Prediction of the impact of shrinkage on concrete strength with the beam-particle approach

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PREDICTION OF THE IMPACT OF SHRINKAGE ON CONCRETE STRENGTH WITH THE BEAM-PARTICLE APPROACH

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Abstract

Durability is a relevant criterion for preserving a safe structure and avoiding the renewal of costs. However, several phenomena – such as delayed deformation, corrosion, leading to cracking – can severely affect the service life. Not only cracks opening have an influence on concrete performance, but also the crack pattern. In the case of drying shrinkage, due to the low rate of gas and water transfers, stress that may lead to a network of micro-cracks Mechanical and hydric properties are directly impacted by those cracks.

Therefore, it seems essential to consider shrinkage when studying cracking of cementitious materials. This study focuses on a beam-particle model in order to investigate the formation and impact of drying shrinkage cracks. The cohesion of the material is obtained with a lattice of Euler-Bernoulli brittle beams. When a crack occurs, cohesion disappears. To capture the crack closure, a contact law with friction is considered between the polygonal particles. 2D simulations on three points bending test with or without considering drying shrinkage are performed.

The finite element method is used to obtain the drying shrinkage strain field. Then, a reanalysis method – inspired from [1]– is used to obtain the cracking patterns caused by drying. The parameters of the numerical models are identified on the results of an experimental campaign carried out by Soleilhet.F [2]. This same campaign is then used to validate the pertinence of an explicit representation of cracking.

Introduction

In this paper, the beam particle model and the hydric transport model are presented. Then, three points bending modelling is achieved in two cases: with and without considering previous drying.

Moreover, the beam-particle model generates a random mesh which represents material's heterogeneity. It reproduces the experiment variability.

1. Beam-particle model

This model is constituted by a set of polygons. It is generated in four steps [3] with a Voronoi's tessellation and Delaunay's triangulation. Each rigid particle has a centroid which is randomly placed, to represent the material's heterogeneity. They are connected to each neighbour with Euler-Bernoulli brittle beam to represent cohesion between particles "Figure 1" . E, α, A_b, l_b respectively represent beam young modulus, the inertia, the cross-section area and the length. $\overrightarrow{U_i}, \overrightarrow{U_j}, \theta$ are the three degrees of freedom: 2 translations, 1 rotation. Otherwise, a contact law with friction is introduced to represent particles interaction such as cracks closure.

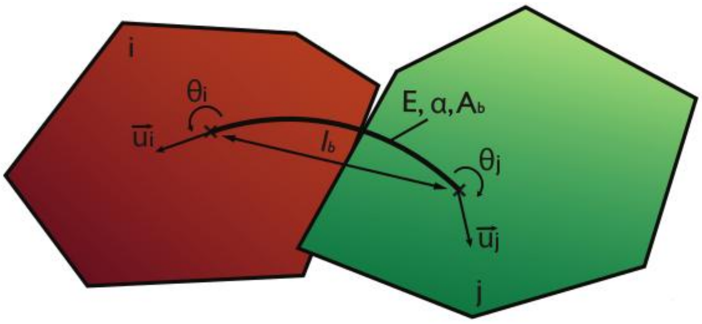

Figure 1 Linked particles [3]

These mechanisms permit to capture the elastic and softening behaviour. Indeed, for a mechanical or a hydric loading, a breaking criterion based on Mohr Coulomb is considered [3] with deformation and beam's rotation, which represent particles displacement. When the criterion threshold is reached the beam is deleted. The link between two particles disappears and it permits to obtain an explicit crack opening.

Furthermore, due to random mesh, each simulation gives different results. Experiment variability is represented. Contrary to an experiment campaign, virtual testing permit to generated more than 3 specimens which is generally considered in an experiment campaign. A statistic model is taken account with the normal distribution. Properties such as flexural strength average seem to convert with more than 20 tests.

2. Hydric transport model

In this study, two steps are needed to obtain a hydric strain field. A simulation is realised on Cast3m which is a finite element program. Then a reanalysed method is used [1]. This method acts as a bridge between continuum and discrete models.

