Identification of Material Properties from Nanoindentation

Application to Cement Paste and Bitumen

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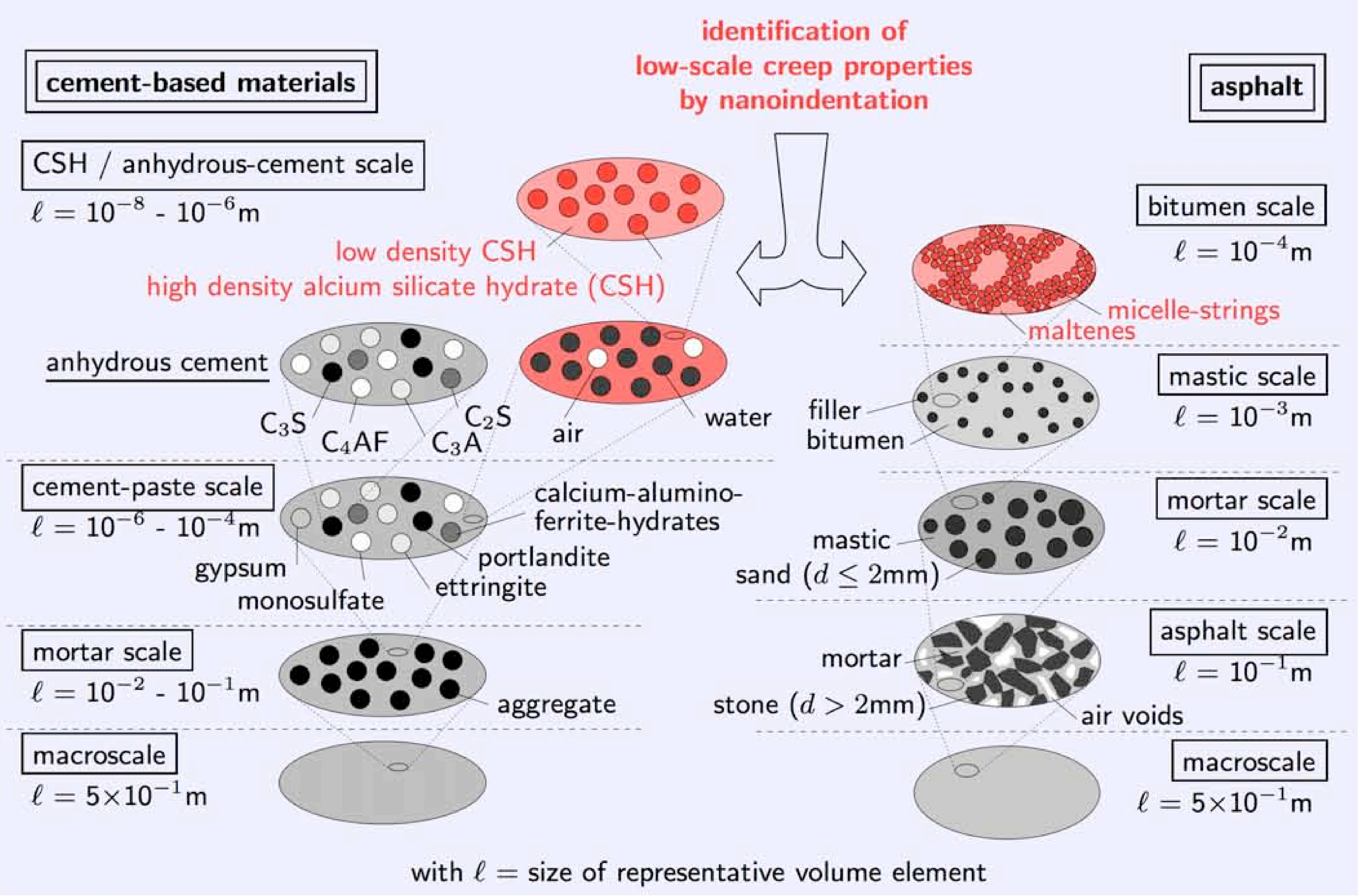
Is it possible to break down building materials (concrete, asphalt, etc.) down to a scale, where materials no more change, and to upscale the encountered behavior to the macroscale of engineering applications? –

