

Numerical modelling of the tensile splitting test and its coupling with gas permeability

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FraMCos-8, Toledo

Introduction

The tensile splitting test : aim and principle

Standard technique to determine the tensile strength of geomaterials such as concrete and rocks

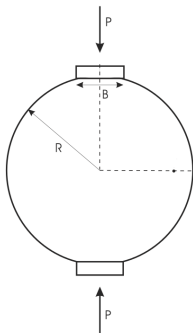
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A cylindrical specimen is loaded along a diametral plane

Principle of the test



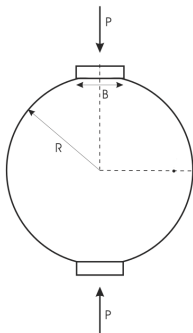
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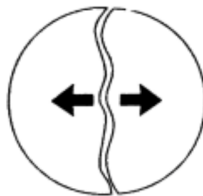
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Failure into two halves
[Rocco et al., 1999]



Introduction

Numerical investigation of the interaction between cracking and permeability in the context of the tensile splitting test for concrete material

Literature results

- [Rodriguez-Ferran and Huerta, 2001] : numerical modelling of the tensile splitting test
- [Dufour *et al.*, 2008] : crack opening from a damage model ?
- [Choinska, Pijaudier-Cabot, Dufour and Huerta, 2008] : coupling between the tensile splitting test/permeability and experimental results

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The proposed approach...

- mechanical model : cracking (strong discontinuity approach) and heterogeneous material (weak discontinuity approach)
- fluid model : interaction between cracking and permeability (Poiseuille law)
- meso-scale : two-phase material (cement paste + inclusions)

- 1 Fine scale FE modelling : quasi-brittle heterogeneous material
 - 3D geometric model
 - Heterogeneous media representation
 - Crack modelling
- 2 Fine scale FE modelling : hydro-mechanical coupling
 - hydro-mechanical coupling
- 3 Mechanical and hydro-mechanical results
- 4 Conclusions et perspectives

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- Goals : tridimensional representation + simple kinematics at the fine scale

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Geometric modelling by a spatial lattice

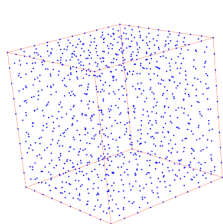
[Schlangen and Van Mier, 1992] [Man and Van Mier, 2007]

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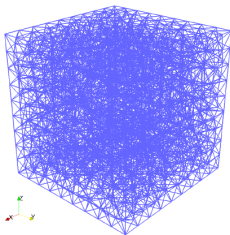
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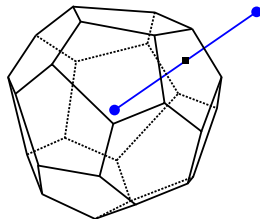
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Random point process



Delaunay triangulation



Voronoi diagram

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Heterogeneous material

two phases material : mortar/aggregates [Wriggers, 2005] – [Hau-Kit Man, 2008]

Fast and efficient meshing process

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- non conforming mesh

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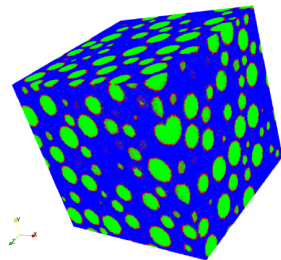
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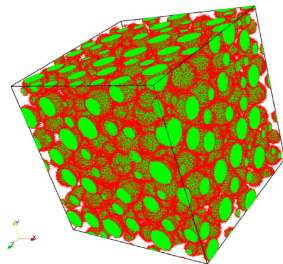


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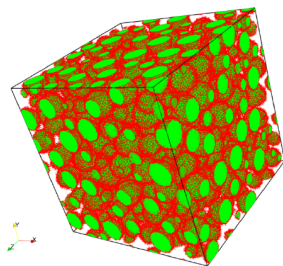


