An intermediately-homogenized electromechanical peridynamic model for damage and fracture in composites

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Abstract

Random networks of conductive nanofibers within a polymer matrix have been increasingly considered for use in flexible and transparent electronics, strain sensors, etc. as they offer higher sensitivity and superior electrical properties. The numerical simulation of the electromechanical response usually includes either homogenization of material properties or of explicit, high-resolution microstructural representations. The homogenization methods may not work, especially when damage and fracture are included, for example, in the case of strain and damage sensing.

In this work, we introduce an intermediate (or partial) homogenization peridynamic (IH-PD) approach for electromechanical modeling of deformation, damage and consequent piezo-resistive response in conductive nanofibers-based nanocomposite. In this model, peridynamic mechanical-bonds are superposed onto recoverable electrical-bonds. Different from the explicit heterogeneity method (which has major limitation on the simulation size), in the IH-PD model we have two types of bonds: inter-phase and intra-phase bonds, representing properties of the distinct composite phases and of interfaces between them. For nanofibers-based nanocomposites with phases A (conductive nanofibers) and B (non-conducting polymer), we define A-A bonds (intra-phase) for the first phase, A-B bonds (inter-phase), and B-B bonds (intra-phase) for the second phase [1]. The distribution of the different bonds depends on the volume fraction of the phases in the nodes. While the specific geometry of the microstructure is not preserved, the specific volume fraction is and, in many instances, this is a critical parameter in modeling the evolution of damage [2].

We verify the IH-PD model of electrical conduction using experimental data for electrical conductivity of metal matrix composites containing high volume fractions of non-conducting inclusions. The model is then used to study damage and the piezo-resistive response under 2D uniaxial tensile tests. Comparisons with the fully homogenized model and the explicit microstructure one show that the IH model captures key deformation and damage mechanisms associated with the complex material (obtainable with an explicit model but not with the fully homogenized one), while preserving the computation efficiency of fully homogenized computations. This model can also be extended to other multi-physical problems with damage and fracture.

[1] Chen, Z., Niazi, S., Zhang, G., & Bobaru, F. (2017). Peridynamic functionally graded and porous materials: Modeling fracture and damage. Handbook of Nonlocal Continuum Mechanics for Materials and Structures, 1-35.

[2] Chen, Z., Niazi, S., & Bobaru, F. A peridynamic model for damage and fracture in porous materials. Submitted.

Keywords: Peridynamics; Composites; Electromechanical model; Damage; Intermediate homogenization.