The hydric transport model is based on a non-stationary transport equation with "Eq.(1)". It is supervised with initial intern and extern moisture. In this equation, liquid transfer is supposed.

$$\phi \frac{\partial S}{\partial P_c} \frac{\partial P_c}{\partial t} = \left(\frac{K.k_r}{\mu} grad(P_c) \right) \quad (1)$$

ϕ is material's porosity, S the degree of saturation, P_c the capillarity suction, k_r the relative permeability, K the permeability and $\mu$the water viscosity. These parameters are identified with van Genuchten model which is basically developed for soil [4] It is also supposed that liquid moisture transport is predominant compared to gas transport in a considered interval of moisture [5]. Otherwise, relative permeability is determined with "Eq. (2)", with the parameter m.

$$k_r = \sqrt{S} \left(1 - \left(1 - S^{\frac{1}{m}} \right)^m \right)^2 \quad (2)$$

Degree of saturation is obtained with "Eq. (3)". Then, Kelvin-Laplace equation "Eq. (4)" permits to create a link between capillary suction and relative humidity with ideal gas hypothesis.

$$S(P_c) = \left(1 + \left(\frac{|P_c|}{a} \right)^{\frac{1}{1-m}} \right)^{-m} \quad (3)$$

ρ bulk weight, $R = 8.314 Jmol^{-1}K^{-1}$, T temperature, M molar mass, HR relative humidity.

$$P_c = \frac{\rho RT}{M} ln\,(HR) \quad (4)$$

Once the finite element analysis is realised, a hydric strain field is obtained. The reanalysis method [1] permits to project nodes or gauss points of this strain field on the beam-particle discretisation. The shrinkage induces a force which is locally estimated on each beam. Then, the discrete model converges to a steady state which induces cracks due to the breaking criterion. Results represent explicit cracks' expansion and trajectory [6].

3. Three points bending modelling

In this part, 2D three points bending simulations are performed to determine the impact of drying shrinkage on an 84x10cm specimen "Figure 2". 21 000 nodes are generated in the random mesh, which is equivalent to 63 000 degrees of freedom. Concerning boundary conditions, an isostatic case is considered. The mechanical and hydric parameters correspond to Soleilhet.F [5] concrete. Then, beam-particle model's parameters are identified. 26 simulations are performed with or without modelling shrinkage. Experimentally [5], drying specimens are conserved in a controlled room at temperature 25°C (±1°C) and 36% RH (±5).

Beam-particle parameters permit to characterise quasi-brittle material's behaviour. Then, drying simulations are realised with the same set of parameters to predict the drying impact on strength resistance.

Figure 2 Cracking pattern

On "Figure 3", numerical and experimental forces-displacements curves are represented. The identification reveals a difference of 2.7%.

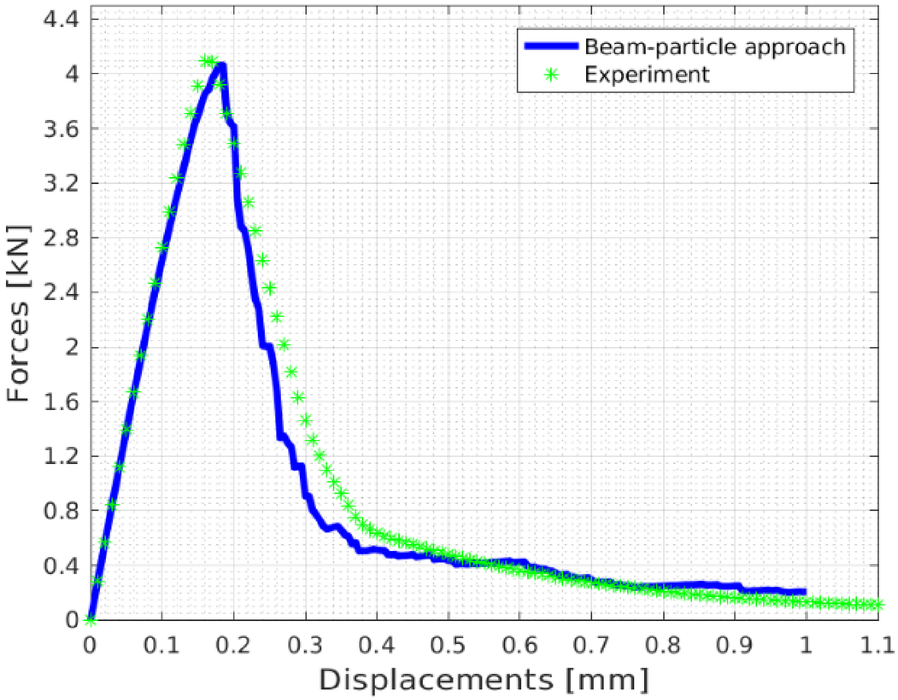

Figure 3 Three points bending forces-displacements average curves without shrinkage

For non-drying case, the results are given in "Figure 3" and for drying case results are given is "Figure 4". It demonstrates a reduction of 12% of the maximum flexural strength due to initial strains at the peak, in the numerical model. Furthermore, in the elastic part, Young modulus decreases slightly due to previous micro-cracks formed during shrinkage. The cracks opening is in the order of 10 μm

In drying case, because of three points bending, the upper part of the beam is compressed, previous shrinkage cracks are closed, and particles are interacted to model the unilateral effect and the stiffness' recovering, whereas on the down side, the beam is in tensile state and cracks are still opened.

