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COMPUTATIONAL MULTISCALE ANALYSIS IN CIVIL ENGINEERING

Herbert A. Mang[1], Josef Eberhardsteiner[1], Christian Hellmich[1], Karin Hofstetter[1] and Roman Lackner[1]

[1]Institute for Mechanics of Materials and Structures, Vienna University of Technology, Karlsplatz 13, A-1040 Vienna, Austria, Herbert.Mang@tuwien.ac.at

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ABSTRACT

Recently, Fish [1] pondered over the “hype and reality” of multiscale computations. Being a relatively new field, “it begins with *naive euphoria* …”. Almost always there is an “overreaction to ideas that are not fully developed, and this inevitably leads to a crash …”. “Many new technologies evolve to this point, and then fade away. The ones that survive do so because industry finds a ‘good use’ “.

In a traditional field such as civil engineering the readiness for a departure from traditional modes of design and analysis strongly depends on the probability of economic gains resulting from the use of new technologies. The expectation of such gains has motivated parts of the Austrian construction industry to support scientific research at the Institute for Mechanics of Materials and Structures of Vienna University of Technology (VUT) in the area of multiscale engineering.

The following three topics in this area, with an emphasis on computational analysis in civil engineering, will be covered in this lecture:

- **(1)** design of shotcrete shells within the framework of the New Austrian Tunneling Method (NATM),
- **(2)** development and experimental verification of a continuum micromechanics model for the elasticity of wood,
- **(3)** multiscale modelling of creep of asphalt – performance-based optimization of flexible pavements.

re (1). In the NATM, a shotcrete shell is used as primary support for the freshly excavated stretch of a tunnel. Elaborate monitoring devices allow for the estimation of the internal forces in the tunnel shell, e.g. through a hybrid method by which displacement vector fields are approximated from measured displacement vectors at discrete points of the tunnel shell and used as boundary values in a three-dimensional finite element model of the tunnel shell. Structural computations require an elaborate material model for shotcrete, accounting for mechanical properties that change because of hydration. Recent advances in micromechanics and nanotechnology have opened a new gateway to relations between the degree of hydration and mechanical properties: Based on mathematical descriptions of the material morphology within representative

volume elements, shotcrete-independent constituents (cement, hydrates, water, air) and their hydration degree-dependent dosages define the overall material behavior.

Good agreement between model-predicted evolutions of elasticity and strength and corresponding experiments across water-cement ratios ranging from 0.35 to 0.60 shows that (i) elastic properties of mature cement paste can be estimated reliably on the basis of both spherical or acicular shaped hydrates, but that (ii) the development of a reliable strength model does require consideration of non-spherical hydrates. At the structural level, the micromechanics model, when combined with 3D displacement measurements, shows that a decrease of the water-cement ratio results in an increase of the safety of the shotcrete tunnel shell.

re (2). A multistep homogenization scheme is found to adequately represent the intrinsic structural hierarchy of wood across all different tree species. The nanoscaled components of the wood cell wall, namely crystalline cellulose, amorphous cellulose, hemicellulose, lignin, and water, exhibit universal elastic properties inherent to all wood species. They allow for prediction of wood tissue-specific macroscopic elastic properties from tissue-specific chemical composition and microporosity by means of a four-step homogenization scheme.

Validation of the presented continuum micromechanics model rests on statistically and physically independent experiments: The macroscopic material stiffness predicted by the micromechanical model on the basis of tissue-independent ('universal') phase stiffness properties of hemicellulose, amorphous cellulose, crystalline cellulose, lignin, and water for tissue-specific composition data are compared to corresponding experimentally determined tissue-specific stiffness values. For the elastic moduli in the longitudinal direction (aligned with the stem axis), E_L, and in the transverse direction (in the cross-sectional plane of the stem), E_{Trans}, as well as for the longitudinal shear modulus, G_{LTrans}, model estimates and experimental results show good agreement over a large variety of softwood and hardwood species.

re (3). The rapid degradation of the road infrastructure was the reason for founding the Christian-Doppler Laboratory for “Performance-based optimization of flexible pavements” at VUT. Currently, a multiscale model for asphalt is being developed, allowing identification of fundamental mechanisms of behavior of asphalt at several observation scales. By means of application of advanced upscaling methods, the gain in knowledge at the finer scales is translated to the structural scale and finally used for the design of new pavement structures and the assessment of existing ones.

Upscaling of rheological properties of bitumen-aggregate composites is performed in the framework of continuum micromechanics, utilizing the Mori-Tanaka scheme in the Laplace-Carson space.

The elastic-viscoelastic correspondence principle gives access to the effective (homogenized) creep compliance of a matrix/inclusion-composite. Finally, by means of the inverse Laplace-Carson transformation the time-dependent effective behavior of the composite material and, hence, the macroscopic viscous properties of asphalt can be quantified as a function of the asphalt mix design.

REFERENCE

[1] J. Fish: Multiscale computations: boom or bust. IACM Expressions 22 (2008) 4-7.