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Development and qualification of cementitious matrices : Relevance and use of analytical homogenization methods for thermo-poro-mechanical modelling

R&D on cementation conditioning of liquid, sludge and powder nuclear waste

R&D for the commissioning of new industrial workshop and development of new matrices is investigated.

Performance of industrial and prospective composite matrices must be assessed according to an array of physical requirements, including compressive strength, gas permeability and leachability.

- [1] IAEA Technical reports series n.350, Improved cement solidification of low and intermediate level radioactive wastes, 1993
- [2] G. Cardinal et al., Cementation in High Energy Mixer of ILW Surrogate Slurry - Demonstration of the Process at Semi-industrial Scale, NUWCEM 2011
- [3] Frizon, Cau-dit-Coumes, Lambertin, Poulesquen, New Binders, New Trends, New Potentialities in Waste Cementation, NUWCEM 2015



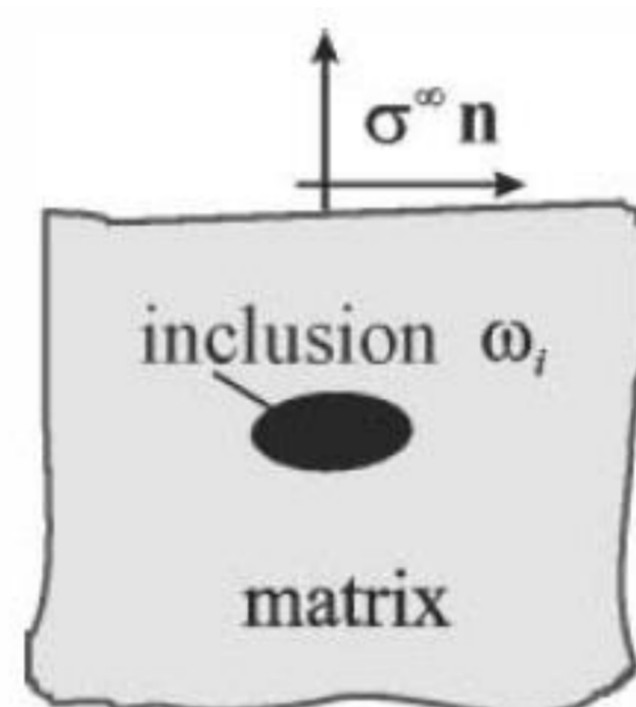
Objectives

To assist the development and qualification experiments with a finite element model, using the possibilities of homogenization techniques. Goal is to apply to cemented waste the modelling tools now commonly used in classic cement and composite R&D.

Continuum Micromechanics, a versatile tool

for the evaluation of macroscopic properties, during solidification, and then deterioration :

- Thermal conductivity
- Diffusion coefficient
- Elastic properties
- Biot parameters (Poromechanics)
- Compressive strength
- Gas permeability



- [1] A. Zaoui, Continuum Micromechanics: Survey, Journal of Engineering, Mechanics, vol.128 n.8 pp.808-816, 2002

Gaz permeability induced by (post-pic) localized cracking

Diffuse damage is estimated by homogenization of (pre-pic) crack-induced loss of rigidity.

