EMI 2023 International Conference
Palermo, Italy, August 27 - 30, 2023

Title: A Finite Element approach to address the 3D coupled thermo-mechanical and neutron diffusion problem on cementitious materials

Authors: Jiangkun Zhang[1], Beatrice Pomaro*[1], Gianluca Mazzucco[1], Beaudin Freinrich Dongmo[1], Valentina Salomoni[2], Carmelo Majorana[1]

[1] Department of Civil, Environmental and Architectural Engineering, University of Padova, Via F. Marzolo 9, 35131 Padova, Italy, jiangkun.zhang@phd.unipd.it, beatrice.pomaro@unipd.it, gianluca.mazzucco@unipd.it, beaudinfreinrich.dongmo@phd.unipd.it, carmelo.maiorana@unipd.it

[2] Department of Management and Engineering, University of Padova, Stradella S. Nicola 3, 36100 Vicenza, Italy, valentina.salomoni@unipd.it

Keywords: Multiphysics; Multiscale; Coupled problems; Finite Elements; Irradiated concrete

Abstract

Concrete is an attractive material for nuclear radiation shielding purposes [1]. Structural and integrity assessment of biological shielding during the operational life of nuclear facilities invokes the study of the interrelated physical mechanisms taking place in the absorbing medium during irradiation. This work pursuits the idea to address the problem via a deterministic approach, formulated within the framework of continuous numerical methods. Specifically, a Finite-Element based formulation for cementitious materials at in-service irradiation conditions is proposed. The model combines thermo-mechanical, and neutron diffusion processes. The mathematical problem resorts to a two-group neutron diffusion theory to tackle the particle transport problem [2]. The heat conduction theory takes into account the transition of fast to thermal neutrons, and the heat rise due to the thermalization process of the fast neutron flux during radiation absorption. The interaction between the thermal, and the radiation field with the mechanical field reflects on both, thermal expansion, and radiation-induced volume expansion [3] effects on concrete. The weak formulation of the system of governing equations is derived via a Galerkin approach. Discretization in time is accomplished by using an implicit finite difference scheme. The strong problem is, then, reconducted to the solution of a nonlinear system of ordinary differential equations, for which a monolithic solution is sought, iteratively, via a Newton Raphson scheme in terms of the state variables of the problem. The performance of the model is checked through the results provided by theoretical models available in the literature [4]. For the purposes of investigating material durability, the proposed numerical formulation is extended to the mesoscale. From the results obtained at this scale, considerations are made on the aggregate, and macropores distribution in relation to heat, and particle fluxes.

References

[1] Kaplan M.F., Concrete radiation shielding: Nuclear physics, concrete properties, design, and construction, John Wiley & Sons Ltd, New York (1989).
[2] Price B.T., Horton C.C., Spinney K.T., Radiation shielding, Pergamon Press, London (1957).
[3] Kontani O., Ichikawa Y., Ishizawa A., Takizawa M., Sato O, "Irradiation effects on concrete structures", book chapter 27, 459-473. In: Infrastructure systems for nuclear energy, John Wiley & Sons Ltd (eds T.T.C. Hsu, C.-L. Wu and J.-L. Li) (2014).
[4] Jing Y., Xi Y., "Modeling long-term distribution of fast and thermal neutron fluence in degraded concrete biological shielding walls", Construction and Building Materials, 292, 123379, 2021.