A Multiscale Approach to Model Thermo-Hydro-Mechanical Behaviour of Plain Concrete During Early Stages of Construction

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Introduction

This research focuses on the study of coupled thermo-hydro-mechanical behaviour of plain concrete during early stages of construction, especially immediately after hardening. Processes such as (i) thermal expansion, (ii) autogenous/drying or heat-induced shrinkage, and (iii) thermal/drying creep may combine to initiate/propagate cracks in plain concrete. These are fundamentally triggered by cement hydration kinetics, thermal/moisture gradients due to internal heat source and/or environmental exposure, and external mechanical load. Such problems are of great relevance in the field of nuclear waste storage and disposal from the point of view of safe design of concrete containers/structures.

Objectives

In the first phase of this PhD, the problem of drying shrinkage (no temperature) is addressed via a multiscale framework[1]. The two most important inputs to predict drying shrinkage strain are the moisture retention curve and bulk modulus of concrete. A novel technique based on combined particle-packing/cement hydration kinetics/pore network model is developed to predict the moisture retention curve for concrete. An analytical homogenization scheme, which uses inputs from the cement hydration kinetics model, is then applied to upscale the bulk modulus of concrete. Fig.1 shows the multiscale framework.

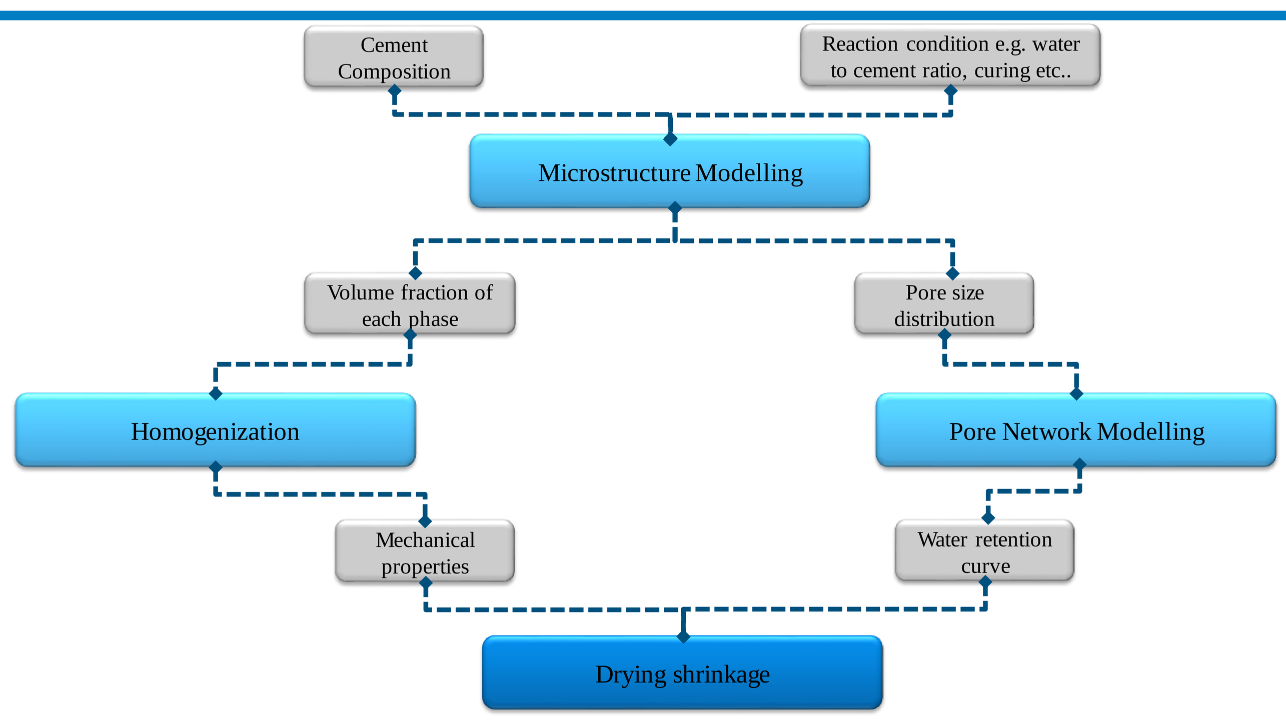

Fig.1. Framework proposed in this research

Materials and Methods

Microstructural modelling and homogenization

- Existing microstructure modelling tools are employed to provide inputs for the homogenization scheme and pore network modelling.
- The required information from microstructure for the homogenization scheme are volume fraction of each phase and porosity. Other fundamental parameters include chemical composition of cement, W/C ratio and curing conditions. Fig.2 shows an example of input and output structure.

