Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 19-20, 2022

Thermal Resistance Analysis for Estimating Thermal Conductivity of UO_2 – 5 vol% Mo Microcell Pellet

Heung Soo Lee[a*], Dong-Joo Kim[a], Dong Seok Kim[a], Jae Ho Yang[a], Ji-Hae Yoon[a]
[a]*Nuclear Fuel Safety Research Division, Korea Atomic Energy Research Institute, 111, Daedeok-daero 989Beon-gil, Yuseong-gu, Daejeon, 34057, South Korea*
[*]*Corresponding author: hslee88@kaeri.re.kr*

1. Introduction

In nuclear fuel of light water reactor (LWR), the high temperature can be caused to decrease pellet structure stability by increasing thermal stresses [1]. Thus, in order to overcome this potential problem, the thermal conductivity of fuel pellets need to enhance [2]. For improving thermal conductivity of fuel pellets, various studies have been developed. In particular, composite nuclear fuels employing heterogeneous materials with high thermal conductivity are attracting attention, and among them, microcell nuclear fuels in which metal Mo is arranged in a network in UO_2 showed thermal conductivity about 1.6 times as high as that of UO_2 at 1000˚C [3,4]. The characteristics of thermal conductivity in microcell fuel pellets have been confirmed through experiments and computer simulations. Specifically, the content of metallic material and the aspect ratio of microcell are important factors in determining the thermal conductivity characteristics of the metallic microcell nuclear fuel [4]. In this study, the thermal conductivity of the microcell was predicted using the thermal resistance of the unit cubic cell model.

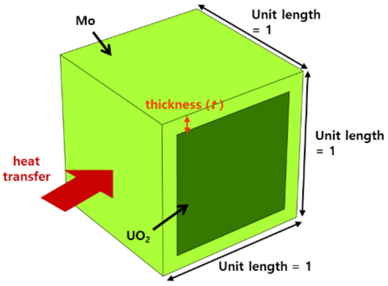

Fig. 1. Designed unit cubic cell model of UO_2-Mo microcell pellet for calculating thermal resistance.

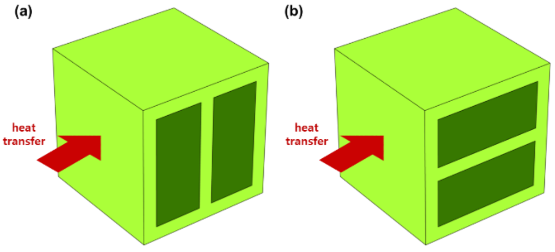

Fig. 2. Schematics of unit cubic cell models as microcell aspect ratio. The microcell aspect ratio of (a) 0.5 and (b) 2.0.

2. Unit cubic cell model

It is possible to predict the effective thermal conductivity of a composite material having a repetitive structure by calculating the overall thermal resistance [5,6]. To calculate thermal resistance of cubic cell model, the Fourier's law equation was used (Eq (1)).

$$q = \frac{kA}{l}(\Delta T) = \frac{1}{R}(\Delta T) \quad (1)$$

, where q is the heat transfer rate (W), k is material thermal conductivity (W/m·K), A is the cross section area of heat flux, l is the length of domain, ΔT is the temperature difference (K) and R is thermal resistance (m·K/W). By normalizing the length of a side of cubic model as unit length (=1), the reciprocal of overall thermal resistance was calculated as the effective thermal conductivity (Eq (2)).

$$R = \frac{l}{k_{eff}A} = \frac{1}{k_{eff}} \quad (2)$$

, where k_{eff} is effective thermal conductivity of unit cubic model (W/m·K). In here, a unit cubic cell model as shown in Fig. 1 was devised to calculate the thermal resistance of a microcell. As the length of each side of the cubic model was fixed to unit length, the thickness and arrangement of metal walls could reflect the metal content and the aspect ratio. The following assumptions were considered in calculating the thermal resistance of the unit cubic cell model. (1) The unidirectional heat transfer in unit cubic model was consider, (2) no defect in unit cubic cell model, (3) heat transfers of convection and radiation were negligible, (4) the interface between UO_2 and Mo was perfect, and (5) the Mo wall is uniform in unit cubic cell model. Since the aspect ratio of UO_2 – 5 vol% Mo microcell is known to be 0.5 and 2.0 in the axial and radial directions, respectively, the same aspect ratios were considered in the unit cubic models (Fig. 2).

