The gap size effects on the specimen temperature for an LBE Capsule development

Y. H. Kang, M. H. Choi, S. J. Park, Y. T. Shin, S. Y. Oh, M. S. Cho, K. N. Choo, B. G. Kim

Korea Atomic Energy Research Institute, P.O. Box 105, Yusong, Daejon, 305-600, yhkang2@kaeri.re.kr

1. Introduction

The development of a SFR as one of the advanced reactor systems requires new fuels, claddings, and structural materials. To characterize the performance of these new materials, it is necessary for us to have leading-edge technology to satisfy the specific test requirements such as the conditions of high neutron exposures (~ 200 dpa), high operating temperatures (390-700℃) and a specific chemistry (Na). Thus, literature surveys about the system design characteristics of various irradiation devices being developed or used in the foreign research reactors(i.e. ATR[1], MITR[2], JHR[3]), which are helpful in understanding the key issues for the on-going R&D programs related to a SFR, were conducted to develop new design concepts. For the application of the high temperature irradiation tests in the HANARO reactor, the candidate holder material should have a high gamma heating rate which is needed to obtain the required specimen temperatures, and results a small temperature difference within the specimens. From an extensive survey of the literature, one of the candidate specimen holder materials is selected as an LBE (lead bismuth eutectic alloy, 44.5w/o Pb+55.5 w/o Bi) for the high temperature irradiation devices.

For the conceptual design of a LBE capsule, a series of thermal analyses was implemented to provide a reasonable demonstration and guidance on its limitations or applications.

2. LBE Capsule Description

An irradiation using an LBE capsule is expected to begin in 2010 for the SFR fuel and materials tests. The test will be performed in the OR-5 test position of the HANARO reactor at KAERI. The overall shape of an LBE capsule is quite similar to the present standard material capsule except for the use of an LBE as a thermal media. The main body of the capsule, which is about 56mm in diameter and approximately 876 mm long, consists of specimen holders with structural components, test specimens, an LBE container and an external tube. In order to maximize the specimen space in a capsule, four columns of 10x10mm specimens are placed in a rectangular array within an LBE cylinder as shown in Fig 1. A gas gap exists between the LBE container and the external tube for heat transfer purposes.

In this paper, the capsule's outside diameter, the gap between the holder and the specimens, and the specimen are assumed to be fixed, but the gap between the LBE container and the external tube which are designed to effectively control the temperature of the specimen 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 [4]. The analysis model for the circular cylinder with multi specimens is generated by the coupled-field elements of PLANE223 with a 2-D structural-thermal field. Fig. 1 shows the two-dimensional analysis model for a quarter section with 4-specimens. However, the simple structural components for supporting the specimens in an LBE container are not considered in this model. The LBE zone was modeled as a conductive region. Table 1 shows the material properties at different temperatures for the calculations of the temperatures.

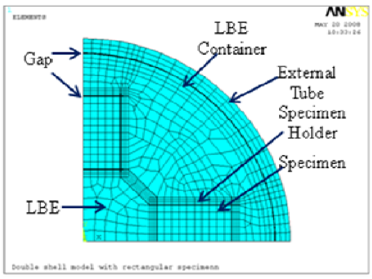

Fig. 1 Typical finite element model of the circular cylinder.

Table 1. Material properties of LBE

Properties \ Temp.(°C)	200	400	600	800
Thermal expansion Coeff. (α) 1×10^{-6}/°C	1.26	1.29	1.33	1.37
Thermal conductivity (κ) W/m°C	11.7	13.7	15.7	17.7
Mass density(ρ)kg/m^{3}k	10.46	10.21	9.96	9.71

3.2 Boundary conditions

In the reactor, the specimens, the LBE, and the internal and the external tube of a capsule act as a heat source due to a high γ-ray flux. Heating rates for the material specimens, the LBE, and for the structural materials were obtained from the KAERI neutronic analysis group for the LBE capsule [5]. The gamma heat values were for a reactor power of 30MW.

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 33.0 $KW/m^2.C$ [6] and the reactor coolant temperature is about 40 ^oC.

4. Results and Discussions

To obtain the thermal characteristics of an LBE capsule, gap sizes from 0.1 to 1.0 mm are considered. The temperature data for a circular cylinder with multi specimens are obtained by a finite element analysis.

Fig. 2 shows the temperature distribution of an LBE capsule with a wall thickness of 1.0 mm and a gap size of 1.5 mm in the highest gamma flux region and its temperature profile in the radial direction. The maximum temperature is around 1125 ^oC at a specimen. The temperature profile at the specimen positions is found to be relatively uniform as compared with the data of a typical capsule using a solid thermal media. But, the temperature distribution near a gap is decreased rapidly like a typical capsule using solid thermal media. Especially the effect of the gap between the internal and the external tube is larger than that between the specimen and the holder, and it has an important influence on the control of the temperature of a specimen.

Fig. 3 shows the effects of the gap size between the LBE tube 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 1166 ^oC at the OR5 hole. The surface temperature and temperature differences within the same specimen are nearly constant with an increasing gap size from 0.1 to 1.0 mm. In addition, due to the unique physico-chemical and stable nuclear properties of an LBE, it could be used as a thermal media for very high temperature tests (>900 ^oC) in the OR holes of HANARO.

5. Conclusions

Based on the performed evaluations, it is concluded that the conceptual design of an LBE capsule will meet the test requirements for a high temperature irradiation of new materials in the HANARO reactor. Final design activities will include an analysis with control rods in the normal operating range to verify that the heat rates do not exceed the acceptable values, and to correctly place the experiment relative to the reactor centerline.

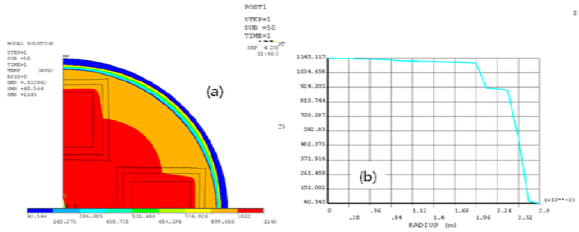

Fig. 2 Temperature distribution (a) and temperature profile in the radial direction (b)

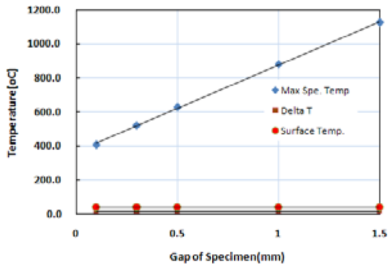

Fig. 3 Effects of the He gap size between the Mo holder and the external tube of a capsule.

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