Characterization of damage-induced evolution of building materials hygric properties

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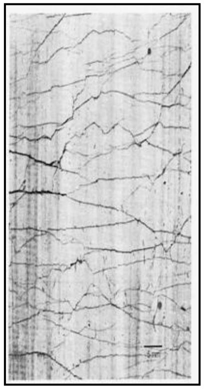
Motivation

• Progressive cracking of cementitious materials during their lifespan due to mechanical loading

➢ Infiltration of carbon dioxide and chloride ions ⟶ carbonation, corrosion

➢ Deterioration of hygric and thermal transport properties



• Implementation of damaged media in HAM simulation codes

• Measurements of damage-induced evolution of water vapour permeability

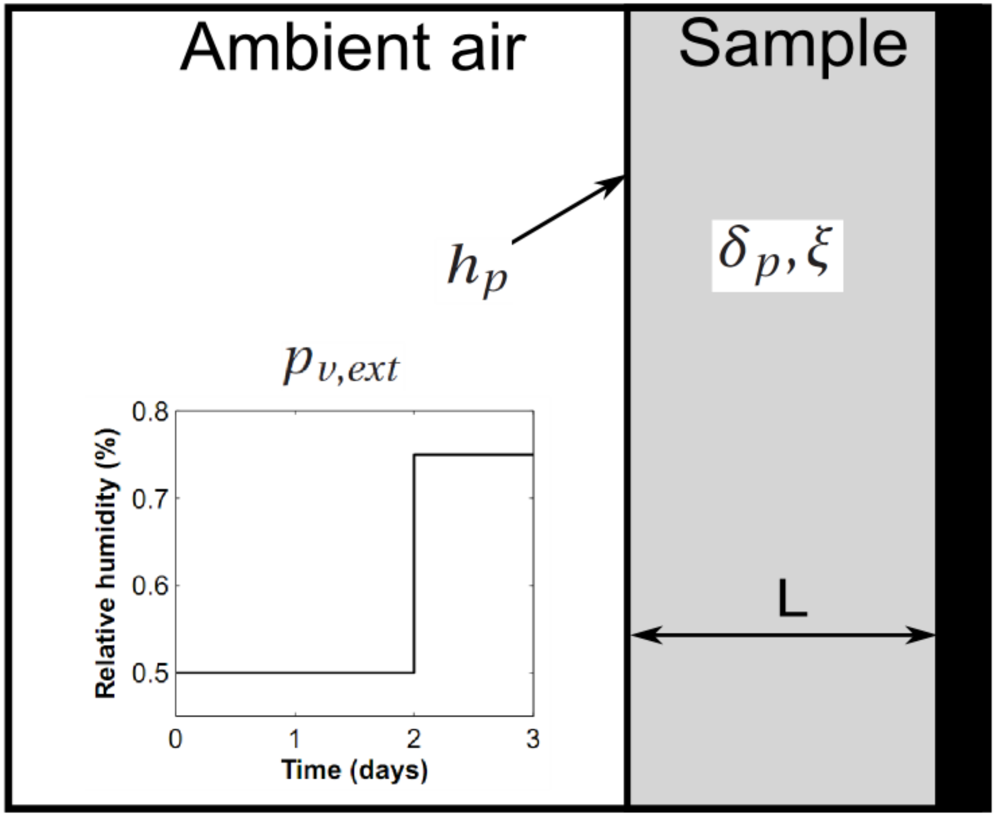
Modelling hypotheses

Simplification of the transport equation for 1D transfer in a narrow humidity interval of the hygroscopic range

⇓

$$\frac{\xi}{p_{sat}} \frac{\partial w}{\partial t} = \delta_p \frac{\partial^2 w}{\partial x^2}$$

$$\delta_p \left(\nabla p_v \cdot \mathbf{n} \right) = h_p \left(p_{v,ext} - p_v \right)$$



Estimation of the transfer properties

• Resolution of the 1D transport equation under simplification hypotheses:

$$m = \int_0^L \left(w(x,t) - w_0\right) \mathrm{d}x \Longrightarrow \begin{cases} m = L\xi\Delta\phi\left[1 - \sum_{k=1}^{\infty} \dfrac{2\sin^2 a_k}{a_k\left(a_k + \sin a_k \cos a_k\right)} \exp\left(-a_k^2 \dfrac{\delta_p}{\xi} \dfrac{p_{sat}\, t}{L^2}\right)\right] \\ \dfrac{\mathrm{Bi}_h}{a_k} = \tan a_k \end{cases}$$

