Modeling the transition of microcracks into macrocracks in heterogeneous viscoelastic media using a two-way coupled multiscale model

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ABSTRACT

Fracture in heterogeneous media is still an open topic in the research community. One of the main reasons is the fact that cracks may occur in widely different length scales. While microcracks can be satisfactorily modeled by a loss in the tangent moduli tensor without considering the microcracks explicitly, such as in continuum damage models, macrocracks cannot be accurately modeled unless a discontinuity is explicitly considered. This is especially true in wave problems, since reflection or transmission of the waves is greatly affected by the presence of a discontinuity. Furthermore, the (scale) transition of microcracks into macrocracks is a key mechanism that must be considered in order to accurately model fracture in heterogeneous materials. This paper presents a two-way coupled multiscale approach for modeling fracture in heterogeneous viscoelastic media and proposes a scheme to account for the transition of microcracks into macrocracks. The model has been implemented into a finite element code and numerical results are shown for demonstration purposes.

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1. Introduction

The need for economically feasible and efficient applications has increased significantly the complexity of engineering structures. As the complexity of applications increase, more complex materials need to be designed, as most materials found in nature do not have the desired features. For example, in the aerospace industry, high-strength and low-weight fiber-reinforced composites are used to minimize fuel consumption and still satisfy the minimum structural design criteria. In military applications, highly dissipative viscoelastic polymers are combined with high-strength fibers in order to produce materials that can be used in protective devices, such as tank armor and soldier helmets.

The idea is to combine different materials with different properties and produce a third material that meets the design requirements, and which is inherently heterogeneous. In fact, all materials in nature are heterogeneous because matter is composed of an assemble of discontinuous particles, i.e., atoms and molecules. Furthermore, the properties of the individual constituents and their interaction determines the behavior of the heterogeneous composite materials.

Therefore, models that can account for these microstructural details are of extreme importance in the design of composite materials and structures. One of the most promising approaches are the so-called two-way coupled multiscale models (Feyel and Chaboche, 2000; Fish and Shek, 2000; Kouznetsova et al., 2004; Souza and Allen, 2010b), which can calculate the homogenized properties of heterogeneous media based on classical homogenization techniques as long as a Representative Volume Element (RVE) exists for the material under consideration. For discussions on the definition of an RVE, a number of manuscripts are available in the literature, of which only a few are cited herein (Hill, 1963; Hazanov and Huet, 1994; Huet, 1997; Helms et al., 1999; Allen, 2001; Ostoja-Starzewski, 2002; Swaminathan and Ghosh, 2006; Swaminathan et al., 2006).

Two-way coupled multiscale models are especially promising for cases where the microstructure evolves in time and/or is history-dependent, such as viscoelastic composites (Souza, 2009; Souza and Allen, 2010b). An example of evolving microstructure is the case where microcracks initiate and propagate thus changing the geometry of the microstructure. In such cases, the homogenized properties of the composite cannot be determined a priori, using classical homogenization theory (Eshelby, 1957; Hill, 1963; Hashin, 1964; Hill, 1965; Allen and Yoon, 1998), for example, as the evolution of the microstructure is governed by the loading history at each particular point in the global scale continuum, which is unknown prior to actually performing the analysis. Similarly, continuum damage models are not expedient for such cases, as the material parameters need to be calibrated for each particular loading history (Lemaitre, 1996; Kumar and Talreja, 2003).

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