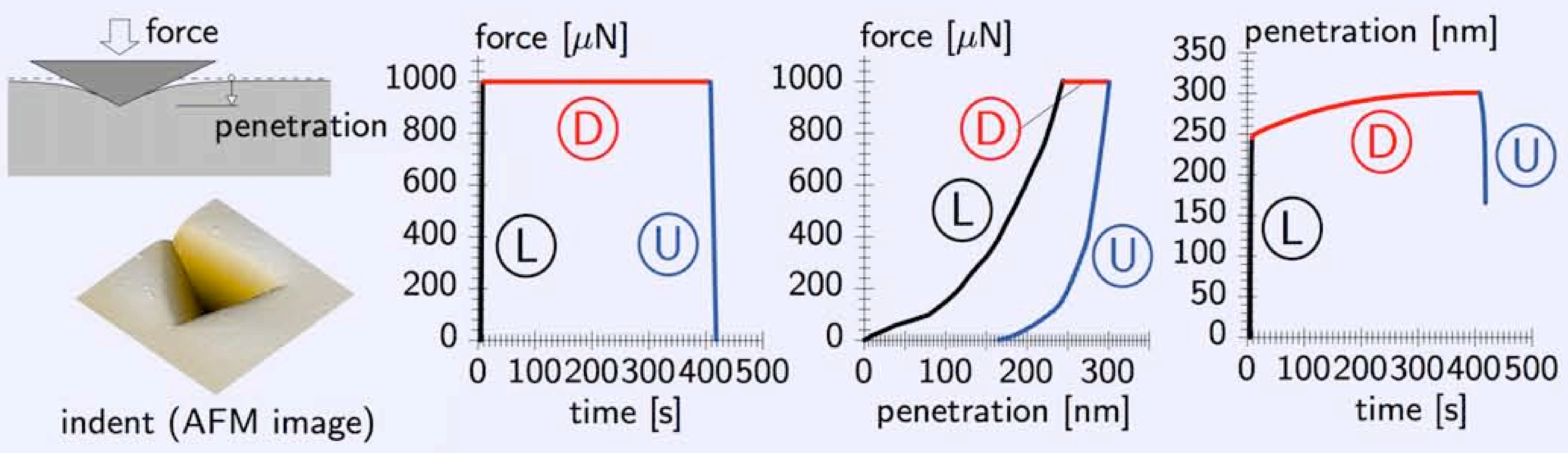
Nano-to-Macro Mechanics of Building Materials

Most (man-made) building materials are composed of several constituents in order to optimize both their performance as regards mechanical properties and durability and their cost of production. The different constituents are characterized by different properties and different spatial distribution (e.g., matrix or inclusion). The effect of the constituents on the overall performance of building materials are properly represented by so-called multiscale models. At the IMWS at TU Wien, two multiscale models for the most commonly used building materials, i.e., concrete [3] and asphalt [1], were developed. These models comprise several observation scales ranging from the hydrate- and bitumen-scale, respectively, towards the macroscale.



Exploring the Finer Scales

In order to relate the macroscopic performance of concrete and asphalt to finer-scale information, knowledge of the material behavior at the finest observation scale (hydrate- and bitumen-scale, respectively) is required. Nowadays, this information is accessible by nanoindentation (NI) and, as regards TU Wien, by the recent establishment of the NanoLab@TU Wien. During nanoindentation, an indenter is penetrating the material while both the penetration and the applied load are monitored. Each NI-indent loading cycle consists of a loading (L), dwelling (D), and unloading (U) phase.

