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Thermomechanical theories for swelling porous media with microstructure

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Abstract

Thermomechanical microstructural dual porosity models for swelling porous media incorporating coupled effects of hydration, heat transfer and mechanical deformation are proposed. These models are obtained by generalizing the three-scale system of Murad and Cushman [56,57] to accommodate heat transfer effects and their influence on swelling. The microscale consists of macromolecular structures (clay platelets, polymers, shales, biological tissues, gels) in a solvent (adsorbed water), both of which are considered as distinct nonoverlaying continua. These continua are homogenized to the meso (intermediate scale) in the spirit of hybrid mixture theory (HMT), so that at the mesoscale they may be thought of as two overlaying continua. Application of HMT leads to a two-scale model which incorporates coupled thermal and physico-chemical effects between the macromolecules and adsorbed solvent. Further, a three-scale model is obtained by homogenizing the particles (clusters consisting of macromolecules and adsorbed solvent) with the bulk solvent (solvent not within but next to the swelling particles). This yields a macroscopic microstructural model of dual porosity type. In the macroscopic swelling medium the mesoscale particles act as distributed sources/sinks of mass, momentum and energy to the macroscale bulk phase system. A modified Green's function method is used to reduce the dual porosity system to a single-porosity system with memory. The resultant theory provides a rigorous derivation of creep phenomena which are due to delayed intra-particle drainage (e.g. secondary consolidation of clay soils). In addition, the model reproduces a class of lumped-parameter models for fluid flow, heat conduction and momentum transfer where the distributed source/sink transfer function is a classical exchange term assumed proportional to the difference between the potentials in the bulk phase and swelling particles.

Keywords: Swelling clay; Mixture theory; Homogenization; Dual porosity thermal effects; Secondary consolidation; Physico-chemical effects

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