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Computational Homogenization for Heat Conduction in Heterogeneous Solids

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Introduction

Materials with a high temperature resistance are indispensable in many engineering applications. Furnace linings and thermal barrier coatings are just to name some examples where a structure is exposed to strong temperature changes and cycles.

Objective

Under severe thermal conditions, the damage mechanism originates from the thermal expansion anisotropy, nonuniformity and/or mismatches between the constituents at the meso or micro level. Therefore an accurate prediction of the deterioration process and failure requires a comprehensive understanding of the temperature distribution at all relevant levels of observation. The objective is to construct a computational homogenization procedure which can be used for the heat conduction analysis in heterogeneous solids with complex microstructures including temperature and orientation dependent conductivities.

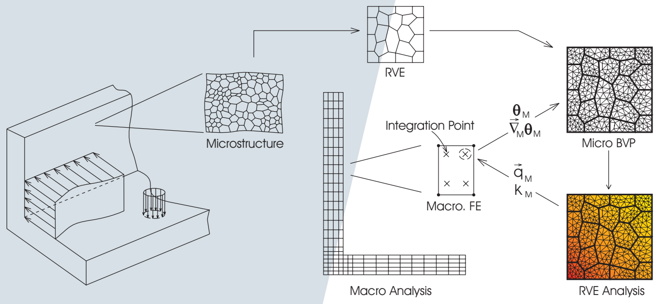

Figure 1 *Schematic representation of the computational homogenization scheme*

Modeling

The basic idea is the derivation of the macroscopic material response from the underlying microstructure. In a finite element model this is realized by solving, at each integration point, a micro boundary value problem (BVP) which is excited by the macroscopic temperature θ_M, and the temperature gradient $\vec{\nabla}_M\theta_M$. Upon the solution, the macroscopic heat flux $\vec{q}_M$ is obtained by a proper averaging relation and the macroscopic conductivity K_M by an extraction procedure from the microstructural conductivity (see figure 1). A nested finite element solution procedure is developed and implemented.

Results and Discussion

The first illustrative problem is depicted in fig. 2. To investigate the effect of microstructural anisotropy, the principal conductivity directions of granular microstructure is tuned, eg. small-scatter for a strongly textured microstructure. Furthermore, the effect of pre-damage is investigated qualitatively with the aid of a cracked RVE. The resulting macroscopic temperature profiles including the rule of mixture solution are presented in fig. 2. The method delivers also the microstructural fields from which it is clearly seen that the pre-damage hinders the heat conduction and acts as a barrier for the heat flow at micro level (see figure 2).

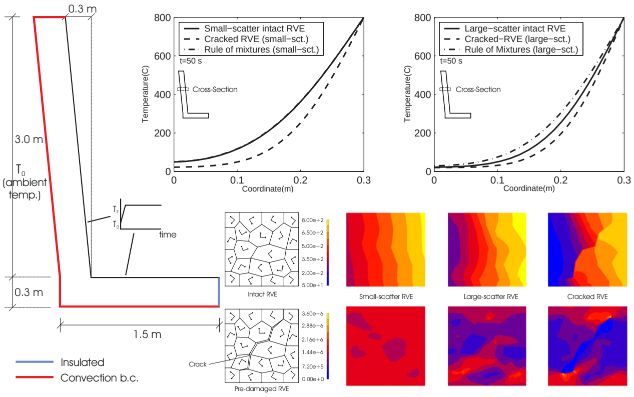

Figure 2 *Macroscopic temperature profiles and the microscopic state (top row temperature, bottom row magnitude of heat flux) at the identical integration points*

The temperature evolution through the thickness of a fire retardance unit made of closed cell aluminium foam, is also investigated. The temperature dependence of conductivity is taken into account and furthermore the rule of mixtures solution is also presented. Obviously, the temperature dependency in heat conduction yields some significant difference on the outer surface temperature of the wall which is the crucial information (see figure 3).

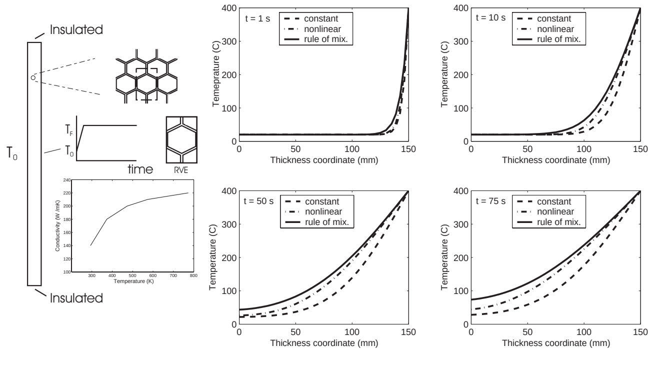

Figure 3 *Temperature profile along the thickness at different times*

Future Work

The thermal homogenization will be combined with the mechanical homogenization [1] including cohesive elements to investigate the thermally induced interfacial damage.

References:

[1] KOUZNETSOVA ET AL: *An approach to micro-macro modeling of heterogeneous materials* (Comp. Mech., 27, 37-48, 2001)