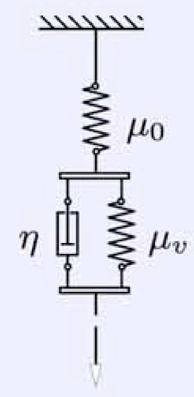


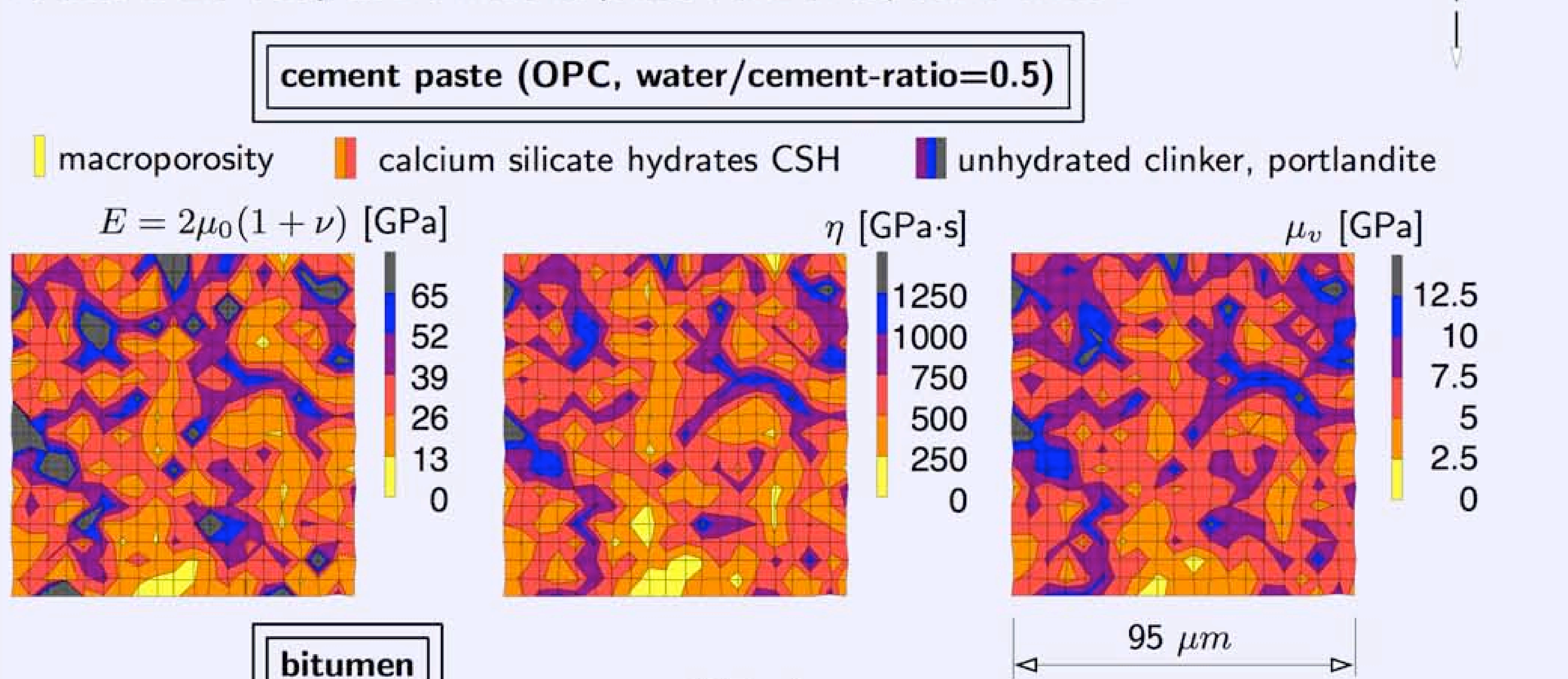
The load-time and penetration-time curves allow ...

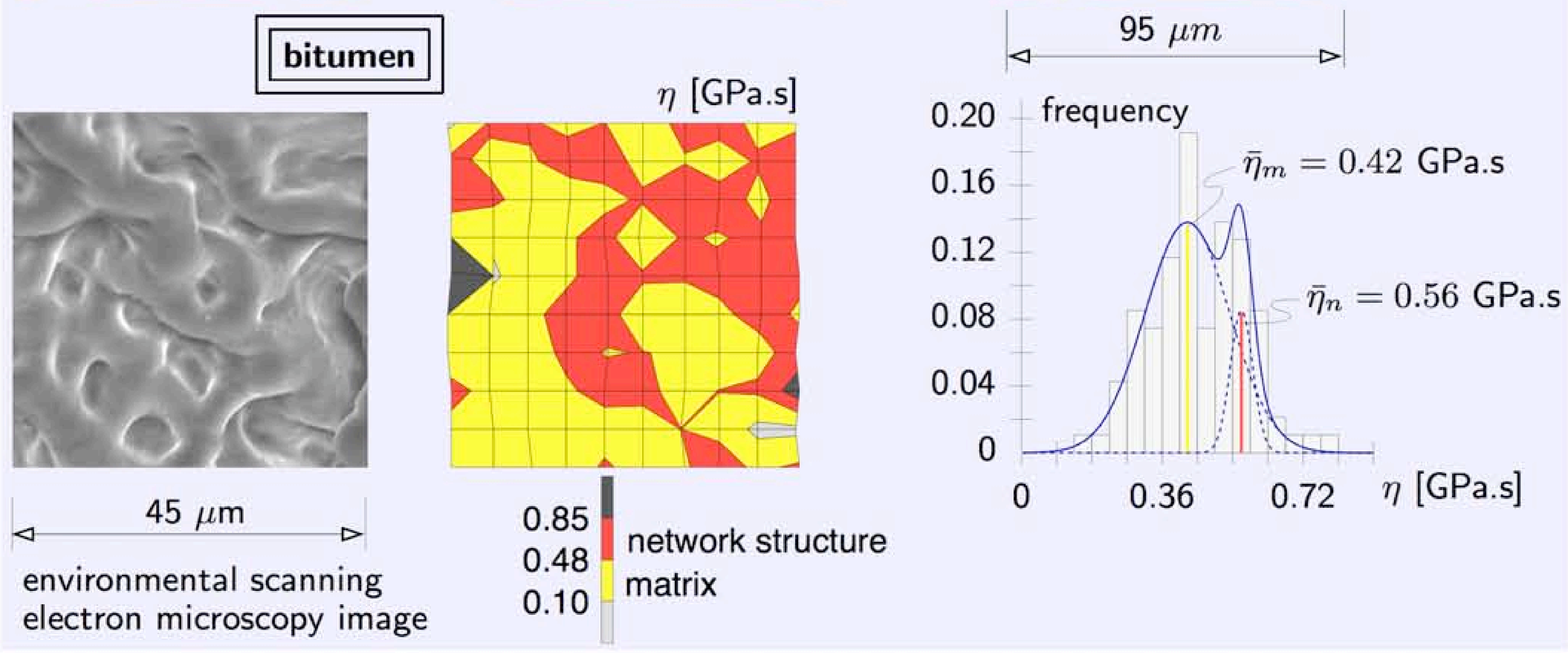
- determination of elastic properties using initial slope of unloading (U) branch in the force-penetration diagram [2] , and
- determination of viscous properties from back calculation using dwelling (D) branch in the penetration-time diagram [4] .