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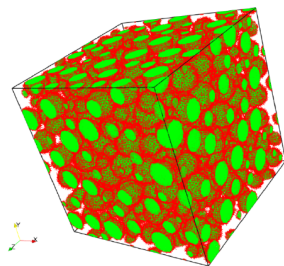
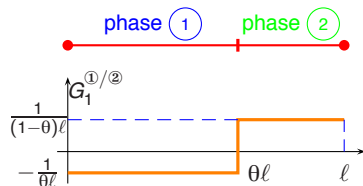


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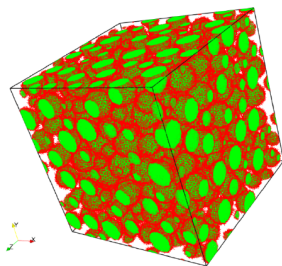
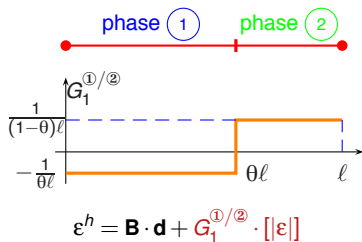


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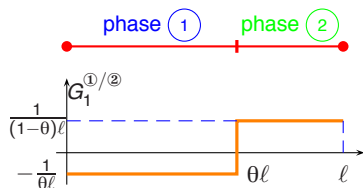


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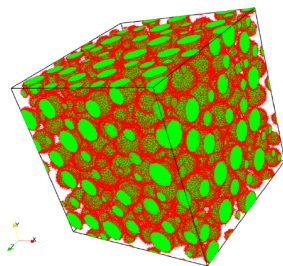
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$$\boldsymbol{\varepsilon}^h = \mathbf{B} \cdot \mathbf{d} + G_1^{1/2} \cdot [[\boldsymbol{\varepsilon}]]$$

AES – method, [Simo and Rifai, 1990]



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quasi-brittle material [Armero and Garikipati, 1995] – [Wells and Sluys, 2002] –
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Explicit representation of the crack

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Explicit representation of the crack

- cracking into the cement paste and interfaces debonding
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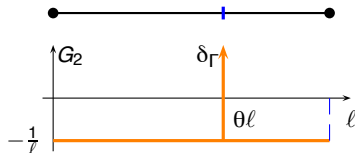
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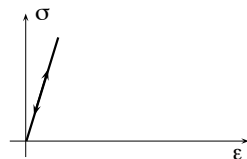
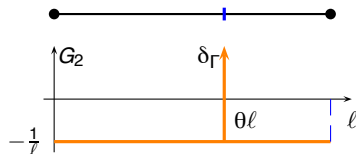
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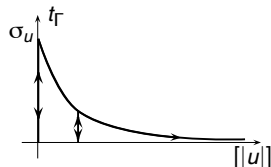
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volumic behaviour



surfacic behaviour

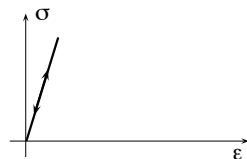
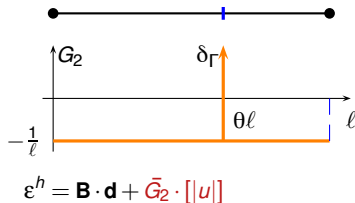
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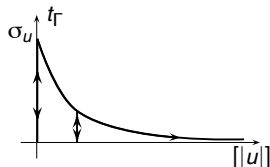
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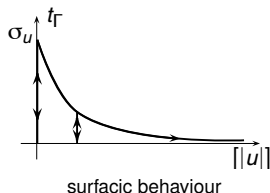
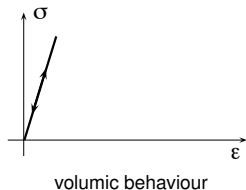
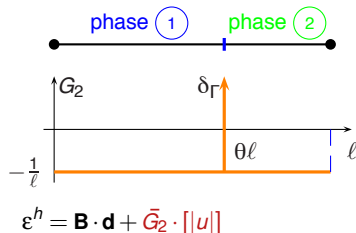
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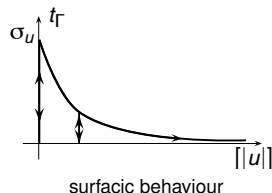
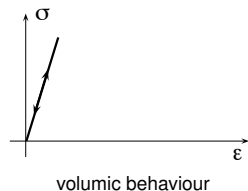
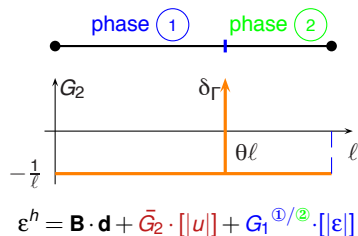
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Hydro-mechanical coupling features

