The 8th European Congress on Computational Methods in Applied Sciences and Engineering
ECCOMAS Congress 2022
5-9 June 2022, Oslo, Norway

A FE^4 multiscale scheme for CNT-reinforced concrete accelerated by deep neural networks

Stefanos Pyrialakos[*,1], **Ioannis Kalogeris**[2], **Vissarion Papadopoulos**[1]

[1] MGroup, Engineering Simulations Lab, Institute of Structural Analysis and Antiseismic research, National Technical University of Athens, 15780 Athens, Greece
[2] Computational Science and Engineering Laboratory, ETH Zürich, CH-8092 Zürich, Switzerland

Keywords: *concrete, carbon nanotubes, multiscale scheme, nonlinear homogenization, neural networks, surrogate modeling*

This work presents a hierarchical modeling strategy developed for the analysis of structures comprised of carbon nanotube-reinforced concrete. With respect to the material modeling, a 3-level approach is considered in order to characterize the mechanical properties of the composite material at multiple scales. Specifically, cement paste enhanced with carbon nanotubes (CNTs) is studied at a microscale level, and subsequently the reinforced mortar consisting of the CNT-enhanced cement paste as the host material and small-size aggregates as inclusions is studied at a mesoscale level. The next scale consists of the previously defined reinforced mortar along with large-size aggregates and, lastly, a structure made up from the composite constitutes the macroscale problem. In all cases, information between two consecutive scales is passed using a FE^2-based homogenization technique, leading to a multiply nested scheme, termed FE^4 herein. To overcome the immense computational demands of this approach, feed-forward neural networks are utilized to approximate the nonlinear constitutive laws of each scale. The data required for training these neural networks involve pairs of strain vectors and material parameters as inputs and the corresponding stresses as outputs, which are collected by performing nonlinear homogenization on representative volume elements of each scale. Ultimately, the surrogate modeling process results in the substitution of the FE^4 scheme with one single neural network. This leads to a remarkable computational speed up that enables us to perform sensitivity analysis on the macroscale structure and examine how the variability of the material's constitutive law parameters impact the macroscopic response. Even though this process requires a large number of model runs, it is performed at a reasonable computational cost, by virtue of the elaborated surrogate modeling scheme.