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Thermal multiscale formulation accounting for flux effects across micro-structural surfaces

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A two-scale thermal formulation which considers heat fluxes across generic surfaces at the micro-scale domain is presented. The physical nature of the flux is irrelevant to the formal establishment of the proposed multiscale framework. Thus, convection, radiation mechanisms or any kind of micro-scale phenomenon in the bulk material that can be approached just in terms of the heat flux across its surface boundary are embraced within the present multiscale technique. The fluxes, defined at the micro-scale level, have an impact on the overall response in the macro-scale thermal equilibrium problem; an effect that is accounted for through consistent homogenization procedures.

One of the noteworthy applications of the present theory is the modelling of porous materials, where the void population exchanges heat with the surrounding matrix through convection and/or thermal radiation phenomena. In this scenario, the fluid convection within non-closed pores is modelled using the classical Newtons law of cooling. Besides, the void surface radiation is considered in terms of the non-linear Stefan-Boltzmann law applied to convex closed cavities. More sophisticated flux definitions could also be considered, if required.

The multiscale formulation is based on the RVE notion (Representative Volume Element). It has been developed resorting to the Method of Multiscale Virtual Power (MMVP [1]). As basic postulates, this approach assumes the following ingredients: *(i)* the thermal admissibility concept, relating micro-scale temperatures and temperature gradient fields with their corresponding macro-scale counterparts, *(ii)* duality relations between primitive thermal variables and power-conjugated quantities and *(iii)* the variational Principle of Multiscale Virtual Power (PMVP [1]), which enforces a balance between the Virtual Power at any generic point at macro-scale and the Virtual Power density on the corresponding RVE. As a consequence of these hypotheses, it is obtained: *(i)* the homogenization formula for the flux vector, *(ii)* the homogenization rule for the source-like terms accounting for not self-equilibrated fluxes across micro-structural closed cavities at the micro-scale domain and *(iii)* the variational thermal equilibrium for the micro-scale problem.

Several numerical examples are presented and validated to show the potentiality of the method. Solutions are compared with those provided by a Direct Numerical Simulation (DNS) approach. The micro-cell size influence on the results (size effect), the impact of the temperature level, the heat conduction tortuosity (micro-scale matrix topology) and the relative magnitude of material properties are studied.

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