Otherwise, contact law, between particles, has an impact on post peak behaviour. Indeed, with contact law between each particle the drop is less significant because cracks' closure is considered.

On "Figure 4", the beam-particle model's prediction underestimates the experimental curves. Indeed, it has to consider complementary phenomena. The comparison between numerical and experimental results reveals a difference of 12% at the peak. The average of 26 virtual testing drying specimen is represented on the force-displacement curve. Standard deviation reveals that the maximal and minimal strength force is respectively included between 20% and 14% of the average value.

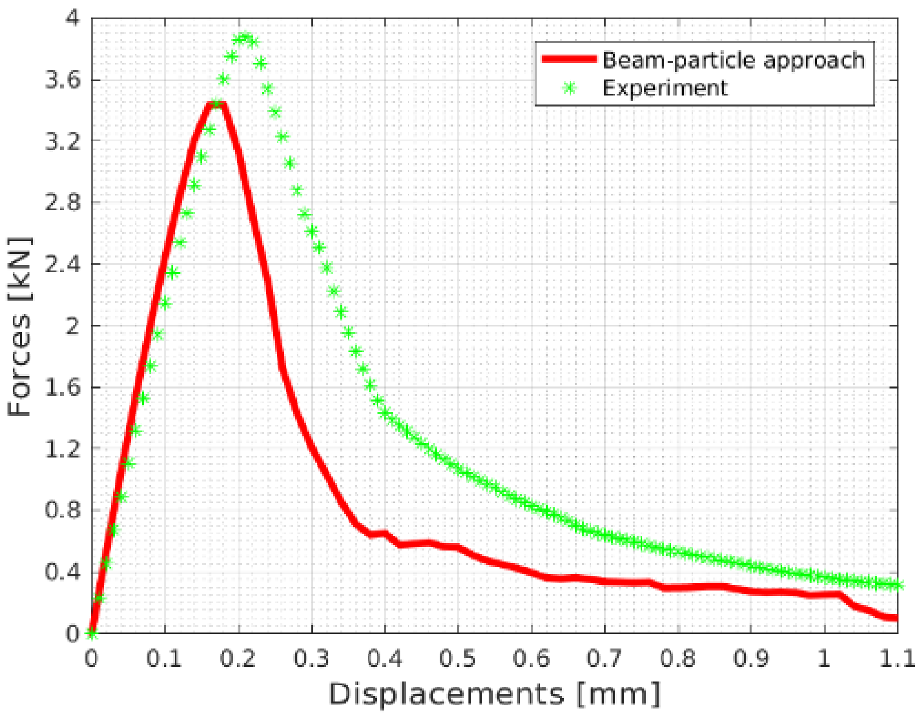

Figure 4 Three points bending forces-displacements average curves with shrinkage

It is important to emphasize that experimentally, there's generally not enough considered specimens to represent reality with certainty.

It is noticed that the main crack caused by mechanical loading is often initiated on a shrinkage crack. It is not possible to claim that shrinkage cracks directly impact the specimen force-strain, with certainty. Indeed, in Euler-Bernoulli beam's theory, three points bending test induces a maximal moment at the middle of the beam. However, numerical crack appears around this zone.

So therefore, to examine only the macroscopic crack openings without forcing the initiation in the middle of the beam, four points bending tests are achieved. As a matter of fact, moment is both maximal and constant between the two points of loading.

Besides, the prediction of decrease of flexural strength and Young modulus are lower (and thus closer to experimental values) than the ones obtained with a macroscopic damage approach [2]. This may be due to the explicit considered cracking and cracks closure. The consideration of additional phenomenon such as creep should also improve the numerical results.

5. Conclusion

In this study, the impact of shrinkage on concrete's strength is examined with a beam-particle approach. It indicates that natural shrinkage due to a gradient of moisture, induces a decrease of concrete's strength.

Then, this decrease depends on crack initiation. Indeed, in case of mechanical crack initiation on a previous shrinkage crack, a drop of 12% of the flexural strength is observed.

Variability is also highlighted. Maximal force strength depends on material heterogeneity, which is represented by Voronoi polygons' mesh. The model's confidence interval seems to be excessive to represent the reality.

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