Preliminary Thermal Analysis of an LBE Capsule with Multi Specimens

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1. Introduction

A liquid metal capsule device offers advantages compared with typical solid metal capsules [1] that were used for an irradiation for PWR reactor material, including smaller and more uniform temperature gradients. The liquid metal technology has become accepted as an alternative way for use in an application of high temperature irradiation for Gen IV reactor material development [2]. Recent study on heat transfer experiment of an LBE capsule [3] have shown that measured temperature on the specimens showed the specimen temperature of the mock-up increased linearly with an increase of heat input. The regional temperature distribution of the mock-up in the horizontal direction was relatively uniform and less than 30℃, which can provide a more favorable environment for a high-temperature test, and a maximum controllable temperature range with variations in the mixing gas ratio was 150. This work highlighted only the heat transfer capability of an LBE capsule with a single heater as a simulated specimen in a liquid metal medium. Hence, a liquid metal capsule with multi specimen sets has been designed. A thermal analysis using ANSYS program was performed to understand the effect of specimen array on the temperature profile of the capsule.

2. The design of an LBE Capsule

The overall shape of a new LBE capsule is quite similar to the previous LBE capsule [4-6] except for the number of specimen sets or heat flux per unit volume. For an effective temperature control and safety in a research reactor, the design concept of the capsule was also created by applying a double containment concept. From a series of thermal analyses [4, 5], the dimensions of the capsule were determined. The main body of the capsule, which is about 56mm in diameter, consists of 3 heaters of 7 kW each as a simulated specimen, LBE as a thermal media, an internal tube as an LBE container, and an external tube. In order to simulate the specimen space such as fuel or materials in a capsule, three heaters were considered and assumed to be placed at the center of an LBE cylinder. For heat transfer purposes a gas gap exists between the LBE container and the external tube. The dimensions of the capsule are shown in Table 1.

Table 1. Design Data of a New Capsule

Main body	External tube diameter/thickness(mm)	56/2
	Internal tube diameter/thickness(mm)	50/2
	Gap between external and internal tube(mm)	1
Heater	Outside diameter(mm)	19
	Power(kW)	7
	Hot length(cm)	89
Thermal media	LBE(44.5w/o Pb+55.5 w/o Bi)(kg)	10

3. Thermal Analysis

The temperature calculations for a newly designed capsule are performed using a finite element analysis program, ANSYS [7]. The analysis model for the circular cylinder of double containment concept is generated by the coupled-field elements of PLANE223 with a 2-D structural-thermal field. Fig. 2 shows the two-dimensional analysis model for a new capsule with a heater as a heat source. 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. However, for this numerical study heating rates for the material specimens, the LBE, and the structural materials were not considered except for only the heat flux of a heater ($27.5kW/m^3$).

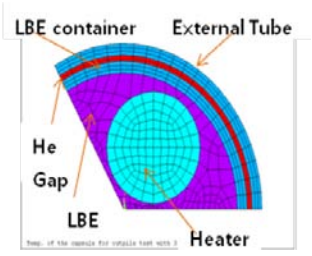
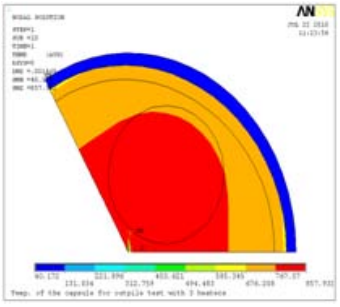


Fig. 1 Finite element model

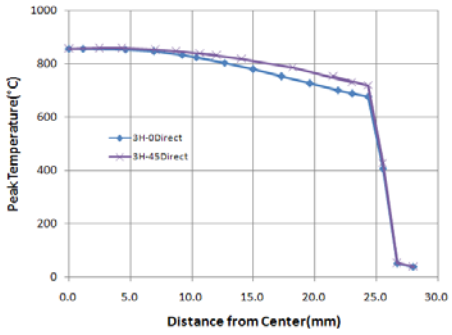
The boundary conditions in the FE analysis are symmetrical for the 0- and 120-degree in the cylindrical coordinates. The heat transfer coefficient used in this study is 33.0 KW/m^2.C [8], which will be evaluated from the heat transfer experiments, and the reactor coolant temperature is 40 ^{o}C.

Fig. 2 shows the temperature distribution of a newly designed LBE capsule and its temperature profile in the radial direction. As seen in the figure, the maximum temperature is around 858 ^{o}C at a heater surface and small temperature gradient (26 ^{o}C) arises within a specimen. But, the temperature distribution near a gap is also decreased rapidly like a previous LBE capsule with a single specimen.

Although the heat flux per unit volume decrease from 43.7 to 27.5 kw/m^3, the maximum temperature of the specimen is close to the previous data of 869 ^{o}C, and temperature difference within the specimen is also small compared with that of 30 ^{o}C. This trend is believed to be related to the good thermal properties of LBE [6]. This result indicates that the new concept has the potential as a high temperature testing device.



(a)



(b)

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

4. Conclusions

A new concept of an LBE capsule with multi heat sources was proposed for an application of high temperature irradiation tests. The effects of specimen space or relative heat flux on the temperature gradient of the specimens are investigated. It was demonstrated that the concept has the potential as a high temperature testing device and can provide a more favorable choice for the high temperature tests. An LBE capsule mockup will be prepared to evaluate quantitatively the analysis results through a heat transfer test.

ACKNOWLEDGEMENTS

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