• Application of a Levenberg-Marquardt algorithm for the correlation with experimental measurements

$$\left[\mathbf{J}^t \mathbf{J}\right]_n \mathbf{u}_{n+1} = \mathbf{J}_n^t \left[m_{exp,i} - m\left(\mathbf{u}_n, t_i\right)\right]$$

$$\mathbf{u} = \left(\delta_p, \xi, h_p\right)$$

$$\mathbf{J}_{i,j} = \frac{\partial m\left(\mathbf{u}, t_i\right)}{\partial u_j}$$

• Possibility of extrapolating all transfer properties from the mass uptake profile in this humidity range

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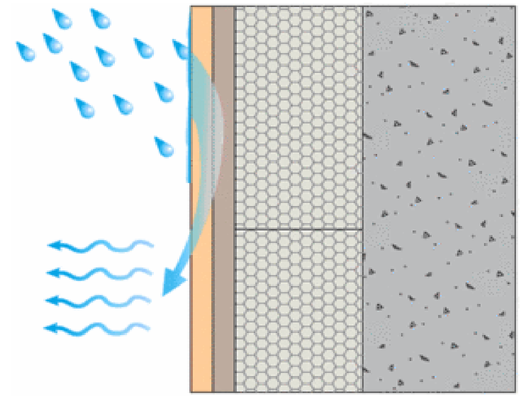
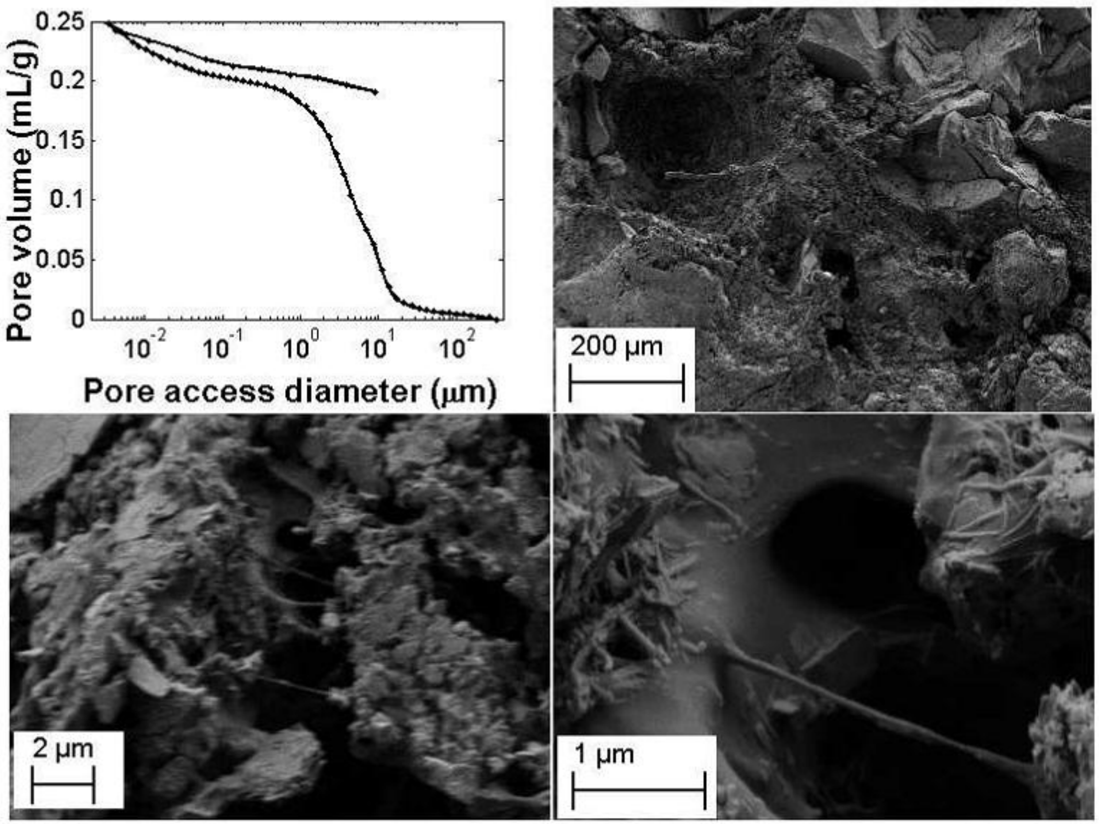
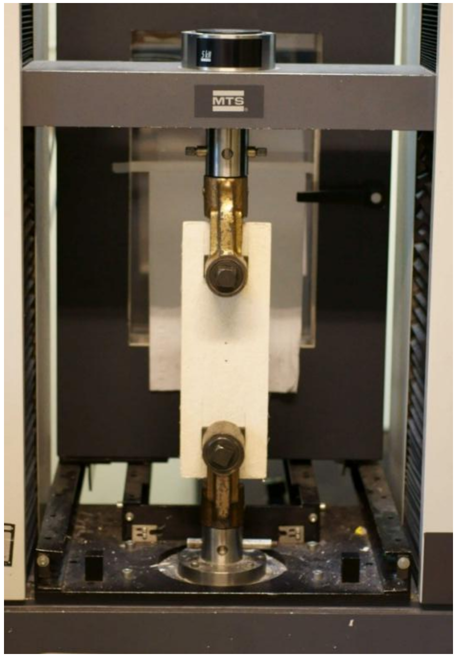
Material used in the study

