A Structural Analysis of the Circular Cylinder with Multi Holes under Thermal Loading

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ABSTRACT: A structural analysis of the circular cylinder with multi holes is performed using the finite element analysis program ANSYS. This structure is similar to the capsule used for material irradiation tests. The temperature distributions of the cylinder due to gamma heating are obtained and various parameters such as hole sizes, number of specimens and gap sizes between the holder and the specimen are considered in the analysis to estimate the temperature distributions. To assess the structural integrity of the capsule, the stress analysis under thermal loading is also performed. The analysis results show that the peak temperature occurred in the specimens, and was significantly dependent on gap sizes between the holder and the external tube or the specimen. The stress of the cylinder under thermal loading was lower than the allowable stress of the material used.

1. INTRODUCTION

The development program of advanced nuclear materials in Korea includes the experimental evaluation of irradiated materials exposed to the irradiation environment. In case of the non-integral test, these experiments can be conducted by using suitable capsule [1~5]. The capsule designed is inserted in seven vertical holes, and irradiated in the research reactor HANARO in Korea. Therefore, the material capsule should be designed to satisfy various requirements related to the nuclear, thermal and geometrical characteristics of the reactor in-core. The estimation of the exact characteristics of the cylinder with multi holes is very important; parametric studies are needed, and the effects of parameters such as hole and gap sizes, the number of specimens *etc.*, on the temperature and thermal stress of the capsule should be also investigated.

Harayama [6] *et al.* have proposed models to estimate the temperature distribution in a cylinder with multiple holes under thermal loading. Solving the steady-state heat conduction equation with practical assumptions develops an analytical expression of the temperature distribution in the cylinder. Generally, it is known that the gamma heat of the material at the middle of the reactor core is higher than that at the top and bottom in the longitudinal direction. The temperature distribution and thermal stress of the circular cylinder is obtained using the finite element analysis program, ANSYS[7] and is also discussed for the effects of various parameters on the thermal and mechanical characteristics of the capsule.

2. MODEL DESCRIPTION

The instrumented capsule mainbody, as shown in Fig. 1, consists of a holder with multi holes, test specimens and an external tube. The external tube is a cylindrical shell with 60 mm in external diameter, 2.0 mm in thickness and 870 mm in length. The mainbody of the capsule is divided into 5 stages in which an independent heater and thermocouples are installed. The specimen holder is a cylinder with many specimen holes and a length of 120mm, and it is used for fixing irradiation test specimens. The gaps are designed to effectively control the temperature of the specimen between the holder and the specimens and between the holder and the external tube.

Fig. 1 Schematic view of the instrumented capsule mainbody.

Table 1 presents the geometrical data of a circular cylinder with multi holes. In this paper, the dimensions of the capsule's external tube and the outer radius of the holder are assumed to be fixed, but the size of the center hole and the specimen are considered as variables. The specimen holder is assumed to have even specimen holes and a center hole, and have equal spaces between the specimens in a circumferential direction. The centers of the specimen holes are located at an equal distance of 16.74mm from the center of the holder.

Table 1. Geometrical data of a circular cylinder with multi holes

Descriptions	Symbol	Dimension (mm)
Capsule outer radius	R_{co}	30.0
Capsule inner radius	R_{ci}	28.0
Holder outer radius	R_o	27.9
Holder inner radius	R_i	Variable
Specimen radius	R_a	Variable

3. FINITE ELEMENT ANALYSIS

Modeling

The temperature calculation and thermal stress analysis of the capsule under thermal loading are performed using a finite element analysis program, ANSYS. To analyze the temperature and thermal stress at the same time, the analysis model for the circular cylinder with multi holes is generated by PLANE13 element with 2D thermal and structural field capability with coupling between the fields. The cylinder in an arbitrary cross section in the axial direction is modeled as a quarter of the whole cross section because it has a symmetric shape. Fig. 2 shows the two-dimensional analysis model of a quarter section having 4-specimens and one center hole. This model consists of four main parts; the external tube, the holder, the specimens and the helium gaps. Table 2 shows the material properties with the temperature of the capsule used for the calculation of the temperature and the stress.

Fig. 2 Typical finite element model of the circular cylinder.

Force and boundary conditions

In the reactor in-core, the specimens, the holder and the external tube of the capsule work as a heat source due to γ -ray irradiation. The heat generation rate of each material is changed with the axial position of the reactor in-core due to the difference in heat flux distribution. It is generally known that the γ -flux in the middle of the reactor core has the highest value. To analyze the temperature and the thermal stress for the capsule structure with multi holes, the force that was considered in this study is a heat generation density of the specimen including the external tube and the holder by γ -heating. The gamma heat for the aluminum holder and the stainless specimen in Watts per cubic meter is assumed as follows;

- Aluminum holder (A1050): $21.7 \times 10^6 \text{ (W/m}^3\text{)}$
- Specimen/External tube (SUS 304): $37.0 \times 10^6 \text{ (W/m}^3\text{)}$

The boundary conditions in the FE analysis are symmetric in the x and y axis in the model.

