Thermal Analysis of 6-Hole Instrumented Capsules for irradiation Tests in the HANARO OR hole

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1. Introduction

With the global concentration on the development of next-generation nuclear systems and SMRs, the demand for neutron irradiation tests of their structural materials is surging rapidly[1]. The Korea Atomic Energy Research Institute (KAERI) operates the research reactor 'HANARO' and is currently designing an irradiation capsule for structural materials of i-SMR.

There are various irradiation holes in HANARO, such as, CT, IR and OR holes. For this test, the OR hole with comparably low neutron flux is planned to be used[2]. To enhance the efficiency of the irradiation tests, 6-hole specimen structure which have been only applied to the CT hole will be implemented in the OR hole. The CT hole is located at the center of the reactor core, so the variation in neutron flux and gamma heating rate across horizontal position is negligible within the irradiation capsule. However, the OR holes are located at the core periphery, introducing horizontal gradients in flux and gamma heating rates depending on the distance from the core. Therefore, a thorough computational analysis is required when designing the 6-hole instrumented capsule for OR hole irradiation tests. In this study, we conducted a thermal analysis focusing on the temperature distribution in the 6-hole irradiation capsule, induced by variations in gamma heating rates.

2. Methods and Results

2.1 Methods

Two main computation tools were utilized to evaluate the temperature distribution of the 6-hole irradiation capsule in the OR hole. First, to calculate the neutron flux and gamma heating rate, the representative nuclear analysis code MCNP 6.1 was utilized[3]. The analysis was performed for HANARO operating at 27 MW, and a full-core calculation was carried out using the KCODE mode of MCNP. In addition, the nuclear fuel burnup was calculated for the beginning, middle, and end of the cycle, with control rod positions set to 350 mm, 450 mm, and 550 mm, respectively. Second, the finite element method (FEM)-based software COMSOL Multiphysics was utilized to perform thermal analysis of the irradiation capsule. Thermal analysis was conducted for the cross-section of the irradiation capsule, with material properties for each structure referenced from GENGTC code.

2.2 Results

In the 6-hole instrumented capsule, total 60 Charpy specimens with dimension of 10 mm × 10 mm × 55 mm will be loaded. A schematic of the specimen arrangement within the irradiation capsule is shown in Fig. 1. The capsule consists of 5 axial levels in the vertical direction, with 6 specimen holes arranged on horizontal plane.

Table 1 shows the gamma heating rates of the components in the third stage of the irradiation capsule calculated via MCNP 6.1. The gamma heating rates shows radial gradients, with specimen #4 and #5, which are located closer to the core exhibiting higher values, while specimen #1 and #2 positioned further away have lower values.

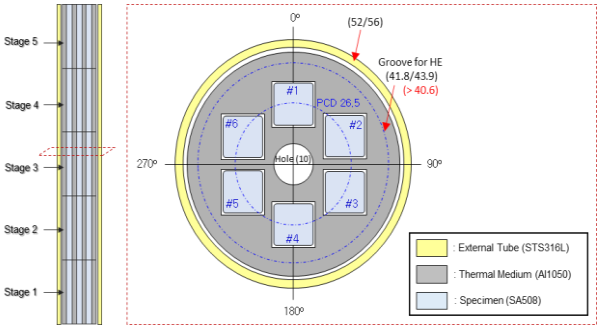


Fig. 1. A schematic of the specimen arrangement within the 6-hole instrumented irradiation capsule.

Position [cm]	Gamma heating rate [W/g]						
	#1	#2	#3	#4	#5	#6	TM*
8.55~11.4	1.29	1.30	1.38	1.54	1.58	1.44	1.11
5.7~8.55	1.35	1.34	1.45	1.59	1.64	1.50	
2.85~5.7	1.35	1.37	1.50	1.65	1.65	1.55	
0~2.85	1.34	1.35	1.45	1.62	1.66	1.54	

Table. 1. The gamma heating rates of the specimens and thermal media (TM) in the third stage of the irradiation capsule.

Thermal analysis results for the cross-section of the irradiation capsule, performed using COMSOL Multiphysics, are presented in Fig. 2. To maintain the specimen temperature within the target range of 290 ± 10℃, the thermal conductivity of helium was adjusted using a scaling factor of k=0.55. Under this condition, the specimen temperature ranged from a minimum 289.81℃ to a maximum of 300.87℃ and the temperature variation within each specimen was within approximately 5℃. The detailed temperature distribution of each specimen is shown in Fig. 2(b) and Table 2.

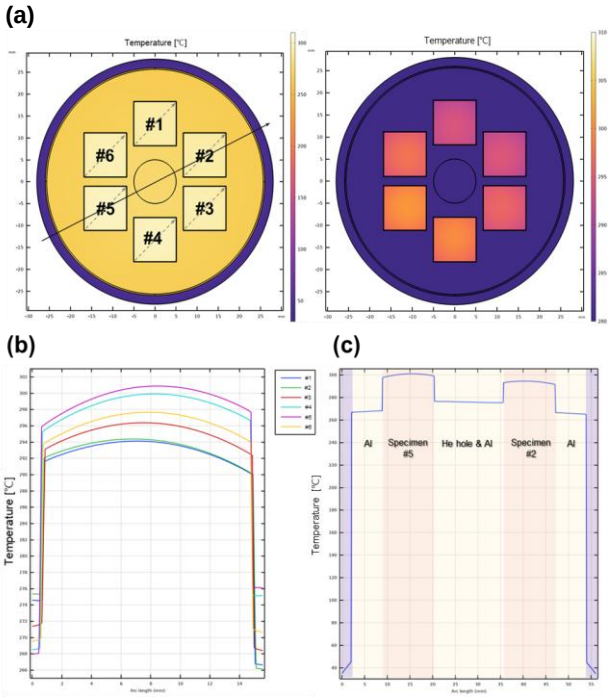


Fig. 2. Thermal analysis results for the cross-section of the third stage of irradiation capsule.

	#1	#2	#3	#4	#5	#6
Max.	294.13	294.37	296.41	299.93	300.87	297.70
Min.	289.81	289.86	291.75	294.99	295.71	292.84

Table 2. Maximum and minimum temperatures within specimen #1~#6.

3. Conclusions

Thermal analysis of 6-hole instrumented capsules for irradiation tests in the HANARO OR hole was performed utilizing FEM-based COMSOL Multiphysics. Although temperature variations were observed among the specimens due to the differences in gamma heating rates depending on their location, all specimen temperatures were confirmed to be within the target range. Nevertheless, as this represents the first application of the 6-hole structure in the OR hole, precise monitoring of the specimen temperatures during the irradiation test should be essentially conducted.

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