[Jourdain *et al.*, 2012]

Coupling features

- weak coupling : mass balance equation

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Hydraulic model features

- double porosity [Choinska et al., 2009]

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$$k_{iso} \mathbf{I} + \mathbf{k}_{ani}$$

Hydro-mechanical coupling features

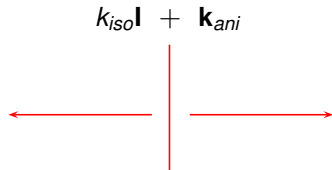
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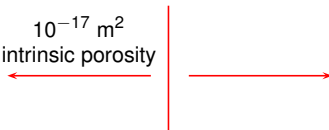
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Hydraulic model features

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10^{-17} m^2
intrinsic porosity



Hydro-mechanical coupling features

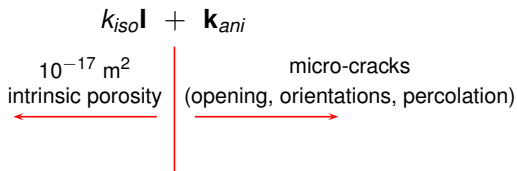
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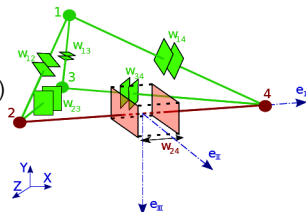
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micro-cracks
(opening, orientations, percolation)



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Mechanical results

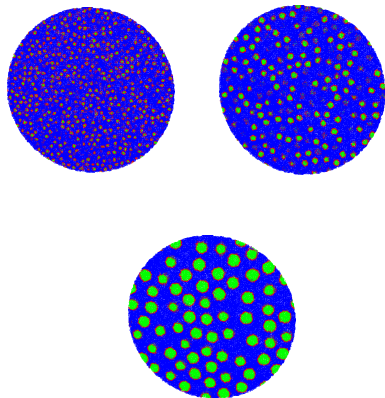
tensile splitting test

- Imposed displacement at the top of the cylinder
- Cracking in the cement paste and debonding
- Inclusions diameter : 2, 4, and 8 mm
- $E_{incl}/E_{paste} = 7$

