of 5.35% and it is the best agreement with the irradiation test data of 10M-01K.

The results of this study will be helpful to thermal analysis of capsule design. To The reliability of the temperature, should be more study for thermal mechanism about irradiation capsule.

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