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Elastic Percolation of Composite Structures With Regular Tessellations of Microstructure

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Abstract

Enhancing the mechanical properties of materials by adding inclusions (particles) into microstructure is a favorite research area for material science researchers. In this paper, overall elastic properties of a microstructure are computed taking into account the effects of different geometrical shapes of inclusions. Representative volume elements (RVE) of the material's microstructures with different tessellations are constructed using a random generation method. The resulting RVEs obtained from the mentioned method were meshed and finite element method (FEM) was used to analyze the deformation of the microstructure including particles under tension and shear loadings. The FE results were then used to compute the stiffness the microstructure. Numerical results are compared with the available theoretical relations. The results show that the dependency of tensile and shearing properties of the microstructure on volume fraction of particles can completely have different trends in some ranges of volume fractions. Also the effects of mechanical percolation on the elastic properties of microstructures were obtained. The presented approach opens a systematic method for investigating the enhanced properties of microstructures with different shapes of tessellations.

Keywords:

Enhanced Mechanical Properties, Inclusion, Microstructure, Percolation, Lower Bound Limit

1. Introduction

Enhanced mechanical properties have been observed in polymer nanocomposites at uncharacteristically low volume fractions. These effects are thought to be due, in part, to the significant scale effect of the matrix–particle interface region in nanocomposites [1-3]. This interface region occurs as a result of a perturbation of the properties of the matrix material due to the presence of the included particles. Factors that may cause this perturbation are, e.g., the quality of bonding between phases of the material, confinement of the matrix, or interference in the mobility of the flexible chains of the polymer [4-6].
A number of researchers have attempted to include more mechanics in modeling mechanical percolation. Early work included the Generalized Effective Media model [7], which interpolated between a mean field model, at low volume fractions, and percolation theory, above the percolation threshold. This model has been used to predict both electrical and mechanical percolation [6, 8]. The series–parallel model included an intermediate parameter that described the volume fraction of material that was active in the transfer of forces [9]. A limitation of both of these models is that a previously identified value for the percolation threshold is required as input. In some cases the influence of an interface region, as well as the effects of clustering using the concentric cylinder micromechanics model, but not in the context of percolation thresholds [10]. A hybrid numerical analytic model was used in to investigate polymer nanocomposites with complex microstructural configurations; the model included the effects of an interface as a third, independent phase, i.e., not linked to particle placement [11]. The relative influence of the competing and compounding effects of the spatial position/distribution of the particles (microstructure) and of the composite constitution (micromechanics) are examined [12].