Mechanical results

tensile splitting test

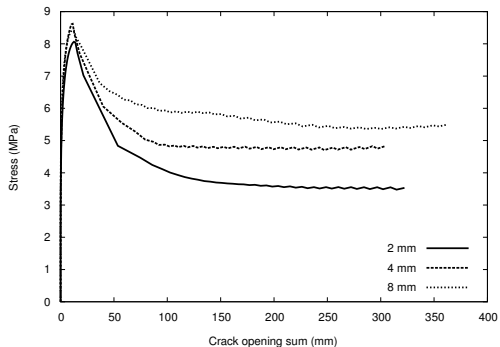
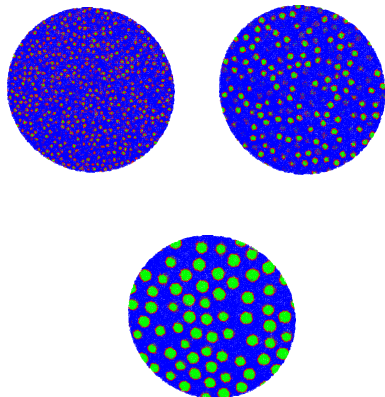
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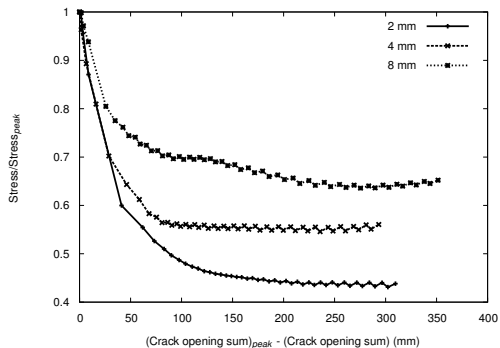
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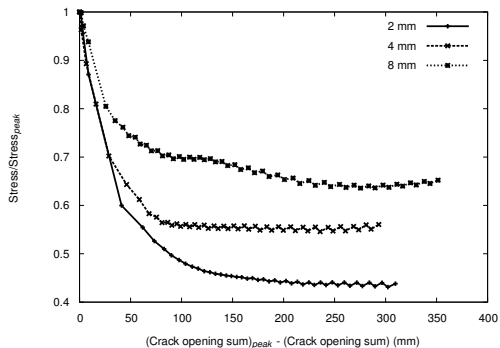
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Mechanical results

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- Fracture energy increases with respect to diameter

Mechanical results

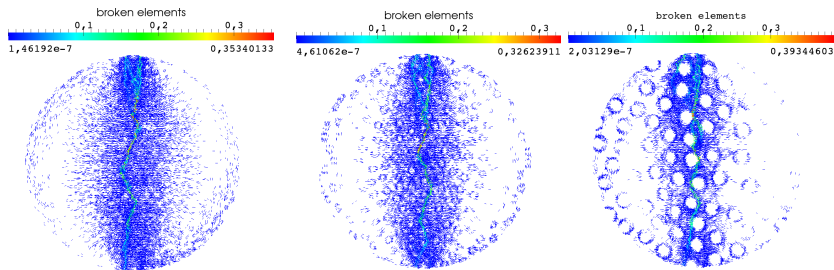
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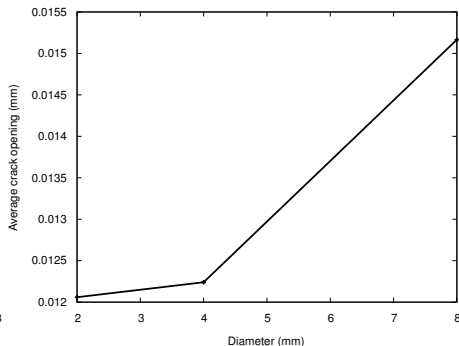
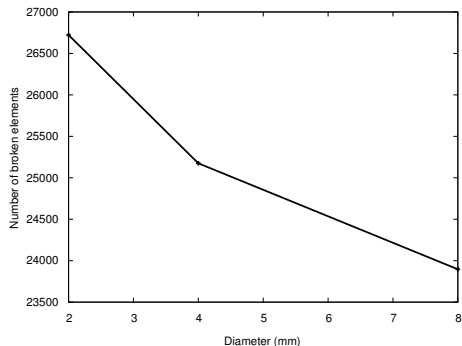


