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THE NUMERICAL HOMOGENIZATION OF THE CONCRETE BEHAVIOR

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Summary The following extended summary will expose a numerical model using the finite element method to evaluate the concrete homogenized behavior. In this present paper, we describe the model and some results on the damage evolution of a High Strength Concrete subjected to thermal loads.

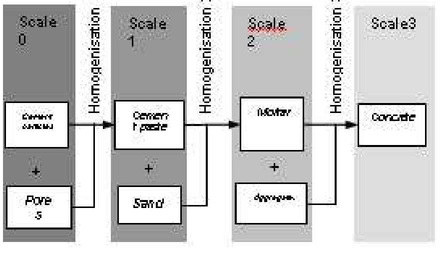
INTRODUCTION

In this research we propose to simulate the cement-based materials behavior subjected to thermal, hydrous and mechanical loads using multi-scales approaches. Multi-scales techniques allow characterizing, from the knowledge of the microstructure, the heterogeneous material behavior by substituting it an equivalent homogeneous material. Using these approaches, it is then possible to reach the local fields and so, to be able to predict and to follow the evolution of the damage within the microstructure. Various homogenization models have been proposed these last years [1]. These models are different of the choice of the Representative Elementary Volume (REV) of the material and the way with which the load is applied. Simplified approaches adopt a REV with simple geometries, and representing only one heterogeneity to give explicitly the equivalent behavior [1]. The homogenization of periodic media is a numerical approach and gives a good approximation of the local fields. It allows to model accurately the microscopic damage [2]. These approaches require, in most of cases, a numerical resolution. Others numerical approaches are based on a more realistic representation of the REV by describing the microstructure of porous media with a random generation of the heterogeneities size distribution [3]. Either by a digital-image-based [3], or by a finite element method [4]. Our numerical method is based on the exploitation of the Digital Concrete model (" Béton Numérique ") [5] developed in the general Finite Element (F.E.) code 'SYMPHONIE'. This model allows the generation of a rich and more realistic REV by considering the heterogeneous microstructure as a multi-phases material. It takes in account the aggregate and pore size distributions. These heterogeneities are generated in a random way inside the REV which is discretized by the finite element method. Here, we present first the numerical aspects concerning the REV grid generation. After, we remind briefly the method of homogenization in the case of a linear thermal-hydro-mechanical problem. The application of the model concerns the study of a High Strength Concrete (HSC) subjected to thermal loads. By using the multi-scales approaches, the global damage is defined by local damages in the microstructure. Finally, the equivalent permeability of the concrete is evaluated as a function of the damage evolution.

THE DIGITAL CONCRETE MODEL

The Digital Concrete implementation

In this method, we consider several scales of modelling: cement paste, mortar, and concrete. The homogenization is needed on each scale to go to the following upper one (scheme below). The local approach is based on the random 'Digital Concrete' model developed by Mounajed [5]. The random character is due to the concrete heterogeneously led by the random aggregate size distribution, and the random pore size distribution in the cement paste. Aggregates and pores have some characteristics different of the solid cement matrix. The proposed approach allows considering the Digital Concrete material as a multi-phases material with successions of n materials phases distributed spatially in a random way. After the model has validated the inclusions position, the finite elements concerning these inclusions are affected by the material characteristics defined by the user. The model verifies that two heterogeneities do not overlap.



Homogenization of a thermal-hydro-mechanical problem

The homogenization principle defines the equivalent homogeneous behavior for heterogeneous materials. The material equivalent homogeneous behavior is given by the following homogenized behavior law [6]: $\mathbf{\Sigma} = \mathbf{C}^{\mathbf{hom}} : \left(\mathbf{E} - \alpha^{\mathbf{hom}}\mathbf{\Delta}\theta\right)$.

The macroscopic stress field $\mathbf{\Sigma}$ is so defined as the average on the REV of microscopic stresses, solutions of the cellular problem, generated by the imposed macroscopic strain field $\mathbf{E}$. In practice, the rigidity homogenized tensor $\mathbf{C}^{\mathbf{hom}}$ and the thermal expansive tensor $\alpha^{\mathbf{hom}}$ are obtained due to the problem linearity. Results obtained appear in good agreement with experimental results [7]. As the same way the equivalent homogeneous permeability tensor ($\mathbf{K}^{\mathbf{hom}}$) is then given by the Darcy's law [8].

STUDY OF A HIGH STRENGTH CONCRETE BEHAVIOR

The localization principle constitutes the interest of the homogenization method proposed with regard to certain simplified homogenization approaches. These approaches do not take in account interactions between heterogeneities. In this frame a study of a thermal-mechanical coupling with damage was realized. The Digital Concrete model is coupled with the damage model MODEV developed in SYMPHONIE [9]. The model allows evaluating the global damage according to the local damage evolution in the microstructure. After, the equivalent permeability is calculated and we define a relation between the permeability and the damage of the High Strength Concrete. The localization principle allows evaluating the damage evolution in the microstructure and predicting the failure growth. The follow-up of the drainage at the microscopic scale can turn out of a big interest, in the damage modelling, the role which the water can play in the coupled behavior for these materials. We can imagine this interest to simulate, for example, the microstructure degradation further to high variations in temperature (fires, freeze-thaw ...).

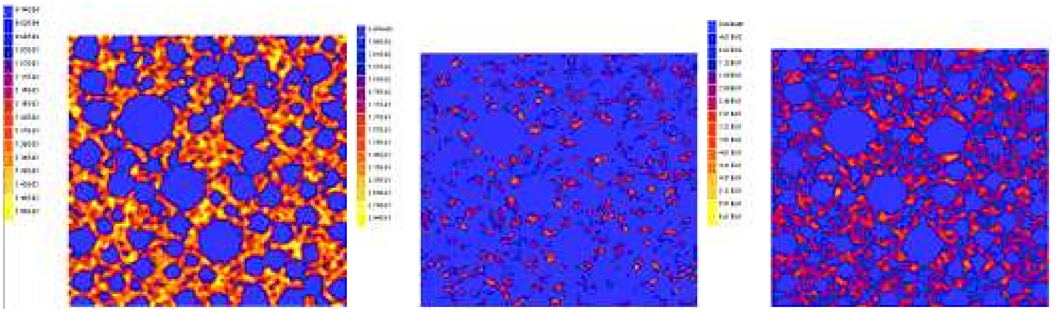


Figure 1. Simulation results for the damage calculus in a HSC under thermal loads (thermal strain fields, damage at $50°C$, $120°C$)

CONCLUSION

In this research, we adopt a multi-scale approach to identify the thermal-elastic behavior concrete as well as the effect of the damage evolution on the permeability of the material. This is done by using a numerical method based on the Digital Concrete model developed into the general F.E. code SYMPHONIE. It allows characterizing the concrete homogenized behavior under a thermal-mechanical load by a multi-scales approach. We take in account random heterogeneities size distributions at the mortar scale and at the concrete scale. The obtained simulations results confront in a completely encouraging way with experimental results [10]. Furthermore, this method allows reaching the strain fields and the stress fields which reign in the microstructure. The damage evolution is observed with a micro-mechanical analysis. Recent studies allow determining the equivalent permeability of the HSC, from the permeability of material constituents.

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