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

S. Babaei1,2, S. Seetharam1, U. Muehlisch1, A. Dizier1, A. Steenackers2, C. Bruggeman1 & B. Craeye2

1 Belgian Nuclear Research Centre, SCK•CEN, Mol, Belgium
2 Faculty of Applied Engineering, University of Antwerp, Belgium
3 Euradice
E-mail: saeid.babaei@sckcen.be

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. 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.

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.

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.

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.

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.

1 Babaei, Saeid; Seetharam, Sreenath; Muehlisch, Ulrich; Low, Andrew; Steenackers, André; Craeye, Bart. Modeling of drying shrinkage in concrete - a multiscale poromechanical approach. RILEM PROCEEDINGS - ISSN 1401-1467 - RILEM Publications, 2018, p. 365-390

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