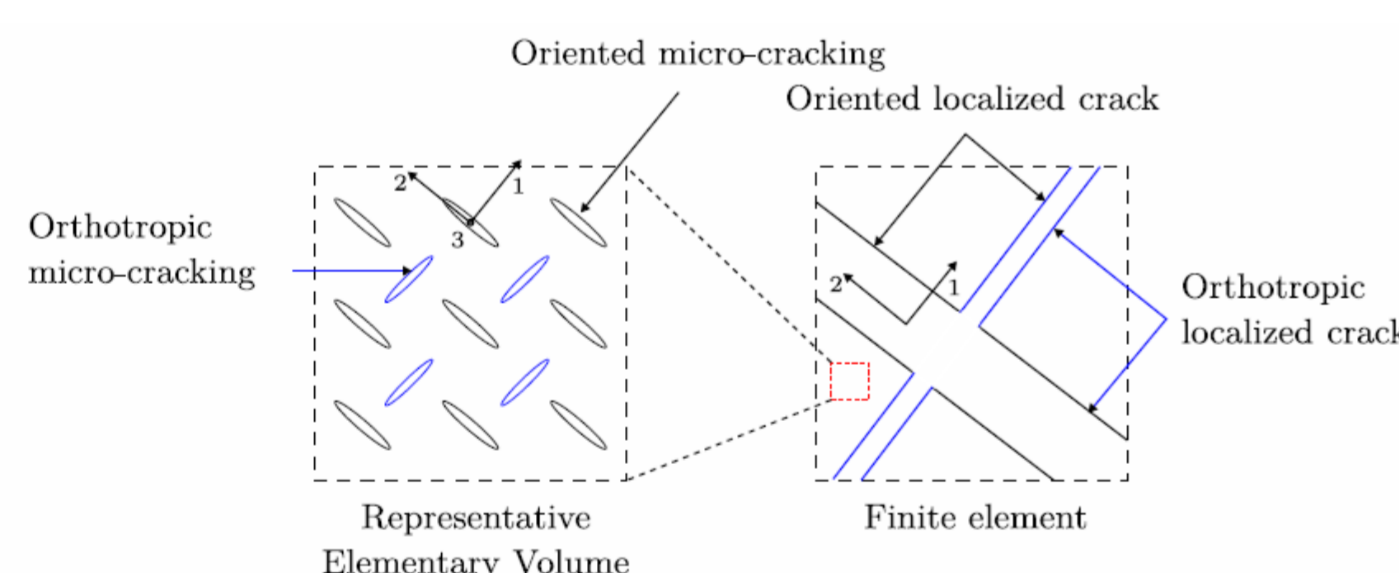
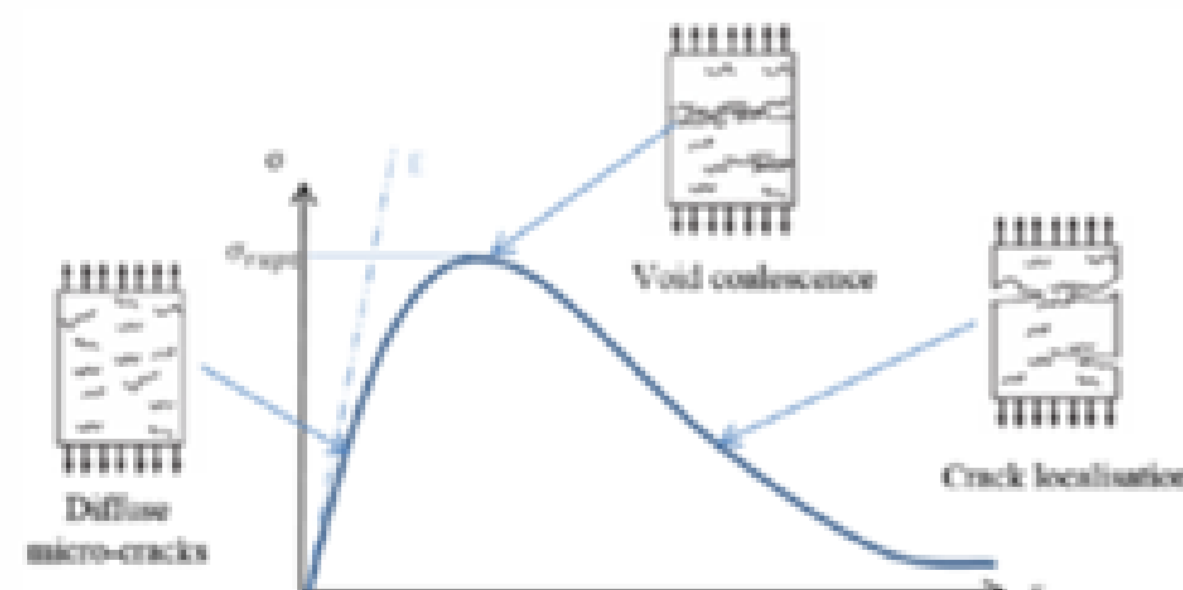


Fig. 1. Idealized finite element crossed by orthotropic diffuse and localized cracking as explained in Sellier et al. (2013a).

Localized damage assessed with an amended effective stress, and fracture energy control (Hillerborg's method).



Permeability deduced with modified Poiseuille's law applied to the fluxes in each f.e.

