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PROBING THE CHEMO-MECHANICAL PERFORMANCE OF CEMENTITIOUS MATERIALS

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ABSTRACT

Recent advances in modeling [1] allow one to upscale the mechanical response of complex heterogeneous material systems (concrete being an example) and obtain effective properties that can be used in structural mechanics applications. Upscaling techniques may vary from analytical, namely theoretical micromechanics, to numerical, namely finite element solutions, utilizing in the process physicochemical models that analytically [2] or digitally [3] synthesize microstructures. Such approaches, which have their origin at the level of the individual chemical constituents of the composite material, provide a direct link between physical chemistry and mechanics [4]. Furthermore, they allow one to trace the origin of chemo-mechanical degradation at the length scale where the chemical reactions occur [5]. A common requirement to all modeling approaches is the need for intrinsic mechanical properties of the individual constituents composing the composite material, and their temporal response as chemical softening or stiffening occurs. In the case of concrete, the main constituent phase that governs the macroscopic response (Calcium Silicate Hydrates or in short C-S-H) manifests itself in the nm to μm length scale. This constituent phase cannot be recapitulated effectively *ex-situ*; one has to, therefore, access the mechanical properties of C-S-H *in-situ* at the length scale where it can be naturally found [6]. Refinements in instrumented nanoindentation allow one to efficiently determine the mechanical blueprint of these phases and trace their mechanical response in a temporal and spatial resolution [6, 7].

In this paper we utilize recent advances in experimentation, namely instrumented indentation and micromechanical modeling, namely homogenization in an attempt to quantify the multi-scale heterogeneity observed in all cement-based materials (Fig. 1a)

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as well as the effect of thermal/chemical phase transformations [4-8]. We report a systematic framework for mechanically enabled imaging, measuring, and modeling of structural evolution at length scales on the order of constituent phase diameters (nm to µm). This general framework is equally applicable to other man-made and natural composites. Examples from chemically (calcium leached) and thermally (heat cured) affected concrete (Fig. 1a) as well as hydrated exemplar tissues (porcine skin and liver, see Fig. 1b) are presented. A recently developed technique that allows indentations in liquid and its potential use in durability mechanics issues is also discussed [9].

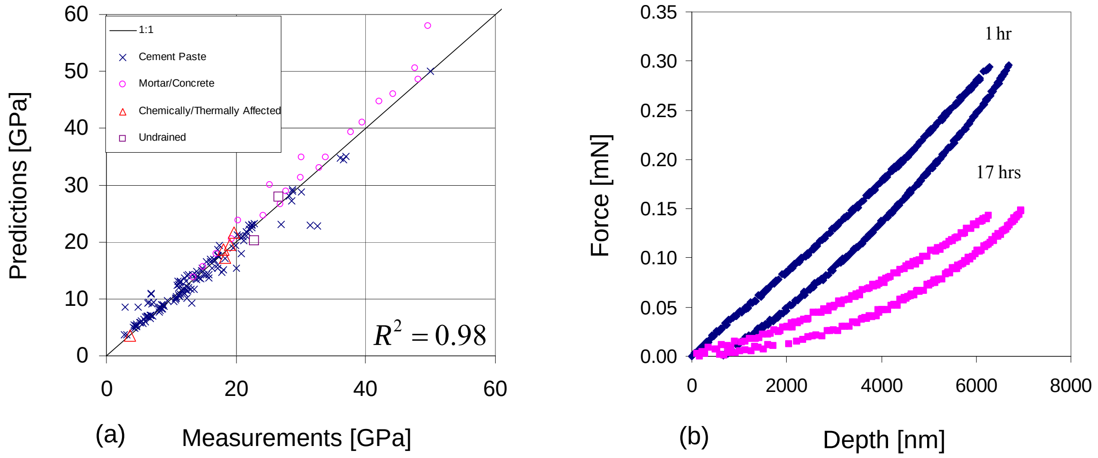

Figure 1: (a) Experimental results vs. predicted values for a range of cement-based materials. The correlation coefficient between micromechanical predictions and experiments is also shown. (b) Deformation response of porcine skin to spherical indentation in physiological saline solution after 1hr and 17hrs immersion.

REFERENCES

[1] S. Torquato, *Random Heterogeneous Materials*, Springer, 2001.

[2] P.D. Tennis and H.M. Jennings, “A Model for Two Types of C-S-H in the Microstructure of Portland Cement Pastes,” *Cement Concrete Res.*, Vol. **30**, pp. 855-863, (2000).

[3] http://ciks.cbt.nist.gov/monograph/

[4] G. Constantinides, F.-J. Ulm, “The nanogranular nature of C-S-H” *J. Mech. Phys. Solids*, Vol. **55**, pp. 64–90, (2007).

[5] G. Constantinides, and F.-J. Ulm, “The effect of two types of C-S-H on the elasticity of cement-based materials: Results from nanoindentation and micromechanical modeling”, *Cement Concrete Res.*, Vol. **34**, pp. 67-80, (2004).

[6] G. Constantinides, K.S. Ravichandran, F.-J. Ulm, K.J. van Vliet, “Grid indentation analysis of composite microstructure and mechanics: Principles and validation” *Mat. Sci. Eng. A-Struct.*, Vol. **430**, pp. 189-202, (2006).

[7] G. Constantinides, E.C.C. Silva, G.S. Blackman, and K.J. van Vliet, “Dealing with imperfection: Quantifying potential length scale artefacts from nominally spherical indenter probes” *Nanotechnology*, Vol. **18**, 305503, (2007).

[8] F.-J. Ulm, G. Constantinides, F.H. Heukamp, “Is concrete a poro-mechanics material? A multi-scale investigation of poro-elastic properties”, *Mater. Struct.* (Special Issue of Concrete Science and Engineering), Vol. **37**, pp. 43-58, (2004).

[9] G. Constantinides, I. Kalcioglu, C.A. Tweedie, J.F. Smith, and K.J. van Vliet, “Probing biological and polymeric surfaces in liquid” submitted for publication.