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Technical Note

A further discussion on the effective thermal conductivity of metal foam: An improved model

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ABSTRACT

In this study, we explain the causes and effects of the geometrical impossible result encountered in the widely adopted tetrakaidecahedron model (Boomsma and Poulikakos, 2001; Dai et al., 2010) for the effective thermal conductivities (ETCs) of metal foam. The geometrical impossible result is successfully eliminated by accounting for the size variation of the node with porosity. The improved model provides predictions of ETCs that are more precise than available models. For aluminum foams ($k_s = 218$ W m^{-1}K^{-1}) using water and air as fluid media, the relative root-mean-square (RMS) deviation of the present predictions from the experimental data is about 5.3%; for the reticulated vitreous carbon (RVC) foams ($k_s = 8.5$ W m^{-1}K^{-1}), the relative RMS deviation is about 7.4%.

1. Introduction

High-porosity metal foams are promising materials for thermal management applications. Since the effective thermal conductivity (ETC) is one of their most important thermal properties, an accurate evaluation of it becomes especially important. Studies on modeling the ETC of metal foams have been carried out numerically [1–3], experimentally [4–6] and analytically [5–12]. Among these approaches, the analytical approaches are less time consuming but more universal, and have attracted the attention of investigators. A review of the analytical approaches for prediction of the ETC has been conducted by Coquard and Baillis [13,14], and Randrianalisoa and Baillis [15].

One of the most widely used analytical approaches was developed by Boomsma and Poulikakos [10] who first used the idealized three dimensional tetrakaidecahedron model to predict the metal foam ETC. Predictions were reported to accurately match the experimental data. However, Dai et al. [11] pointed out a few problems in their work. Dai et al. [11] extended the model by accounting for the ligament orientation. Predictions of the extended model were compared with the experimental data [5], and a relative RMS deviation of about 12% was observed. The deviation indicated that there was still room for improvement. In addition, results obtained in Ref. [11] showed that, as the porosity decreased, the diameter of the ligament became longer than the length of the node, which leaded to a geometrical impossible result. The diameter of the ligament should be shorter than the length of the node (see Fig. 1), which was a basic assumption in the development of the model.

In this paper, the tetrakaidecahedron model originally proposed by Boomsma and Poulikakos [10] and later extended by Dai et al. [11] is first discussed. The causes and effects of the geometrical impossible results are examined and explained. The model is further improved by accounting for the size variation of the nodes. We then show that the geometrical impossible results are eliminated. Lastly, predictions of our improved model are compared with several other analytical solutions as well as experimental data available in literature. It is shown that the current model has a steadily high precision in predicting the ETC of high porosity foams with a wide range of phase conductivity ratios (k_s/k_f).

2. Calculation of the effective thermal conductivity

It is important to note that, for a better understanding of the present discussion, reader should be familiar with the analytical approaches developed by Boomsma and Poulikakos [10], and Dai et al. [11]. Therefore, in this part of the discussion, we give a brief review of how the ETC is calculated using their approaches. For more detailed discussions, reader may refer to Refs. [10,11].

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Nomenclature

a	foam ligament radius (m)
d	dimensionless foam ligament radius
e	dimensionless cubic node length
f	function
k	thermal conductivity (W m^{-1} K^{-1})
L	ligament length (m)
R	thermal resistance (m^2 K W^{-1})
r	cubic node length (m)
V	volume (m^3)

Subscripts

A	unit cell layer
B	unit cell layer
C	unit cell layer
D	unit cell layer
eff	effective
f	fluid
i	A, B, C, D
s	solid

Greek symbol

ε	porosity

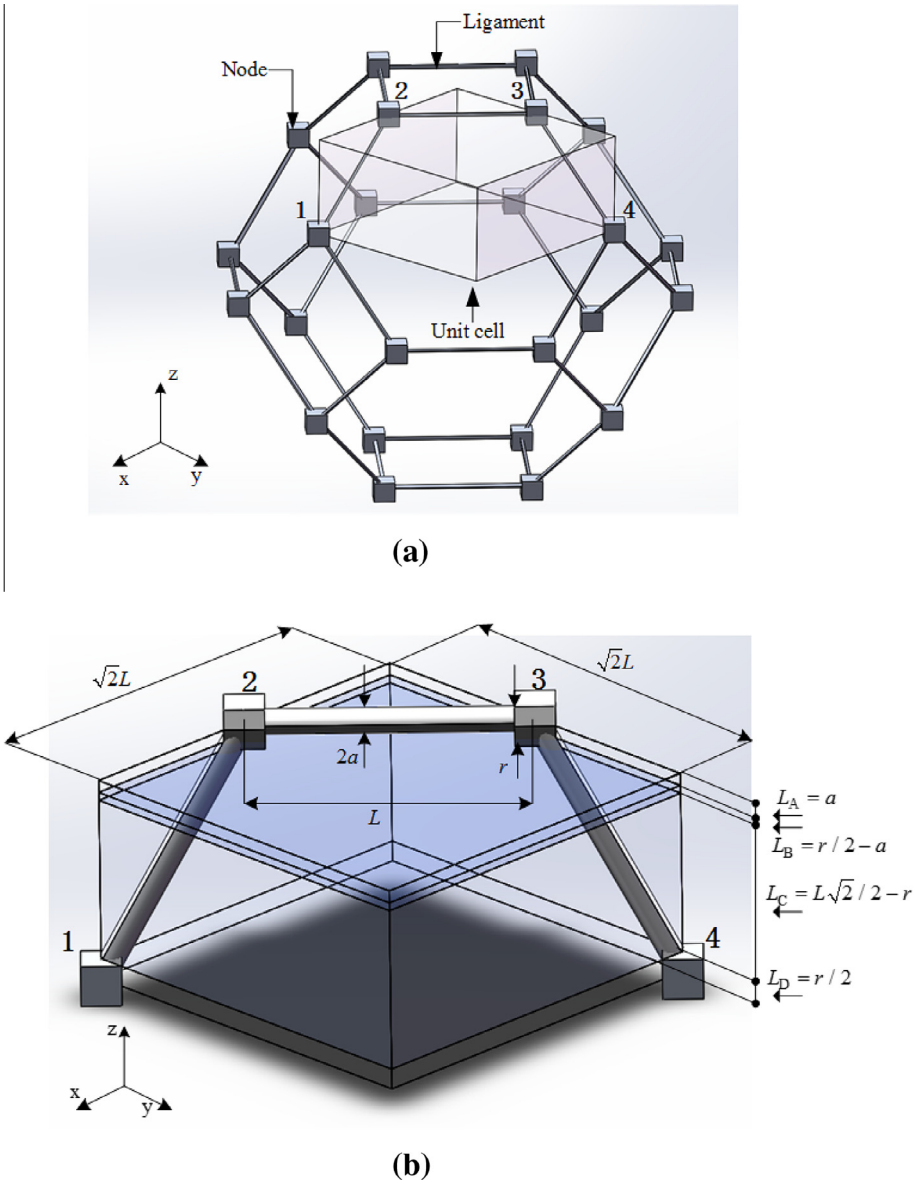

Fig. 1. (a) The tetrakaidecahedron model and (b) four distinctive layers for the unit cell.