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Homogeneous phase and multi-phase approaches for modeling radiative transfer in foams

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A B S T R A C T

The aim of the present study is to investigate the suitability of two different continuum-based approaches for the modeling of the radiative transfer in two types of foams lying in the geometric optic regime: open cell metal foams and closed cell polymer foams. The two approaches are the commonly used Homogeneous Phase Approach (HPA) and the Multi-Phase Approach (MPA) which is rather new in the field of radiative transfer. For both approaches, the radiative properties involved in their respective frameworks are determined using newly developed Ray-Tracing methods applied to 3-D meshes representing the porous structures of open cell or closed cell foams. The 3-D meshes have been obtained from X-Ray Tomography applied to real metal and polymer foams. The radiative properties determined are used to compute the transmittances and reflectances of one-dimensional slabs of foams by the two approaches. They are compared with the results of a baseline Monte Carlo simulation in order to evaluate, for the two types of foams, the suitability of each method. It appears that both approaches are globally appropriate for predicting the radiative transfer in open cell metal foams although they are not able to match exactly the directional distribution of the transmittances and reflectances. For polymer foams, the accuracy of the HPA is demonstrated whereas the MPA provides significant differences with the reference MC simulations.

1. Introduction

During the last decades, the development of solid foams with open or closed cell has permitted the improvement of the performances of standard materials in numerous technological fields. As a matter of fact, they are particularly interesting for applications requiring multifunctionnality. Foams are generally differentiated according to the type of cellular structure (open or closed cells) or the nature of the solid phase (polymer, metal, ceramic, carbon ….). Metal, ceramic or carbon open cell foams have novel thermo-mechanical properties which make them very interesting for implementations in various systems such as fire walls [1,2], light-weight structures [3], impact/blast energy absorption systems [4], sound absorbers [5], compact heat exchangers [6], and electromagnetic wave shields [4]. As regards polymer closed or open cell foams, they are also mostly applied for thermal insulation application but can be also used to provide an excess of mechanical resistance. As example, expanded (EPS) or extruded (XPS) polystyrene foams represent a large proportion of the building insulation market.

For most of these applications, the thermal properties of the foams are of great interest. That is the reason why they have been widely studied from a thermal point of view. Heat transfer by thermal conduction is generally the main mode of thermal transport. However, the contribution of radiative transfer might be non-negligible for foams with low densities (building insulators) or for applications at elevated temperatures (fire barriers [1,2], glass foams in furnaces [7,8]….).

The most part of the prior studies, dealing with radiation propagation in open or closed-cell foams, are based on the so-called Homogeneous Phase Approach (HPA). This approach implies that the radiative behavior of a composite material can be matched faithfully by an equivalent homogeneous semi-transparent medium. Therefore, the radiation propagation is described using a unique homogenized radiation intensity and the radiative behavior of the foams is described by spectral radiative properties $\beta_\lambda(\mathrm{m}^{-1})$, $\kappa_\lambda(\mathrm{m}^{-1})$, $\sigma_\lambda(\mathrm{m}^{-1})$ and $\mathbf{\Phi}(\vec{\Delta} \rightarrow \vec{\Delta}')$. These properties are, in fact, those of the equivalent homogeneous semi-transparent

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