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Najmul Abid , Mohammad Mirkhalaf , Francois Barthelat

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Discrete-element modeling of nacre-like materials: effects of random microstructures on strain localization and mechanical performance

Najmul Abid, Mohammad Mirkhalaf and Francois Barthelat*

Department of Mechanical Engineering, McGill University, 817 Sherbrooke Street West, Montreal, QC H3A 2K6, Canada

*Corresponding author. E-mail address: francois.barthelat@mcgill.ca

Abstract

Natural materials such as nacre, collagen, and spider silk are composed of staggered stiff and strong inclusions in a softer matrix. This type of hybrid microstructure results in remarkable combinations of stiffness, strength, and toughness and it now inspires novel classes of high-performance composites. However, the analytical and numerical approaches used to predict and optimize the mechanics of staggered composites often neglect statistical variations and inhomogeneities, which may have significant impacts on modulus, strength, and toughness. Here we present an analysis of localization using small representative volume elements (RVEs) and large scale statistical volume elements (SVEs) based on the discrete element method (DEM). DEM is an efficient numerical method which enabled the evaluation of more than 10,000 microstructures in this study, each including about 5,000 inclusions. The models explore the combined effects of statistics, inclusion arrangement, and interface properties. We find that statistical variations have a negative effect on all properties, in particular on the ductility and energy absorption because randomness precipitates the localization of deformations. However, the results also show that the negative effects of random microstructures can be offset by interfaces with large strain at failure accompanied by strain hardening. More specifically, this