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Micromechanics modeling of the electrical conductivity of carbon nanotube cement-matrix composites

Enrique García-Macías[a,*], Antonella D'Alessandro[b], Rafael Castro-Triguero[c], Domingo Pérez-Mira[d], Filippo Ubertini[b]

[a]*Department of Continuum Mechanics and Structural Analysis, School of Engineering, University of Seville , Camino de los Descubrimientos s/n, E-41092-Seville, Spain*
[b]*Department of Civil and Environmental Engineering, University of Perugia, Via G Duranti 93, Perugia 06125, Italy*
[c]*Department of Mechanics, University of Cordoba, Campus de Rabanales, Cordoba, CP 14071, Spain*
[d]*Department of R&D, Construcciones AZVI, Seville, Spain.*

Highlights

- Micromechanics modeling of the electrical conductivity of cement-based nanocomposites
- Wavy state of nanotubes modeled by means of a helical approach
- Two-parameter agglomeration model of non-uniform spatial fibers distribution
- Incorporation of electron hopping and conductive network mechanisms

Abstract

The incorporation of Carbon Nanotubes (CNTs) as nanoinclusions for the development of electrically conductive cement-based composites opens a vast range of possibilities for monitoring of concrete structures. A key issue for the design and optimization of these composites is the development of theoretical models capable of providing a quantitative prediction of their overall electrical conductivity. Experimental results have evidenced the strong influence of the waviness and dispersion of the nanotubes on the overall conductivity of these materials, what makes the consideration of these two phenomena essential for the development of realistic theoretical models. Nevertheless, both waviness and agglomeration have been often neglected in the literature or, when considered, have been reproduced with very simple modeling approaches not suitable to catch the complexity of the problem at hand. This paper presents an improved micromechanics model of the effective electrical conductivity of CNT cement-based nanocomposites based on enhanced approaches for reproducing waviness and non-uniform spatial distributions of the nanoinclusions. The two mechanisms that govern the electrical conductivity of these composites, electron hopping and conductive networks, are incorporated in the mixed micromechanics model. On the basis of scanning electron microscopy inspections, a helical waviness model and a two-parameter agglomeration approach are proposed. In order to assess the accuracy of the proposed analytical model, cement-based specimens have been manufactured and tested for providing data to use as the basis of comparison. In particular, specimens of cement pastes, mortars and concretes with different concentrations of Multi-Walled Carbon Nanotubes (MWCNTs) have been prepared. It is shown that the consideration of straight uniformly distributed nanotubes, as typically done in the literature, leads to an overestimation of the overall conductivity. On the contrary, it is highlighted that the wavy state of the fibers as well as their agglomeration in bundles play a crucial role in the conductivity of cement-based nanocomposites, which is demonstrated by achieving a good fit to the experimental data when using the proposed models for waviness and agglomeration. Overall, the paper highlights the physical mechanisms governing the overall electrical conductivity of cement-based composites with MWCNTs and provides a powerful analytical tool for their design.

Keywords:
Carbon nanotube, Cement-matrix composites, Electrical modeling, Percolation, Smart concrete, Structural Health Monitoring

*Corresponding author.
Email address: egarcia28@us.es (Enrique García-Macías)