- crack opening for each element
- micro-cracking
- tortuous macro crack

Mechanical results

tensile splitting test

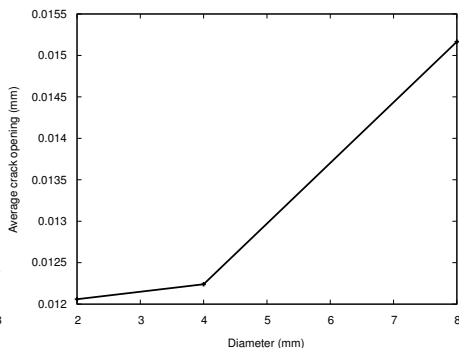
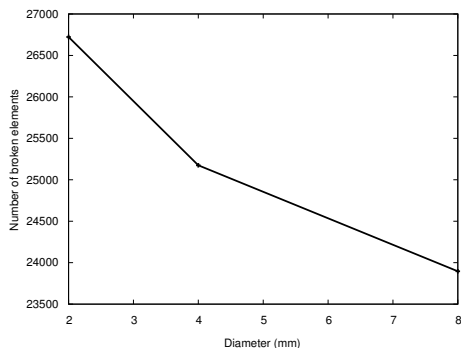
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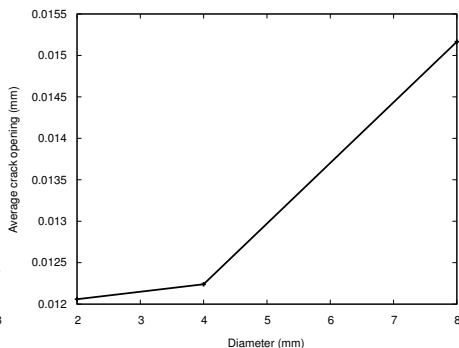
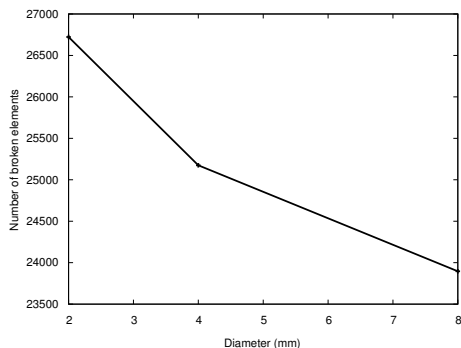


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- Average crack opening increases with respect to the diameter

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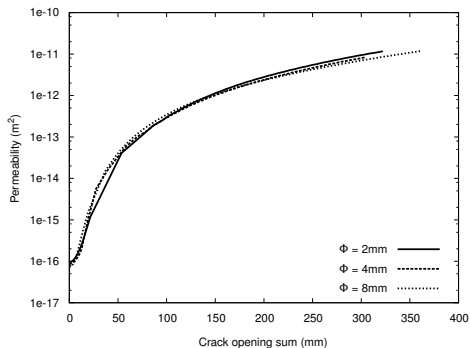


- Number of broken elements decreases with respect to the diameter
- Average crack opening increases with respect to the diameter
- How does permeability evolve with respect to the diameter ?

Hydro-mechanical results

tensile splitting test

- $P_{in} = 2 \times 10^5$ and $P_{out} = 1 \times 10^5$ Pa
- Gas = air : $M = 0.02895 \text{ kg.mol}^{-1}$ and $\mu = 1.82 \times 10^{-5} \text{ Pa.s}$
- $k_{incl} = 10^{-25} \text{ m}^2$ and $k_{paste} = 10^{-16} \text{ m}^2$
- Inclusions diameter : 2, 4 and 8 mm

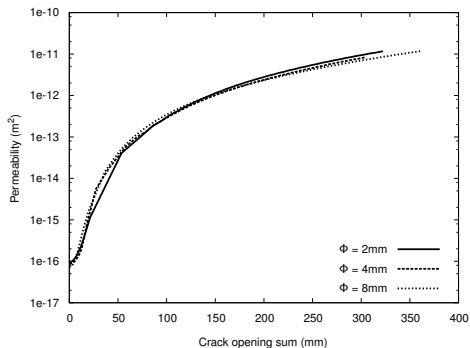


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Hydro-mechanical results

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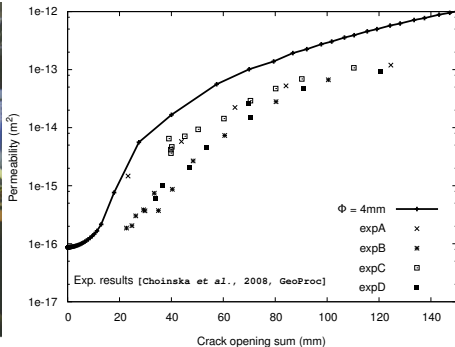
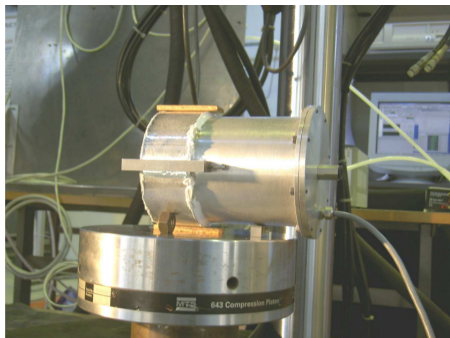


