Offre de Thèse EDF / Mines Paris

Modélisation micromécanique de l'endommagement et des phénomènes de gonflement dans les bêtons /

Micromechanical modeling of damage and swelling in concrete materials

École doctorale / doctoral school : ED 621 ISMME Ingénierie des Systèmes, Matériaux, Mécanique, Énergétique

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Thesis director / Directeur de thèse : François Willot

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Context and objectives of the PhD thesis

Swelling phenomena in concrete materials may be induced by a variety of factors, including thermal expansion, neutron irradiation, alkali-silica reactions. These phenomena typically induce local internal expansion and residual stresses, before damage starts to localize. Over long periods of time, a weakening of the overall mechanical response is generally observed. A physically-sound model of the overall behavior of concrete must incorporate both mechanical and geometrical factors. These include the material's loading history — whether thermal, hygral, chemical, physical or mechanical — the viscous behavior of the mortar, the fracture toughness at the mortar–

aggregate interface, and the geometry and spatial distribution of the aggregates. In addition, the model should account for potential damage to both the aggregates and the cement paste caused by localized swelling phenomena. The present PhD thesis focuses on the development of both full-field numerical homogenization tools as well as semi-analytical models in order to assess the role of each mechanical aspect at play. Given the complexity of the problem, these mechanical phenomena will be included incrementally in order to decouple them and understand their role. Different heterogeneous microstructures representing concrete will be considered: simplified models consisting of one or more aggregates embedded in a mortar matrix, with an interphase transition zone; large representative volume elements (RVE) or cylindrical RVEs that mimic experimental tests. The fast Fourier transform (FFT) method will be combined with a recently developed phase-field model to account for crack nucleation and propagation. This phase-field model will be extended to address aging viscoelasticity in the time regime, with flexible choices regarding creep laws as well as thermal loadings.

During the PhD thesis, mechanical predictions will be validated at all steps by experimental measurements obtained or already available from EDF. EDF will provide expertise on concrete materials, including experimental tests, numerical micromechanical modeling and analytical models as well as mechanics. The CMM lab of Mines Paris has a large expertise in FFT-based methods and micro-mechanical solvers as well as homogenization and description and simulation of microstructures.

References

[1] Willot, F. (2015). Fourier-based schemes for computing the mechanical response of composites with accurate local fields. Comptes Rendus Mécanique, 343(3), 232-245.

[2] Schäfer, S., Willot, F., Bale, H., Rad, M. N., Kelly, S. T., Enke, D., & e Silva, J. M. D. S. (2025). Intermittent in-situ high-resolution X-ray microscopy of 400-nm porous glass under uniaxial compression: study of pore changes and crack formation. Scripta Materialia, 255, 116396.

[3] Bary, Benoît, Julien Sanahuja, and Yann Le Pape. "Mesoscale modelling and simulation of irradiation-induced expansion in concrete." International Journal of Mechanical Sciences 283 (2024): 109646.

Expected candidate profile

We seek a Master 2 research (or equivalent to master 2) student in mechanics or applied mathematics with a strong mathematics or engineering background, excellent coding proficiency and communication skills. To apply, please send a detailed resume, motivation letter and any relevant document such as academic transcription, recommendation letters, student reports to: jean-luc.adia@edf.fr, julien.sanahuja@edf.fr and francois.willot@minesparis.psl.eu