NANO- TO MACROMECHANICS OF CONCRETE

New insight from finer-scale characterization and multiscale modeling of early-age cement-based materials

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The proper description of the mechanical behavior of concrete is essential for the reliable prediction of the performance and safety of structures made of plain, reinforced, and/or prestressed concrete. In case of concrete at early ages, the beneficial increase of the stiffness and strength in the course of hydration is accompanied by autogenous-shrinkage deformations and significant creep under loading. Opposed to material models formulated exclusively at the so-called macroscale, i.e., the scale of structural analysis, capturing the mentioned characteristics of early-age concrete in a phenomenological manner, a multiscale models, allowing consideration of physical/chemical processes at the scale of their occurrence, will be presented in this lecture:

• First, the experimental characterization at finer scales of observation by means of nanoindentation (NI), characterized by driving a tough (usually a diamond) tip into the ground and polished sample surface, is presented. Lacking analytical solutions for conical indentation into materials showing viscoelastic-plastic behavior, numerical results are used to construct solutions for (i) viscoelastic indentation and (ii) viscoelastic-cohesive indentation in dimensionless form. These relations are employed for identification of material properties from NI-test data. Hereby, the creep behavior of calcium-silicate hydrates (CSH) is found to be of logarithmic type.

• Then, schemes for upscaling of elastic and viscoelastic properties based on continuum micromechanics are reviewed. Moreover, classical upscaling techniques are extended towards consideration of (i) eigenstresses for upscaling of autogenous-shrinkage deformations and (ii) viscoelastic behavior of CSH for upscaling of creep properties. As regards the latter, the Laplace-Carson transformation of the Mori-Tanaka scheme is employed, considering the aforementioned logarithmic-type creep of CSH.

• In order to assess the quality of the developed upscaling schemes, autogenous-shrinkage experiments were conducted and results from creep experiments reported in the open literature were employed. The developed multiscale model links the creep behavior observed at the macroscale to finer scales, considering the continuously changing finer-scale composition as well as the stiffening effect of inclusions and the compliance-raising effect of (partially saturated) pores at the different observation scales.

• Finally, the proposed multiscale model is employed to specify the early-age properties of shotcrete within a so-called hybrid analysis of a shotcrete tunnel lining, allowing consideration of the actual mix design and the conditions at the construction site. Within the performed hybrid analyses, in situ measurement data are combined with the multiscale model for shotcrete. The obtained results give access to the history of the level of loading of the tunnel lining, which is illustrated for one cross-section of the Lainzer tunnel near Vienna, Austria.

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