Infrared tomography: towards a novel methodology to investigate the volumetric radiative properties of heterogeneous materials

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Abstract

Knowledge of the volumetric radiative properties of heterogeneous semi-transparent materials is of crucial interest to accurately quantify the propagation of radiative energy carried through them. When the materials exhibit a complex texture, the determination of their radiative properties remains tricky. Experimental and/or numerical methodologies aiming to finely retrieve the spatial dependence of these properties are at their first step of development. The research proposed in this paper uses optical tomography and specific numerical approaches to solve the inherent inverse problem to solve this issue.

1. Introduction

The transport of radiative energy through heterogeneous semi-transparent materials still remains difficult to understand. Due to the somewhat random spatial distribution of the scattering objects (pores, grains, struts, fibres) embedded within the host matrix, these media exhibit both absorption and scattering behaviours more or less intricate according to the spectral range investigated. In particular, the firm connexion between the texture and the wide-range radiative properties appears little understood. The term texture stands, here, for the spatial arrangement of the scattering objects including their respective distributions of size, form and shape [1]. Most of the works deals with heterogeneous materials for which homogenised volumetric radiative properties can be computed. Recent methodologies are based on numerical codes where a huge quantity of rays propagate within the 3D image of the medium [2]. Thus, ray tracing codes can be applied since the mean sizes of the scattering objects, *d*, allows the use of the approximation of the geometrical optics $(d > \lambda$ where λ is here the incident wavelength) when radiation crosses two adjacent phases (fluid and/or solid). This requirement is often fulfilled for open cells foams which can be qualified of beerian media i.e. the radiation intensity decays exponentially for an increasing material's thickness. However this last assertion is not valid below a critical volume making the medium non beerian from a radiative perspective [3]. For open cells foams, such a situation appears when their thicknesses are in the order of their mean cells size. Consequently, 3D images of the transmitted radiation can exhibit a non uniform behaviour according to their variable spaces (see figure 1).

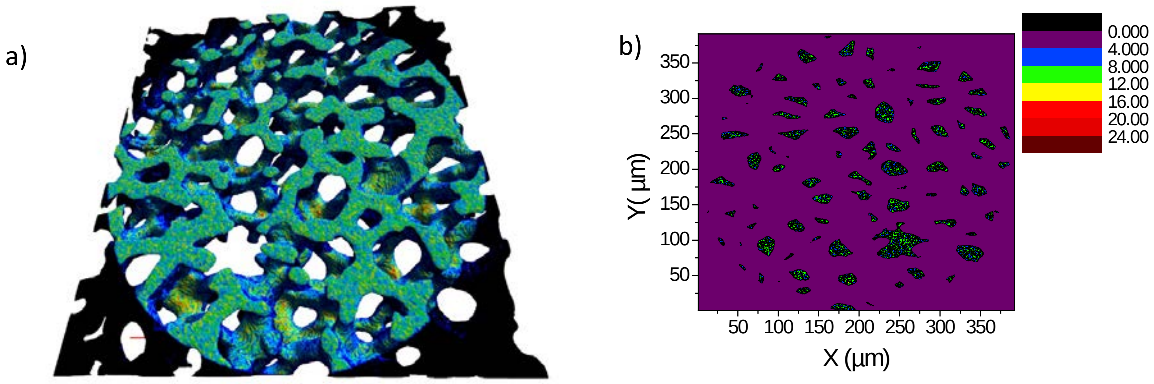

Fig. 1. *Maps of radiative intensity of a α-SiC foam with a size of 12*12*2 mm^3 at T = 300 K obtained with a Monte Carlo ray Tracing code, iMoorphRad [4, 5]: (a) 3 D repartition of the reflected radiation (b) 2D repartition of transmitted radiation where white pixels correspond to the maximum of transmission*

To go one step further, numerical procedures typical of optical tomography can be used to identify the spatial dependence of the radiative properties for the spectral range of infrared radiation.

2. Retrieval of the radiative properties

Optical tomography consists in the retrieval of the spatial dependence of the volumetric radiative properties by solving an inverse problem where some radiation is injected on the boundary of the studied sample and the measurement of the exhausting radiation is performed elsewhere on the boundary. It is worth noting that in most of the work the transport of radiation within the heterogeneous semi-transparent medium is treated following the simplified scheme of the diffuse approximation [6]. This approximation assumes that the radiative intensity of the scanned medium,$L(\vec{r},\vec{s})$ can be accurately approached on the basis of spherical harmonics $Y_{n,m}$ with $(n,m) = (0,1)$ and that the reduced scattering coefficient $\sigma'(\vec{r})$ is much larger than the absorption coefficient, $\alpha(\vec{r})$. In these expressions $\vec{r}$ denotes the position vector and $\vec{s}$ denotes the direction vector. Let us reminder that, practically, according to the diffuse approximation, the radiative intensity is nearly isotropic. The diffusion approximation is limited to media having a minimum layer thickness of the order of a few transport mean free path.

In the proposed work, to verify this approximation, metallic open-cell foams made of aluminium, copper and nickel are first considered. All the samples have a rectangular parallelepipedic shape with a size of 40×40×5 mm^3 and 20 pores per inch (ppi). The textural characterizations of foams show that the approximation of the geometrical optic is valid so that a complete set of transmitted intensities through the six faces of each sample are computed with the iMorphRad code [4]. Different grids with increasing pixel size can be applied on the six faces to collect the data.

Then the inverse problem consists in minimizing the cost function between predictive and collected data. The predictive data are beforehand computed by solving a forward model with a finite element method and based on the diffuse approximation. Due to the high dimension of the control parameter space, gradient-type optimisations are chosen to minimise the cost-function. The Broyden-Fletcher-Goldfard-Shanno optimizer was selected because of its proven effectiveness in solving large-scale optimisation problems. As the inverse problem is ill-posed, regularization procedure is compulsory. Different regularization tools were investigated in this work: parameterization of the control space, Tikhonov penalization and Sobolev gradients, [7].

The paper will be the first to present the resolution of the inverse problem. The results will be discussed according to the textural features of the foams.

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