Multiscale engineering performance of conductive nanocarbon-black (nCB) cement composites

Nancy A. Soliman [1], Konrad J. Krakowiak[2], and Franz Joseph Ulm[3]

Abstract

The development of multifunctional concrete has produced a revolution in the field of concrete materials toward achieving sustainable infrastructures. Once of these emerging multifunctional technologies is the electron-conductive-nanocarbon (nCB) cement composites. Our previous investigation of the electrical conductivity of nCB-cement composites revealed that electrical conductivity is obtained by the electric tortuosity of a "volumetric wiring" of nCB (from percolation to saturation dosages) permeating a highly heterogeneous cement matrix. The current research investigates how the origination of the connected network of nCB 'volumetric wiring' can affect the mechanical and microstructure performances of the nCB-cement composite. This study fosters new understanding of the macroscale mechanical performance with a top-down multiscale approach.

The experimental work performed on cement pastes of three water-to-cement ratios (*w/c*) (0.35, 0.42, and 0.60) incorporating various nCB contents ranging from 0-15% (total volume). We measured the macroscale mechanical performance (compressive strength). The findings were supported by microstructure investigations, namely, micromechanical properties (hardness, and indentation modulus) of microstructure phases using micro and nanoindentation. The fracture toughness property using scratch test at the microscale was also investigated. The cohesion and friction property as well as packing density were also analyzed from the obtained data.

The results showed that the incorporation of the nCB yielded 15–50% reduction in the macro-mechanical strength depending on the *w/c* and the nCB content. Interestingly, this reduction was found to sprout from the decomposition at microstructure scale. At the microscale, the addition of nCB led to a decohesion of the matrix while led to a friction enhancement. This reduction was driven by twofold microstructure changes, i.e.: decreasing the packing density of C-S-H particles and formation of a third low stiffness/hardness phase (volumetric wiring), which permeates through the microstructure. The distinct texture of the volumetric wiring that resulted in electron conductivity, entailed a macroscopic decohesion. Simultaneously, the nCB addition showed an increase in the fracture toughness and fracture energy, attributed to the physical filling effect of the nCB that dispersed homogenously into the cement matrix.

The combined use of microstructural and micromechanical characterization tools at multiple scales provides valuable information towards the material design of electron-conductive-cement-carbon composites. Given the global environmental footprint of concrete, the results can open new venues for the sustainable development of concrete for existing and emerging green technology applications.

[1] Postdoctoral Associate, Department of Civil and Environmental Engineering. Massachusetts Institute of Technology. Cambridge MA 02139, USA, Email: nsoliman@mit.edu

[2] Assistant Professor, University of Houston, Civil and Environmental Engineering Department
Email: kjkrak@uh.edu

[3] Professor and Director of Concrete Sustainability Hub, Department of Civil and Environmental Engineering. Massachusetts Institute of Technology. Cambridge 02139, USA. Email: Ulm@mit.edu