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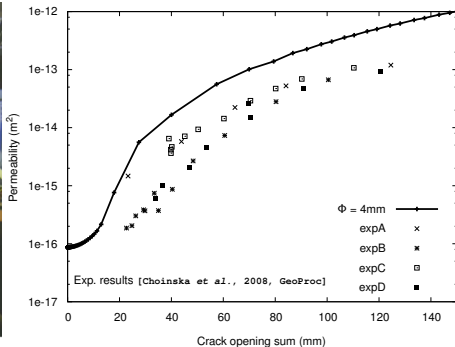
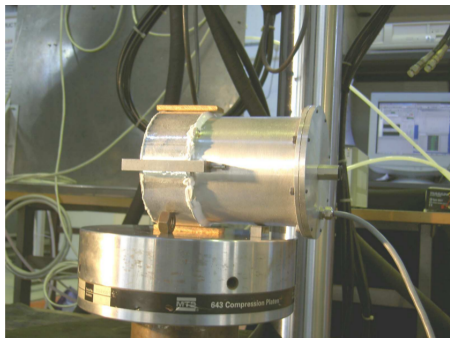
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- rugosity ignored
- no realistic thickness

- 1 Fine scale FE modelling : quasi-brittle heterogeneous material
 - 3D geometric model
 - Heterogeneous media representation
 - Crack modelling
- 2 Fine scale FE modelling : hydro-mechanical coupling
 - hydro-mechanical coupling
- 3 Mechanical and hydro-mechanical results
- 4 **Conclusions et perspectives**

Conclusion : hydro-mechanical coupling

Efficient tools

- Weak discontinuity : two-phase material
- Strong discontinuity : cracking
- ...naturally coupling with the fluid problem by the Poiseuille law
- Extension to others couplings : chloride transfert for instance

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Upscaling information from the fine scale to the macro scale

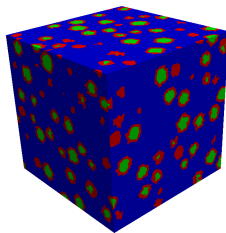
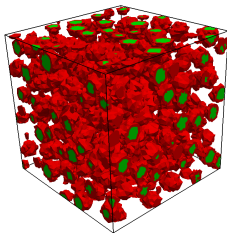
- Mechanical information
- Multi-physics information

Developing fine scale model

- “ Richer ” fine mechanism
- Morphologic variability : random field [Roubin, 2010]
- 3D volumic

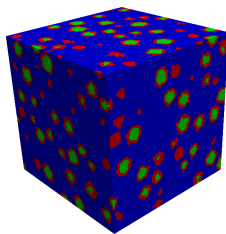
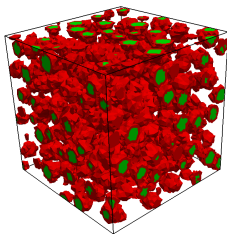
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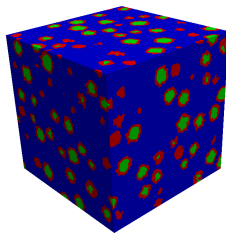
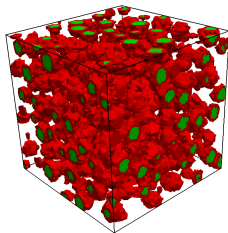


Multi-physics problem development

- Couplings development (chemo-physics coupling, ex : Internal sulfatic reaction)

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Other method

- Nitsche method : chloride propagation