- [1] A. Sellier et al., Orthotropic damage coupled with localized crack reclosure processing, 2013
- [2] S. Rahal, A. Sellier, G. Casaux-Ginestet, Finite element modelling of permeability in brittle materials cracked in tension, 2017

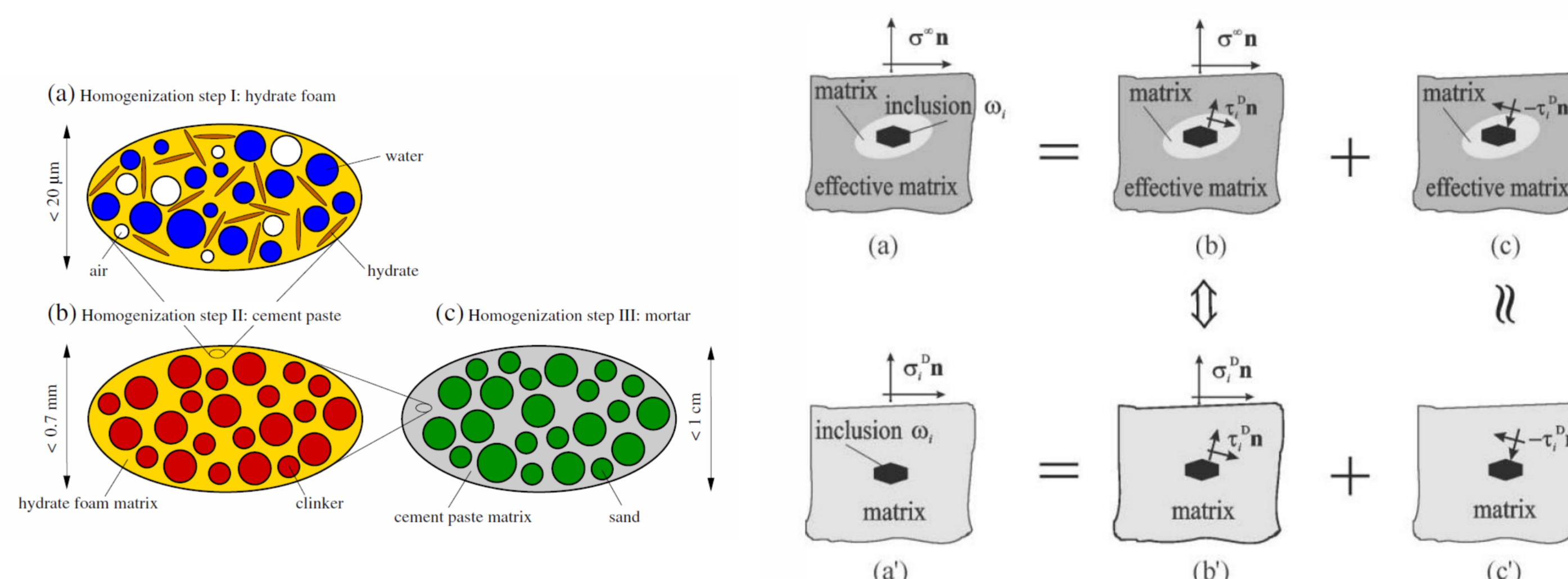
Work in progress

- Chemo-thermal modelling
- Damage evaluation at early-age, with an isotropic model
- Damage evaluation, with the orthotropic diffuse-localised damage model
- Damage impact on permeability
- Solidification model based on the interaction direct derivative (IDD) scheme

Effective Medium evaluation : 'Simple Inclusion' and 'Double inclusion' approaches

Homogenization stands on assumptions/simplifications on the physical description.

'Simple inclusion' variants are popular; 'Double inclusion' alternatives appear more appropriate in some sensitive cases (elastic properties at very early-age, oriented cracks).



IDD : an explicit version of the 'Double inclusion' approach.

- [1] Q.S. Zheng, D.X. Du, An explicit and universally applicable estimate for the effective properties of multiphase composites which accounts for inclusion distribution, 2001
- [2] A. Tognevi, B. Bary, A. Delaplace, Micromechanical estimation of hydro-mechanical parameters in unsaturated microcracked concrete, 2010

Upscaling of the thermal conductivity (Decrease of the thermal conductivity with hydration)

Simple Inclusion applied to thermal diffusion

- Representation: Description of the upscaling levels
- Localization: Choice of the localization scheme, Evaluation of the localization tensors
- Homogenization: Evaluation of the combined thermal conductivity

Idem for Homogenization of the diffusion coefficient, in a damaged composite matrix.

- [1] L. Jendele, V. Šmilauer, J. Cervenka, Multiscale hydro-thermo-mechanical model for early-age and mature concrete structures, 2014

