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THERMAL CONDUCTIVITY OF MODEL CELLULAR VITREOUS CARBON FOAMS

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Introduction

The purpose of our global project was to investigate and separate the impacts of the porosity on the one hand, and of the cell size on the other hand, on the physical properties (mechanical[1], acoustical[2], electromagnetic[3] and thermal) of cellular vitreous carbon foams with a controlled porous structure. Such foams were indeed successfully prepared with identical chemical compositions and carbon nano-textures, but with as much different architectures as possible. This study presents the results of the thermal part. Thus, the thermal conductivity of cellular vitreous carbon foams was measured at room temperature and pressure with a contact method (Hot Disk analyzer). According to the state of the art, the most important structural characteristics for the thermal properties should be the density (thus the total porosity), the average size of the cells, and their connectivity through the average size of the windows. From numerous samples covering a wide range of densities and cell sizes, thermal conductivities were analyzed, and trends were identified and confronted with a 3D numerical model, made with COMSOL Multiphysics and incorporating thermal radiation. The two approaches that were used allowed validating the observed trends and separating the contributions of the solid from the gas phase, as well as quantifying the contributions of density on the one hand and of average cell size on the other hand.

Materials and Methods

Foams were successfully prepared with identical chemical compositions and the same carbon nano-textures, but with as much different structures as possible (**Figure 1**).

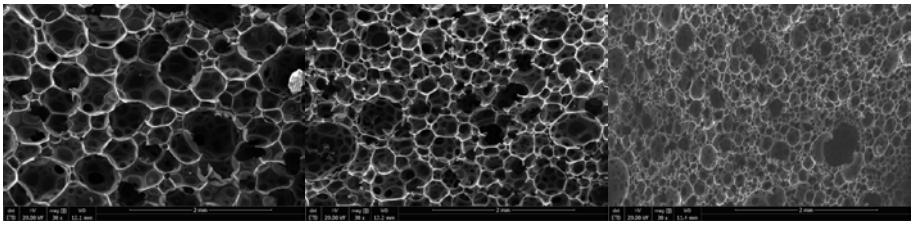

Figure 1. SEM images (secondary electron detector) of Standard carbon foams (magnification × 30) of apparent densities (from left to right) 0.043, 0.051 and 0.111 g cm^{-3}.

Simulations obtained from a 3D-numerical model made with COMSOL Multiphysics and incorporating thermal radiation were compared with our experimental data. The porous structure was modeled by Kelvin cells and the equivalent thermal conductivity was evaluated by calculating the heat flux submitted to a temperature gradient of 1°C over one unit cell (**Figure 2**).

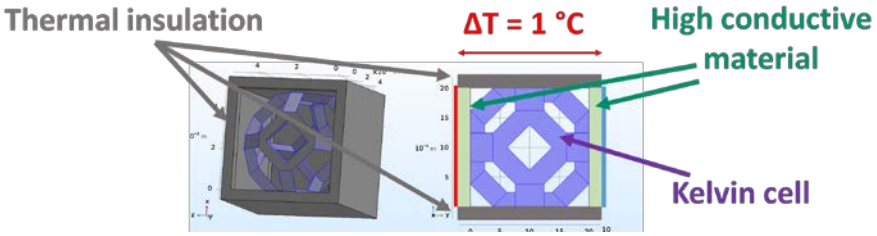

Figure 2. 3D geometry of the model, and boundary conditions.

Results and Discussion

Figure 3 shows that the model is consistent with the experimental data for low densities but leads to higher values at high densities. The impact of cell size is low with respect to that of apparent density. In **Figure 4**, the foams conductivities measured by Hot Disk are sorted by groups of similar densities and compared to the model, as a function of average cell size. It can be observed that for the three groups corresponding to the highest densities, the experimental conductivity increases with the cell size, in agreement with the model. For low densities, the experimental conductivity decreases with cell size, contrary to what the model predicts.

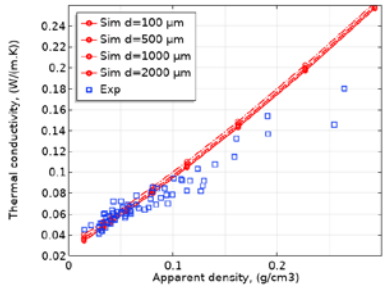

Figure 3: Evolution of thermal conductivity with apparent density

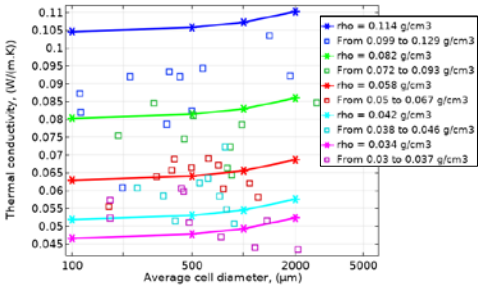

Figure 4: Evolution of thermal conductivity with average cell diameter

Conclusion

The agreement between the simulations and the measurements performed with the Hot Disk method is generally good but must be refined in order to describe the trends better (especially for high-density materials). Anyway, we clearly showed that the major contribution to the thermal conductivity is the porosity, i.e., the apparent density. Although the effect of cell size is not negligible, it is definitely lower than that of the overall porosity.

Acknowledgment

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