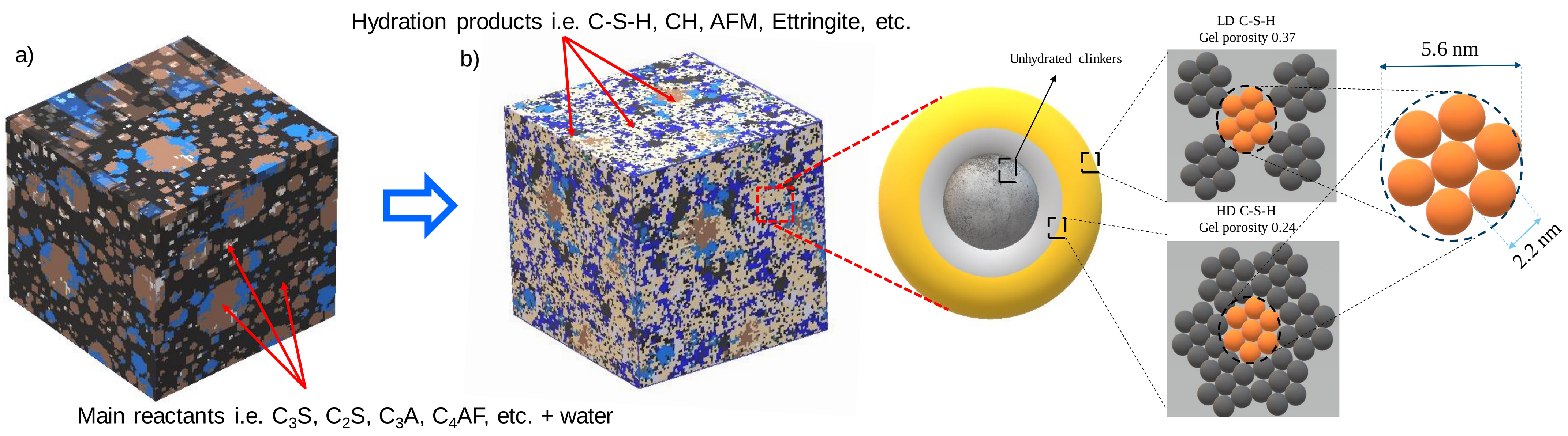

Fig.2. Microstructure of cementitious material. (a) before hydration, (b) after hydration

Pore network modelling and water retention curve

To visualize the cementitious material as a network of pores and throats (Fig.3), the data from hydration model and particle packing are coupled to provide the input for our pore network modelling. Finally the output of our pore network modelling will be water retention curve.

The water retention curve (WRC), contains fundamental information about hydro-mechanical behaviour of cementitious material and it is a key hydraulic parameter. Drying shrinkage is estimated using WRC and theory of poroelasticity.

Fig.3 shows an example of a pore network developed using inputs from microstructural and particle packing model.

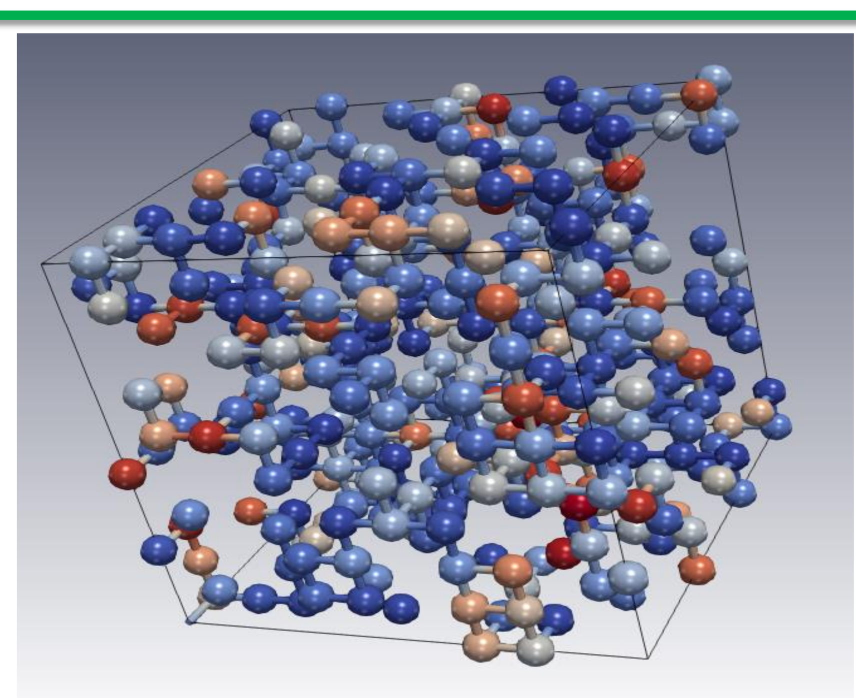

Fig.3. Sample pore network

Results

Water retention curve and drying shrinkage

- Fig.4 shows predicted WRC against the experimental data for hardened cement paste.
- Fig.5 shows the validation of the model for drying shrinkage of hardened cement paste and concrete.

