RAD-13-P04

CONTROL OF THE THERMAL RADIATIVE PROPERTIES OF SiC FOAMS

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ABSTRACT. We investigate links between the textural parameters and radiative properties of SiC-based ceramic foams in order to improve the efficiency of thermal solar processes in which they are used. For this purpose, an highly anisotropic virtual foam is numerically generated. Directional extinction coefficients of the semi-transparent continuous equivalent phase will be determined by Radiative Distribution Function Identification method (RDFI), based on the directional chord-lengths distribution functions of the foam. A ray-tracing technique is also used to compute normal spectral emittance of the virtual foam. This calculation needs the knowledge of local optical properties which are obtained by an inverse method on infrared reflectance microscopy measurement of a real SiC foam strut. Results show that the textural anisotropy leads to a radiative anisotropy. ,.

NOMENCLATURE

Normal hemispherical reflectance	R_H	Temperature	T	K
Normal hemispherical emittance	E_H	Wavenumber	σ	m^{-1}
Normal hemispherical transmittance	T_H	Extinction coefficient	β	m^{-1}

INTRODUCTION

Solar thermal energy processes are of great interest for electric power production. However, the optimisation of volumetric solar absorbers, on which the solar rays are concentrated, is necessary in order to improve their competitiveness. These absorbers allow to deliver hot air in the temperature range of 1000 to 1400 K which is needed to initiate thermodynamic combinated cycles. These cycles permits to increase the yielding of solar energy conversion over 50 %. For this purpose, we need to design "high temperature" solar absorbers in which radiative and convective transfers are optimised. Among the various existing technologies, such as ceramic plates or microchannels, only refractory ceramic foams seem able to reach air temperature over 1400 K [1]. The radiative properties of the volumetric absorbers must both effectively absorb solar radiation in their volumes while minimizing scattered reflections and infrared emission losses. This is equivalent to playing on their spectral selectivity over the incident solar spectrum. This selectivity is particularly related to the three-dimensional spatial distributions of optical scatterer that are pores and struts forming the foam. In this work, we will study the effect of a textural anisotropy on the radiative properties of a SiC foam. For this purpose, virtual numerical foam with a controlled anisotropy of its pore density will be generated. Then directional extinction coefficients will be determined from the directional cumulated chord-lengths distribution functions of the 3D virtual foam data [2] [3]. These values are equivalent to those of the semi-transparent equivalent continuous media. The global radiative properties of the virtual foam along the corresponding axes are calculated by a ray-tracing method. We use local optical properties obtained by an inverse method on infrared reflectance microscopy measurement of a real SiC foam strut. We will finally discuss about the results.

NUMERICAL FOAM GENERATION

Virtual anisotropic foam generation is initialized by a seeding corresponding to the centers of foam's pores. We can control the textural anisotropy of the foam from the seeding: grains are regularly distributed along the three axes, but with an higher seed density along the x axis (there are thrice as many seeds along this axis). Then, a small random perturbation is given to each center to provide a random character to the virtual foam. A fast-marching technique, coupled to a watershed algorithm, permits the growth from the centers and the segmentation of the foam's pores. Finally, thickness is given to the struts to reach the porosity of 70% of our SiC foam of interest (figure 1). The edge sample size is of 400 voxels, with a voxel resolution of 24.14 µm, which leads to a virtual sample size of approximately 1cm and a volume of $1cm^3$.

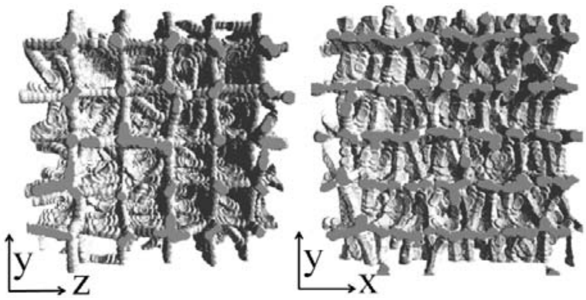

Figure 1 : 3D reconstruction of the anisotropic virtual foam

RADIATIVE DISTRIBUTION FUNCTION IDENTIFICATION

The following assumptions are necessary: the medium is statistically homogeneous along the axis considered, the geometrical optics approximation is valid, the solid phase is optically thick, and the fluid phase is transparent. A large number N_r (10^5) of rays emitted along a given axis (x,y or z) of the foam are launched from points I that are uniformly distributed in the void phase. Rays are traced to their first intersection with the solid-void interface M to obtain the path-length to collision $s_e=|MI|$. At M, extinction occurs by either absorption or scattering, and for a large number of rays, we obtain a set of path length $s_{e,j}$ corresponding with a chord length distribution function expressed as

