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Multi-scale homogenization of strength and transport properties of heterogeneous porous materials

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Microstructure-oriented design of materials with a complex microstructure requires multi-scale models, which are able to capture the influence of the microstructure on the macroscopic material behavior. The paper addresses various scale-bridging modeling strategies for heterogeneous porous materials, focusing on the determination of macroscopic transport and strength properties.

Transport of electrolytes and of fluids in heterogeneous porous materials is strongly determined by the pore-space topology, often ranging from nm-mm scale. Since classical homogenization schemes predict unrealistic effective transport and mechanical properties for low porosities and high porosities, respectively, a novel multi-level homogenization model denoted as the Cascade Continuum Micromechanics model that is able to realistically predict percolation thresholds. The model postulates a new material parameter, denoted as the cascade index, which is related to the tortuosity, i.e. the complexity of the pore space. Furthermore, the model is able to take into account a specific pore-size distribution as well as distributed microcracks existing in the material. An anisotropic percolation threshold is predicted due to pore-space anisotropy induced by distributed micro-cracks. Experimental data assert model predictions.

For the description of the strength behaviour of complex porous composite materials, a novel micromechanics-based approach is proposed for the strength prediction of multi-phase composites with cohesive-frictional matrix. Within the framework of the yield design theory and the Linear Comparison Composite (LCC) approach, the extended applications of LCC method for matrix-inclusion composites are adopted directly for constructing a two-step strength homogenization model. As two application examples of this proposed up-scaling strategy, the macroscopic strength criteria of freezing soils and lightweight concrete are estimated based upon the strength properties of their constituents and the current state of their microstructures. The obtained strength predictions are validated quantitatively by comparisons with experimental results.

Keywords: micromechanics; upscaling; diffusion; permeability; strength, porous materials