High Temperature Test Possibility at the HANARO Out-core Region through a Thermal Analysis

Young-Hwan Kang, Myung-Hwan Choi, Man-Soon Cho, Kee-Nam Choo, Bong Goo Kim
Korea Atomic Energy Research Institute, P.O. Box 105, Yusong, Daejon, 305-600, yhkang2@kaeri.re.kr

1. Introduction

The development of an advanced reactor system such as a next generation nuclear plant and other generation IV systems require new fuels, claddings, and structural materials. To characterize the performance of these new materials, it is necessary for us to have a leading-edge technology to satisfy the specific test requirements such as the conditions of high neutron exposures and high operating temperatures. Thus, nuclear data on HANARO's vertical test holes have been gathered and reviewed to evaluate the usability of the test holes located at the out-core zone of HANARO. In 2007, neutron flux levels of the concerned test holes and the gamma heat of the specimens and two different specimen holder materials of Al and Mo at the concerned test hole were obtained to enhance the utilization of the HANARO reactor and to develop new design concepts for high temperature irradiation tests [1]. Based on the data, a series of thermal analyses was implemented to provide a reasonable demonstration and guidance on limitations or application.

2. Model Description

The capsule mainbody consists of specimen holders, test specimens and an external tube. The external tube is a cylindrical shell with 56 mm in external diameter, 2.0 mm in thickness and 870 mm in length. The mainbody of a capsule is divided into 5 stages of holders in which an independent heater and thermocouples are installed. The specimen holder with a length of 120mm is a cylinder with 4 specimen holes.

In this paper, the dimensions of the capsule's external tube, the outer radius of a holder, the size of the center hole, gap size between a holder and the specimens, and the specimen size are assumed to be fixed, but the gaps which are designed to effectively control the temperature of the specimen between a holder and the external tube and two different holder materials of Al and Mo are considered as variables.

3. Finite Element Analysis

3.1 Modeling

The temperature calculations for a capsule are performed using a finite element analysis program, ANSYS [2]. The analysis model for the circular cylinder with multi holes is generated by the coupled-field elements of PLANE223 with a 2D thermal field. Fig. 1 shows the two-dimensional analysis model for a quarter sections with 4-specimens and one center hole. This model consists of four main parts; an external tube, a holder, the specimens and the helium gaps. Table 1 shows the material properties at different temperatures for the calculations of the temperatures.

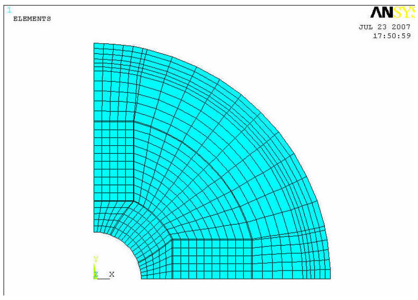

Fig. 1 Typical finite element model of the circular cylinder.

Table 1. Material properties with the temperature.

Properties \ Temp.(°C)		50	100	200	300
Young's modulus (E) GPa	A1050	67.79	65.61	55.16	34.48
	Mo	329	320	300	280
	SUS304	200	194	186	179
Thermal expansion Coeff. (α) $1\times10^{-6}/^{o}C$	A1050	23.29	23.78	24.76	25.73
	Mo	5.18	5,.22	5.29	5.37
	SUS304	17.14	17.27	17.54	17.82
Thermal conductivity (κ) W/m °C	A1050	204.0	206.3	215.2	230.4
	Mo	126.1	123.3	118.5	114.4
	SUS304	15.54	16.18	17.46	18.74
	Helium	0.143	0.174	0.204	0.233
Mass density (ρ) kg/m^3	A1050	2710			
	Mo	10200			
	SUS304	7850			

3.2 Boundary conditions

In the reactor, the specimens, a holder and the external tube of a capsule act as a heat source due to a high γ-ray flux. The heat generation rate of each material is changed with the axial position of the reactor in-core due to the difference in the heat flux distribution. The gamma heat data for the aluminum and molybdenum holders and stainless specimen are determined based on a previous 01S-01K experiment [3].

The boundary conditions in the FE analysis are symmetric for the x and y axis in the model. Heat transfer coefficient used in this study is 0.88 $KW/m^2.C$ [4] and the reactor coolant temperature is about 40 ^oC.

4. Results and Discussions

To obtain the thermal characteristics of a capsule, various parameters such as two different holder materials and the gap sizes between the holder and the external tube are considered for the thermal analysis. The temperature data for a circular cylinder with multi holes is obtained by finite element analysis.

Fig. 2 shows the effects of the helium gap size between the Al holder and the external tube of the capsule on the specimen temperature. The maximum temperature of the specimen is increased linearly with an increasing gap size and is 663 ^oC at the IP9 hole which is equivalent to a gamma heat of 0.5 W/g. This means that the out-of-core region could be used for high temperature irradiation tests. However, as the melting point of Al is around 660°C, the structural integrity of the holder during an irradiation is not maintained. Thus, an aluminum holder material could be used for the intermediate temperature tests (350-600 ^oC) even in the IP holes of HANARO.

Fig. 3 shows the effects of the helium gap size between the Mo holder and the external tube. The maximum temperature is also increased linearly with an increasing gap size and is 975 ^oC at the IP11 hole which is equivalent to a gamma heat of 0.5 W/g. This means that the out-of-core region could be used for high temperature irradiation tests. Furthermore, Mo can withstand an extreme temperature without significantly expanding and softening due to its melting point of 2623°C. Thus, a molybdenum holder material could be used for very high temperature tests (>900 ^oC) even in the IP holes of HANARO.

5. Conclusions

From the thermal analysis of the circular cylinder with different holder materials, the major findings are delineated as below.

1) Test holes located at the out-of-core regions of the HANARO reactor could be utilized for the material tests related to the SWR and LMR by using an Al holder material, and for the high temperature irradiation tests related to the VHTR and MSR by using a Mo holder material.
2) It is expected that the results presented in this paper will be used for a design of the capsule for the high temperature material irradiation tests.

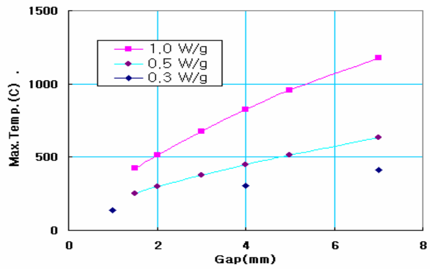

Fig. 2 Effects of the He gap size between the Al holder and the external tube of a capsule.

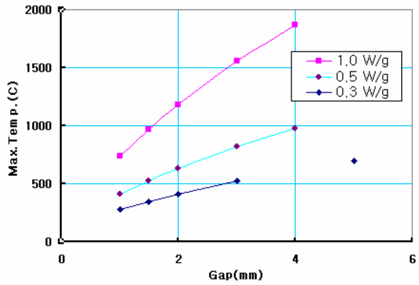

Fig. 3 Effects of the He gap size between the Mo holder and the external tube of a capsule.

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