$$F_e(s) = \frac{1}{N_r}\sum_{j=1}^{N_r} \delta(s - s_{e,j}) \tag{1}$$

where δ is the Dirac delta distribution. The cumulative cord length distribution function is obtained by integration,

$$G_e(s) = \int_0^s F_e(s')ds' \tag{2}$$

The variation of the radiation intensity along the path of an non extinct beam, which is also equal to the fraction of radiant intensity remaining in a ray travelling a distance s through a participating medium with constant extinction coefficient β, can be expressed by Beer-Lambert's law

$$\frac{I(s)}{I_0} \cong 1 - G_e(s); \qquad \frac{I(s)}{I_0} = \exp(-\beta s) \tag{3}$$

The calculated extinction coefficient β is obtained via least mean square fitting of the two equivalent expression of Eq. (3) [2]. The identification of $\beta_{x,y,z}$ are respectively carried along the three axes of the foam. Figure 2 shows the cumulative chord length distribution functions along the three axes. We highlight an anisotropy of the extinction coefficient corresponding to the textural anisotropy previously induced along x axis. Mean values are obtained over 6 realizations of 10^5 rays with a standard deviation of $2*10^{-4}$. We obtain the same values of the extinction coefficient along y and z axis, and we calculate a relative difference of 5.4% for that calculated along the x axis.

EMITTANCE CALCULATION

Normal spectral emittances of the virtual foam (see Fig. 1) are obtained by an homemade ray-tracing code iMorphRad. More details can be found in [3]. The code takes into account the local complex refractive index of SiC s'strut. This is calculated by an inverse method on infrared reflectance microscopy measurement at 300K of a real SiC foam strut. A large amount of rays (106) normal to the face are launched stochastically from a face. Rays interactions (reflection, absorption) with the solid phase are computed using local optical properties. All outgoing rays collected at the opposite face contribute to the normal hemispherical transmittance T_H, those returned to the incident face contribute to the normal hemispherical reflectance R_H. Normal spectral emittance EH is then obtained with the following expression $E_H=1-R_H-T_H$. Figure 3 shows the calculated emittances, from the three faces. Emittance along the x axis is lower due to the textural anisotropy. A difference of 5% can be found for emittance along x axis.

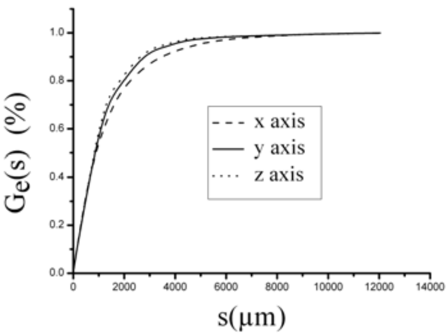

Figure 2 : Cumulated chord length distribution function along the axis x, y, z

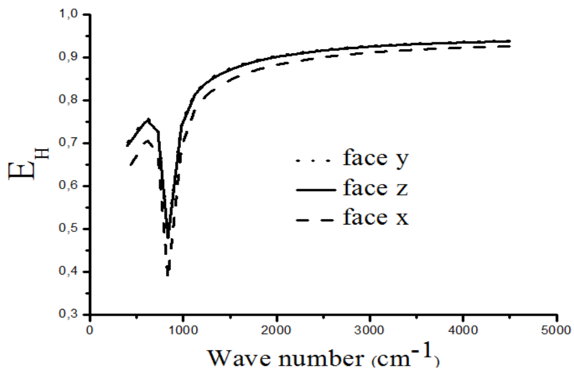

Figure 3: Ray-tracing calculated normal hemispherical emittance from the three faces

CONCLUSION

An anisotropic virtual foam has been generated by a numerical technique. This textural anisotropy leads to an radiative anisotropy, highlight by a relative difference of 5% between directional extinction coefficients (along x axis in comparison with y and z axis). The result of emittance calculation by ray-tracing on each face permits to find a corresponding radiative anisotropy. More works are required to connect these two results and to find whether this radiative behavior is true whatever the studied volume is.

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