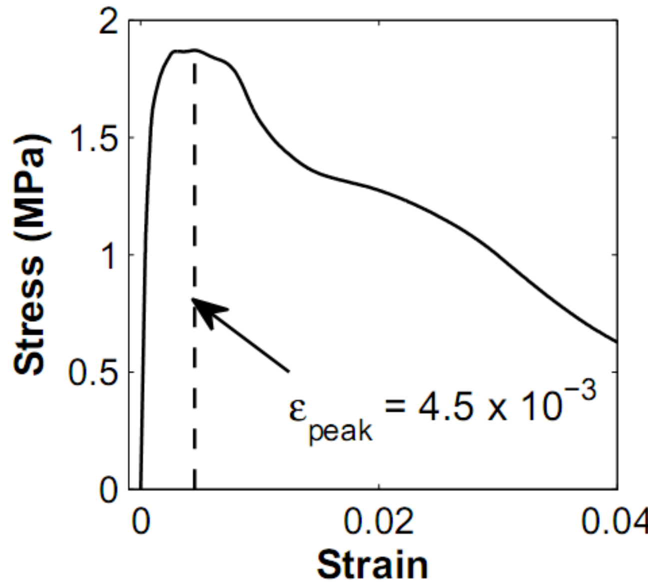
Fibre reinforced mortar used for outer thermal insulation

