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Construction of statistically similar representative volume elements for discontinuous fiber composites

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Abstract

A computational method is proposed for the construction of statistically similar representative volume elements (SSRVEs) for discontinuous fiber composites (DFCs) in order to enable an efficient calculation of material properties based on computational homogenization. The SSRVE is obtained by solving an optimization problem which minimizes the difference between the power spectral density of a target microstructure and SSRVE. The SSRVE is constructed for a virtually generated target microstructure serving as an example for a DFC, which is validated by means of comparing the mechanical properties of the target microstructure with the ones of the SSRVE. The results show that the mechanical properties of the SSRVE agree with that of the target microstructure and that the SSRVE can extremely reduce the computational costs of finite element analyses to derive macroscopic material properties of DFCs.

Keywords: Fiber reinforced composites; Microstructure; Representative volume element; Macroscopic property; Heterogeneous material

1 Introduction

Discontinuous fiber composites (DFCs) with in particular long fiber reinforced thermoplastics [1] are spotlighted as an advanced material for lightweight design. It is important to analyze the mechanical properties in order to ensure the safety of lightweight constructions using DFCs. Usually, the mechanical properties are obtained by a series of material tests. An alternative way is to estimate elastic properties analytically by using mean field methods such as Eshelby’s inclusion [2], the Mori-Tanaka theory [3] or the self-consistent model [4]. The nonlinear mechanical behavior may be predicted using incremental Eshelby-Mori-Tanaka approach procedures [5]. Then, the nonlinear properties of matrix are linearized in each increment and the nonlinear behavior of the composites is calculated with the linearized properties based on the Mori-Tanaka theory. Fiber orientation distributions may also be considered using orientation tensors [6] within the analytical estimation methods [5]. Based on a variational principle, in e.g. [7-10] a suitable homogenization method for nonlinear materials is given where a comparative linear multiphase material is introduced to estimate the nonlinear response. The nonlinear and inelastic material response in the individual phases is directly included in the transformation field analysis [11, 12], where the decomposition in sub-volumes with constant eigenstrain fields is required, or the nonuniform transformation field analysis [13] where these eigenstrain fields are not assumed constant, but computed as superposition of inelastic modes. These semi-analytical methods are comparatively efficient, but their accuracy is typically limited, especially for arbitrary loading situations and for materials with highly complex micro-constituents.