The surface temperature, 50 °C, is considered as a temperature boundary condition at the outer surface of the capsule’s external tube, and the coolant temperature in the reactor is about 40 °C.

Table 2. Material properties with the temperature.

Temp.(°C)		50	100	200	300
Properties					
Young’s modulus (E) GPa	A1050	68.96	65.51	55.16	34.48
	SUS304	200	194	186	179
Thermal expansion coefficient (α) 1×10 ⁻⁶ /°C	A1050	23.4	23.8	24.5	25.5
	SUS304	15.0	16.0	17.0	19.0
Thermal conductivity (κ) W/m °C	A1050	203.0	206.33	215.26	230.39
	SUS304	16.0	16.0	17.0	17.0
	Helium	0.143	0.1747	0.2049	0.2336
Mass density (ρ) kg/m ³	A1050	2710			
	SUS304	7850			
Poisson’s ratio (ν)	A1050	0.33			
	SUS304	0.30			

4. RESULTS AND DISCUSSIONS

The temperature distribution and thermal stress of a circular cylinder with multi holes are obtained by finite element analysis. To obtain the characteristics of those structures, the various parameters such as specimen sizes, the number of specimens and gap sizes between the holder and the specimen are considered in the structural analysis.

Fig. 3 shows the effects of the helium gap size between the holder and the specimen. The model in this case has the specimen $R_i/R_o=0.2$ in the center hole and a 0.1mm gap between the external tube and the holder. When the gap is as small as 0.05mm, the maximum temperature of the specimen is about 306 °C. The maximum temperature is increased linearly with an increasing gap size. If the gap size is increased by 0.05mm, the temperature increases about 20 °C because of a poor heat transfer between the holder and the specimen of the capsule due to the increased gap size.

The effect of the number of the specimens on the temperature is shown in Fig. 4. The radius of the specimens considered is 5.58 mm($R_a/R_o=0.2$) and the effects of the number of specimens inserted at the specimen hole are shown in this figure. The maximum temperature and the stress intensity increase by increasing the number of specimens, regardless of the specimen in the center hole.

In case there are only four specimens at the specimen hole without a center hole, the maximum temperature and the stress intensity are discovered to be 330 °C and 74 MPa, respectively. The increase in temperature and stress are calculated to be 30 °C and 6.3 Mpa, respectively, when the number of specimens increases from 4 to 8. The maximum stress occurred at the outer surface of the external tube because the temperature gradient between the inner and the outer surface of the external tube is larger than other parts. When the specimen is inserted in the center hole, the temperature increases by about 7 percent from the

case where the center hole has no specimen.

Fig. 3 Effects of the gap size between the holder and the specimen.

Fig. 4 Maximum temperature and stress intensity with the number of specimens in the specimen hole.

Fig. 5 shows the temperature and the stress with sizes of the specimen inserted in 4-specimen holes. The specimen of the radius, 5.58mm in the center hole is fixed while the radius of the specimen in the specimen hole is considered as varying in the range of 2.79 to 8.37mm range. When the radius ratio(R_a/R_o) of the specimen is quite small as 0.1 the maximum temperature and the stress intensity are 336 °C and 73.5 MPa, respectively. The maximum temperature and the stress with increasing radius ratios are increased. Results in the case of the radius ratio, 0.2, have a larger value of 7.5 and 6 percent than in the case of

that of 0.1 because the heat generation density is increased as the size of the specimen increases.

Fig. 5 Maximum temperature and stress intensity with various sizes of the specimen.

Fig. 6(a) shows the temperature distribution of the cylinder with specimens inserted in the center and 4-specimen holes. The maximum temperature has occurred in the specimens. The temperature distribution due to the annulus helium gap that exists between the holder and specimen is decreased rapidly along the radial and circumferential direction. However, the temperature gradient of each specimen and holder is very small because the thermal conductivity of materials used is greater than that of other metals. The temperature distribution of the circular cylinder with multi holes in case of other models is the same as that of Fig. 6(a), except the value of the temperature is slightly different.

Fig. 6 Temperature distribution and stress contour of the cylinder with specimens in the center and 4-specimen holes.

The stress contour for the same model is shown in Fig. 6(b), and the maximum stress occurred in the external tube of the cylinder. For the various other models, similar tendency of the stress contour is observed, and the stress induced by thermal loading are about 74~86 MPa that satisfy the allowable stress.

5. CONCLUSIONS

The results of the analysis for the circular cylinder with multi holes shows that the peak temperature in the circular cylinder occurred in the specimens inserted in the center or specimen holes, and is significantly effected by gap sizes between the holder and the specimen. When sizes and the number of specimens are increased, the maximum temperature is varied in the 300~400 °C range. The maximum stress of the cylinder due to the thermal loading is induced in the specimen or external tube made of stainless steel. The values of the thermal stress are about 74~86 MPa, and those are lower than the allowable stress for the material used. It is expected that the results presented in this paper will be used for design of the capsule for material irradiation tests.

ACKNOWLEDGEMENT

This project has been carried out under the Nuclear R&D Program by MOST.

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