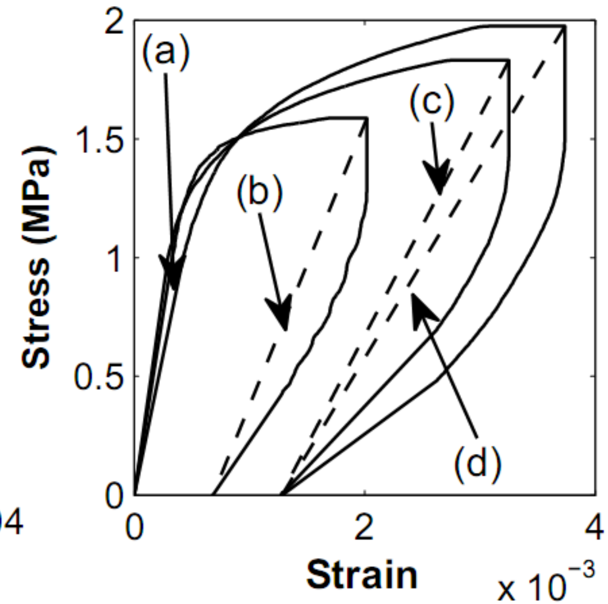




Mechanical characterization



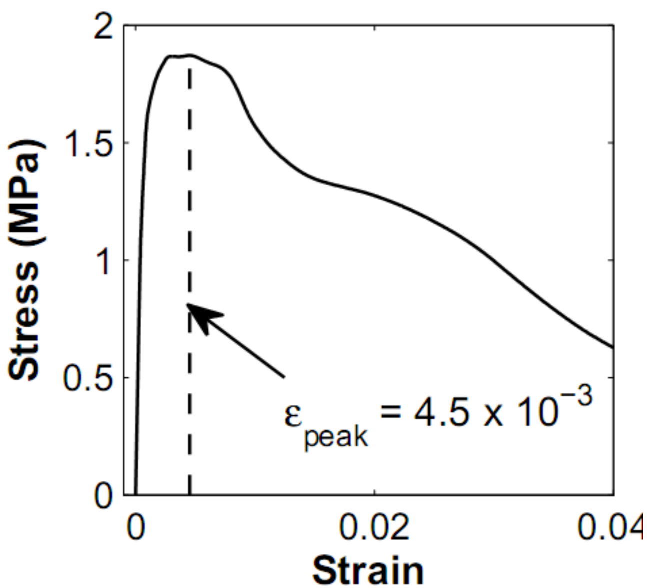


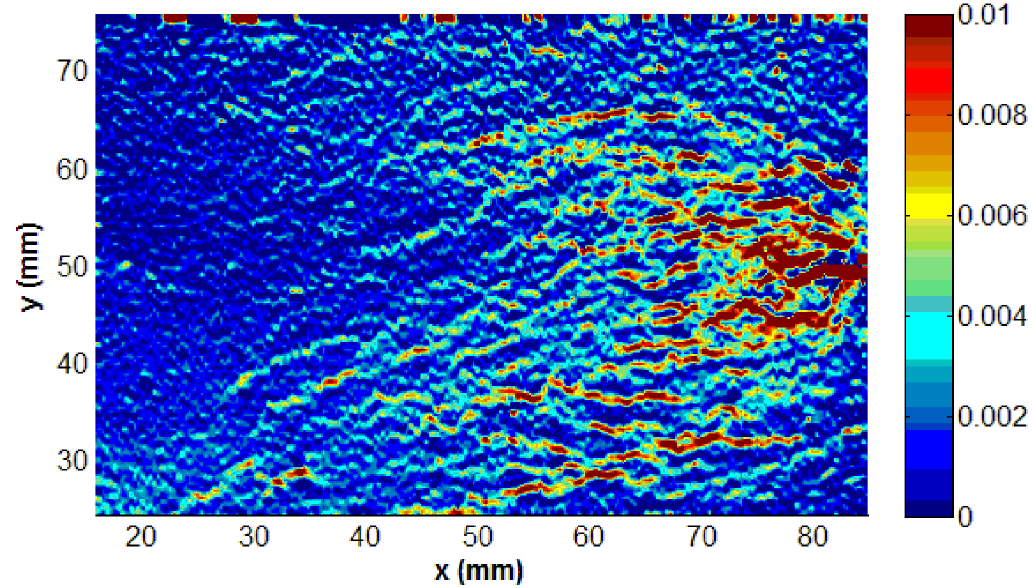


5kN load cell
Constant displacement speed of 2mm/mn
Sample dimensions: 300x100x10 mm

The scalar damage value is defined as the relative decrease of elastic modulus after unloading of the sample (0 < D < 1)

Mechanical characterization





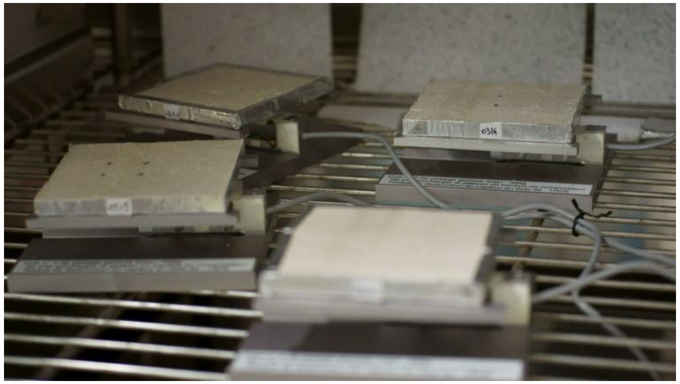
Strain vs. x-y position on the sample surface
View at peak strain with Icasoft© software