Findings

In case of an inhomogeneous distribution of material phases even at observation scales accessed by nanoindentation, the so-called grid-indentation technique is applied. This technique gives, in addition to material properties at the different grid points, access to the microstructure/morphology. As regards concrete and asphalt, this technique was employed for determination of the viscoelastic properties of the binder materials, i.e., cement paste and bitumen. Accordingly, in addition to the viscoelastic parameters of the different phases of cement paste and bitumen, their spatial distribution was identified. The so-obtained information is essential for upscaling the material behavior towards the macroscale, finally giving the creep properties of concrete and asphalt related to the creep-active material phases of the respective binder.







Building materials "a la carte"

The identification of material phases at different observation scales as well as of their effect on the macroscopic behavior in the framework of multiscale modeling allows us to

- relate the macroscopic material properties which serve as input for macroscopic/structural analyses to finer-scale information,
- consider changes in the material in consequence of thermal, chemical, and/or mechanical loading at the respective observation scale and, via upscaling, determine the new macroscopic material properties taking these changes into account and, finally,
- optimize the material performance by adapting the mix design, using different constituents, and/or considering additives (e.g., polymers in case of bitumen).

As regards the presented research work, the creep behavior of concrete and asphalt was reduced to the viscoelastic properties of the binder materials (cement paste and bitumen). By means of nanoindentation, both the (viscoelastic) properties and the spatial arrangement of the encountered material phases were determined, explaining the material characteristics at finer scales, on the one hand, and serving as input for upscaling schemes, on the other hand.

Thanks to ...

Matthieu Vandamme, Georgios Constantinides, and Franz-Josef Ulm (MIT, Cambridge, MA, USA)

Thomas Koch and Sabine Seidler (Institute of Materials Science and Technology, Vienna University of Technology)

Ronald Blab and co-workers (Institute for Road Construction and Maintenance, Vienna University of Technology)

Erwin Schön and Rupert Friedle (LAFARGE Centre Technique Europe Central GmbH, Mannersdorf, Austria)

Financial support by the Austrian Science Fund (FWF), Vienna, Austria, and the Christian Doppler Gesellschaft, Vienna, Austria, is gratefully acknowledged.

[1] A. Jäger and R. Lackner. Nanoscale characterization of bitumen – back analysis of viscoelastic properties. *Zeitschrift für Metallkunde*, 2005. In preparation.

[2] W.C. Oliver and G.M. Pharr. An improved technique for determining hardness and elastic modulus using load and displacement sensing indentation experiments. *Journal of Material Research*, 7:1564–1583, 1992

[3] Ch. Pichler, R. Lackner, and H.A. Mang. Multiscale model for early-age creep of cementitious materials. In *Proceedings of the 7th International Conference on Creep, Shrinkage & Durability Mechanics of Concrete and Concrete Structures – Concreep 7*, pages 361–368, Nantes, France, September 2005.

[4] M. Vandamme and F.-J. Ulm. Viscoelastic solutions for conical indentation. *International Journal of Solids and Structures*, 2005. In print.