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Prediction of effective thermal properties of fibrous material from 3D tomographic images

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Fibrous composites materials are commonly used for thermal insulating purpose and cover a wide range of applications, from high temperature to building insulators. Their effective thermal properties strongly depends on the fibers arrangement, i.e. fibers orientations and number of fibers contacts., which are a consequence of the manufacturing process. Furthermore, local thermal conductivity of the fiber are often anisotropic, as it is the case in natural fibers for example. Thermal optimization of such materials is a major industrial stake and it requires tools to study the complex relation between the materials microstructure and the effective properties. In this work, we make use of tridimensionnal images of the fibrous microstructure to quantify some aspects of the microstructure, like fibers local orientations. These information are then used to compute effective properties directly on an representative elementary volume (REV) of the real structure, within the framework of the volume averaging method applied.

We concentrate on ultra light wood-based/polyester composite insulator used in roof insulation. The X-ray tomography technique is used to get tridimensionnal images of the fibrous structure. The resolution is chosen to be $5\mu\text{m}/\text{pixel}$, which is sufficient to visualize the wood fibers inner porosity (called lumen).

Quantitative analysis of the fibrous network is performed with classical tools of image analysis. It allows for the determination of a REV based on numerous geometrical information (pore size and fibers diameter distribution, porosity, correlation lengths). We also verified that specific constraints over the geometrical moments [1] are satisfied so that some assumptions of the volume averaging method are still valid. The local orientations of the fibers are computed with a developed algorithm based on morphological erosion [2], in order to identify the local thermal conductivity tensor which may not be diagonal due to the orthotropy of the thermal conductivity of wood fibers.

The thermal transfer is described at the macroscopic scale with the use of the volume averaging method in the general case of thermal non equilibrium [1]. Indeed, two-equations model is often needed to process experimental data coming from hot-wire, hot-plate or flash methods. Effective properties may then be computed directly on a 3D image of the fibrous insulator by solving the associated closure problem. A particularity of the developed code is that it is able to deal with non diagonal local conductivity tensor. Results of effective thermal conductivity computed with a one equation model [3] show good agreement with available experimental data. This approach is particularly interesting to complement experimental measurements on this kind of very porous insulators materials.

References

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