Digital Image Correlation used to visualise the strain field on the surface of the sample

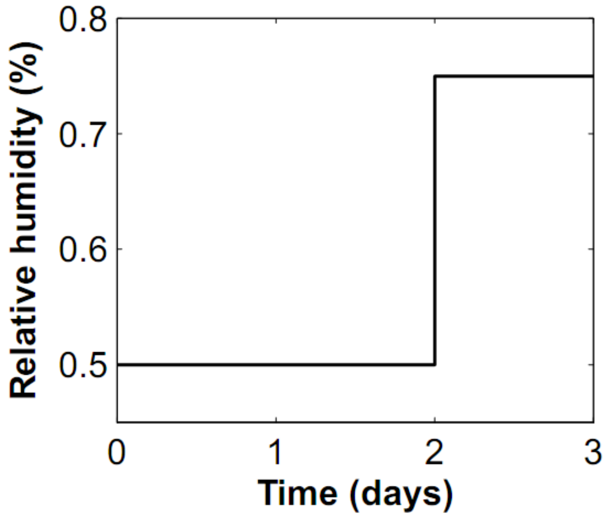
➢ important local discontinuities before propagation of a macroscopic crack

➢ possible preferential paths for moisture uptake

Mass uptake measurements during hygric cycles

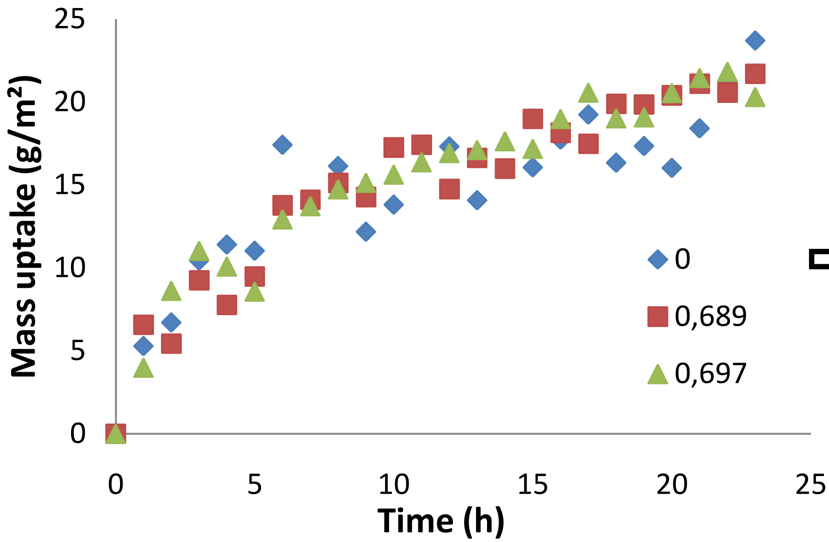


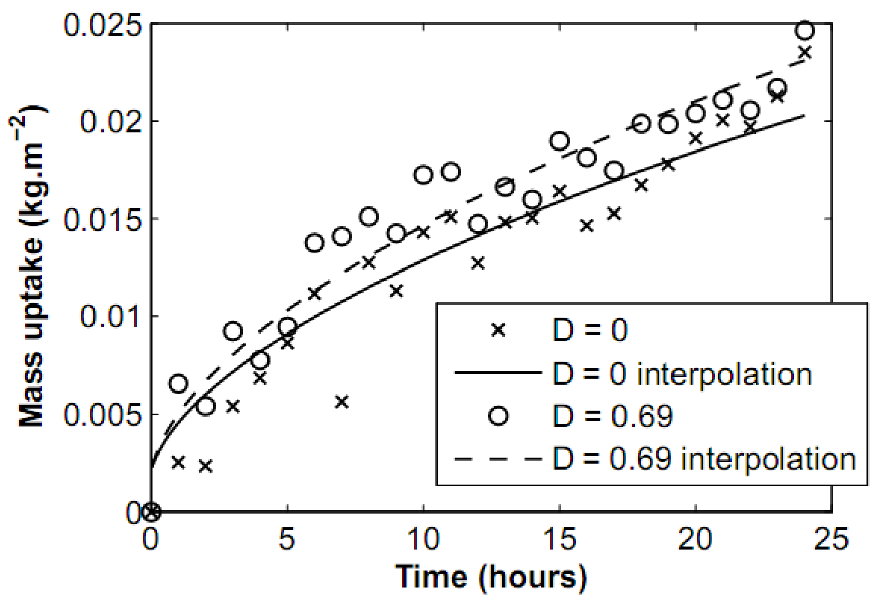
Samples of dimensions 100x100x10 mm, insulated on 5 faces