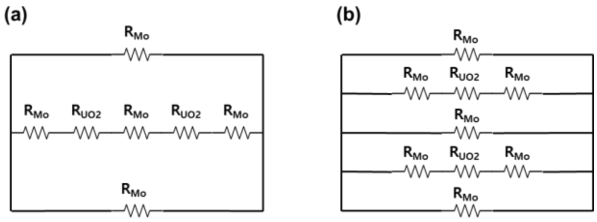

Fig. 3. Circuit diagram of thermal resistance of aspect ratio (a) 0.5 and (b) 2.0.

3. Result and discussion

Through the unit cubic cell model in Fig. 2, the overall thermal resistance was calculated of UO_2 – 5 vol% Mo microcell at 1000˚C. The overall thermal resistance of the unit cubic cell model was configured as shown in Fig. 3. Each thermal resistance element could be expressed by material thermal conductivity, unit length and Mo wall thickness, and when the thickness was calculated by reflecting the Mo content as 5 vol%, both models are 0.008428. The effective thermal conductivities, the reciprocal of the thermal resistance calculated using the unit cubic model, were shown in Fig. 4. The result calculated by computer simulation and the thermal resistance method of unit cubic cell model were consistent within the relative error of 0.4%. In conclusion, it was confirmed that the effective thermal conductivity of microcell fuel pellets according to content of metallic material and aspect ratio could be predicted through the calculation of overall thermal resistance in the unit cubic model.

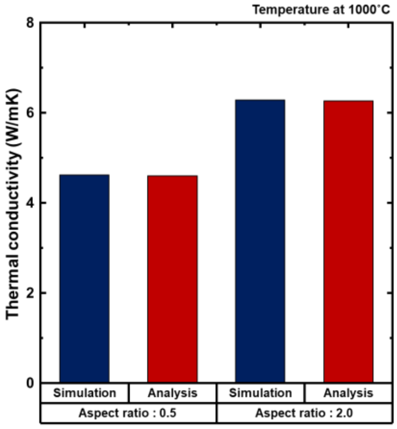

Fig. 4. Comparison of effective thermal conductivity of computer simulation Lee et al. [4] and unit cubic model in UO_2 – 5 vol% Mo microcell pellet.

4. Conclusion

We designed a unit cubic model to predict the effective thermal conductivity of metallic UO_2 microcell fuel pellets using thermal resistance. Through this model, the effective thermal conductivity of AR 0.5 and 2.0 could be predicted similarly to simulation results. The thermal conductivity prediction method through the thermal resistance calculation of the cubic model may reduce the computing load and may be applied to composite materials made of materials other than Mo.

REFERENCES

[1] K.A. Terrani, D. Wang, L.J. Ott, R.O. Montgomery, The effect of fuel thermal conductivity on the behavior of LWR cores during loss-of-coolant accidents, Journal of Nuclear Materials, 448 (2014) 512-519.

[2] S.J. Zinkle, K.A. Terrani, J.C. Gehin, L.J. Ott, L.L. Snead, Accident tolerant fuels for LWRs: a perspective, Journal of Nuclear Materials, 448 (2014) 374-379.

[3] D.J. Kim, Y.W. Rhee, J.H. Kim, K.S. Kim, J.S. Oh, J.H. Yang, Y.H. Koo, K.W. Song, Fabrication of micro-cell UO_2-Mo pellet with enhanced thermal conductivity, Journal of Nuclear Materials, 462 (2015) 289-295.

[4] H.S. Lee, D.J. Kim, S.W. Kim, J.H. Yang, Y.H. Koo, D.R. Kim, Numerical characterization of micro-cell UO_2-Mo pellet for enhanced thermal performance, Journal of Nuclear Materials, 477 (2016) 88-94.

[5] S.C. Cheng, R.I. Vachon, The prediction of the thermal conductivity of two and three phase solid heterogeneous mixtures, International Journal of Heat and Mass Transfer, 12 (1969) 249-264.

[6] C.C. Tee, N. Yu, H. Li, Modeling the overall heat conductive and convective properties of open-cell graphite foam, Modeling and Simulation in Materials Science and Engineering 16 (2008) 075006.