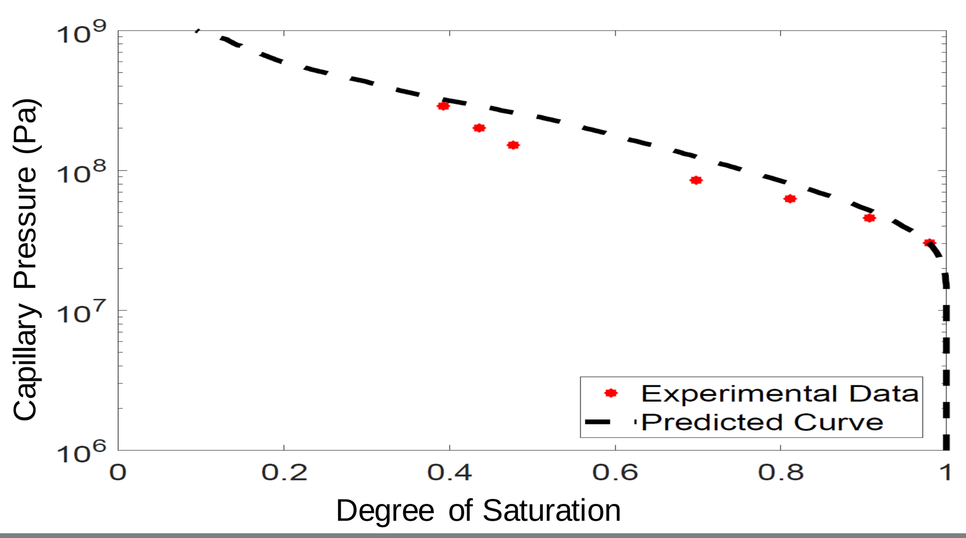

Fig.4. Experimental vs. predicted WRC

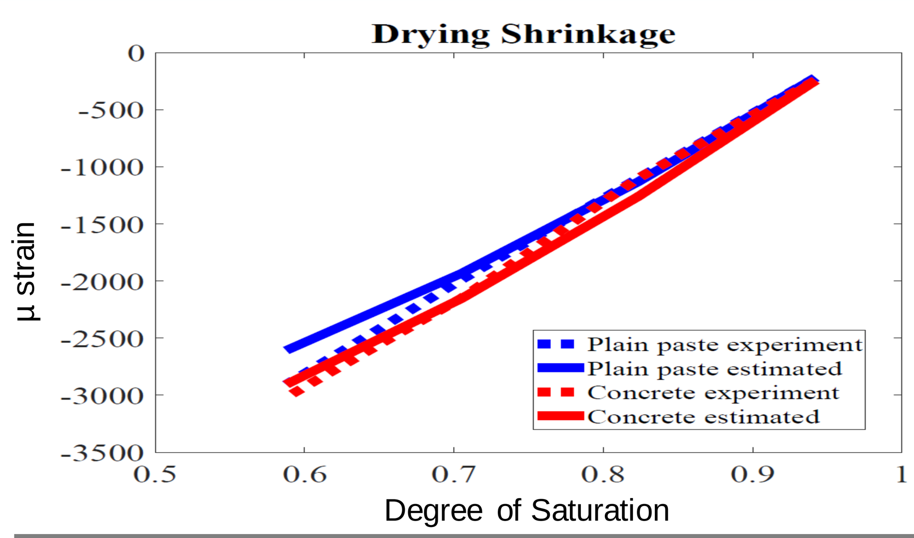

Fig.5. Drying shrinkage strain as a function of saturation

Conclusion

This research presents an approach to compute macroscopic drying shrinkage strain by a multiscale modelling technique. The results show reasonable agreement up to a degree of saturation of 58%, with a maximum of 7% error in the predicted drying shrinkage strain. Further work is ongoing to test the response at lower degrees of saturation and possible cracking initiation and propagation. In a subsequent phase of the study, the model will be elaborated by also including internal heat emitting sources, representative for high-level radioactive waste.

This work is fully sponsored by SCK-CEN, Belgium, and their support is gratefully acknowledged.

1 Babaei Saeid, Seetharam Suresh, Mühlich Uwe, Areias Lou, Steenackers Gunther, Craeye Bart, Modeling of drying shrinkage in concrete : a multiscale poromechanics approach, RILEM PROCEEDINGS - ISSN 1461-1147 - RILEM Publications, 2018, p. 165-169