- The samples are placed on scales inside a climatic chamber
- Continual recording of the samples weight with up to 10^{-3} g precision
- The samples are insulated on 5 faces as to ensure 1D moisture transfer

Approximation of the mass uptake profile





$$m = L\xi\Delta\phi\left[1-\sum_{k=1}^{\infty}\frac{2\sin^2 a_k}{a_k\left(a_k+\sin a_k\cos a_k\right)}\exp\left(-a_k^2\frac{\delta_p}{\xi}\frac{p_{sat}t}{L^2}\right)\right]$$

The Levenberg-Marquardt algorithm is used in 3 steps for the estimation of the permeability

Approximation of the mass uptake profile

$$\left[\mathbf{J}^t\mathbf{J}\right]_n \mathbf{u}_{n+1} = \mathbf{J}_n^t \left[m_{exp,i} - m\left(\mathbf{u}_n, t_i\right)\right]$$

1) Simultaneous approximation of all parameters : $\mathbf{u} = \left(\delta_p, \xi, h_p\right)$
   - ➢ inaccurate estimation of the moisture equilibrium content

2) Approximation of the permeability and surface transfer coefficient : $\mathbf{u} = \left(\delta_p, h_p\right)$

D	0	0.401	0.497	0.689	0.697
δ_p [kg.Pa^{-1}.m^{-1}.s^{-1}]	6.57×10^{-13}	10.7×10^{-13}	8.43×10^{-13}	7.87×10^{-13}	7.97×10^{-13}
h_p [kg.Pa^{-1}.m^{-2}.s^{-1}]	7.94×10^{-9}	11.5×10^{-9}	9.10×10^{-9}	6.04×10^{-9}	7.03×10^{-9}

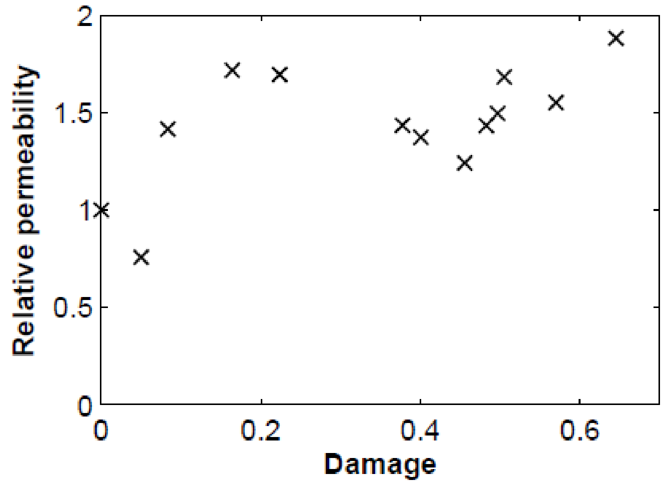
   - ➢ variation of the surface transfer coefficient

3) Approximation of the permeability with an averaged surface transfer coefficient : $\mathbf{u} = \delta_p$

D	0	0.401	0.497	0.689	0.697
δ_p [kg.Pa^{-1}.m^{-1}.s^{-1}]	6.55×10^{-13}	11.7×10^{-13}	8.51×10^{-13}	7.70×10^{-13}	7.80×10^{-13}

   - ➢ increase of permeability with damage

Results and conclusion



• Increasing values of the water vapour permeability with higher values of damage

• High uncertainty due to the coarse definition of the damage variable and the measurement precision

➢ necessity of a finer characterization of the fracture network

Discussion