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Dynamic stress transfer in fibrous composites with damage

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Abstract

A micromechanical model is developed in order to study the dynamically induced stress distribution in fibrous composites with damage. Damage is taken in the form of either a broken fiber or a matrix crack normal to the fiber direction. The unidirectionally reinforced periodic composite, when loaded in the axial (fiber) direction is modeled as a concentric cylindrical system subjected at its outer boundaries to vanishing radial displacement and shear stress. Guided by the symmetry and the fiber–matrix interface continuity conditions, we first assume an approximate radial dependence of some of the field variables. Therefore, we reduce the two dimensional field equations that hold in both the fiber and the matrix together with their interface conditions to a quasi-one-dimensional system. which automatically satisfies all interface and radial boundary conditions. The resulting simple system retains the integrity of the distribution in the fiber and the matrix, individually, with their interaction reflected in well-defined transfer terms. The system is suitable for treating a variety of situations. Besides the case of damage free composites, the cases of broken fibers and cracked matrix are treated by invoking appropriate boundary conditions at the crack faces. Also simple analytical expressions are derived for the crack width opening for both the fiber break and the matrix crack. For our numerical illustration, we subject the composite slab to an axial cyclic loading with varying frequency. We compare results obtained for broken fibers and cracked matrix with the damage free composite system. © 1999 Elsevier Science Ltd. All rights reserved.

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1. Introduction

Isolating and quantifying the stress distribution in the fiber and matrix constituents of structural composites upon their loading is very important for the assessment of their strength. Even in the simplest and most idealized systems of unidirectionally reinforced composites with straight fibers, the problem has presented research challenges. The contributing factors for the difficulties in the analyses are many and include the variability of the geometric arrangements, loading conditions, quality of interfaces and the possible presence of damage in the system. For these man made materials, an unlimited number of designs can he realized depending upon the choice of fiber architecture. Fiber architecture can lead to designs having simple unidirectional reinforcement with straight fibers to three-dimensional reinforcement with undulated fibers (textiles). Loading is general and can be mechanical, thermal or combinations; it can also be of static or dynamic type. Even the direction of applied loads can cause substantial difficulties. The qualities of interface conditions are critical to their response. Perfectly bonded, delaminated or smoothly connected interfaces are possible. Damage in the forms of matrix cracking, fiber break and interface slip conditions are common forms, which were considered in the literature.

Our literature survey revealed that only a modest amount of research was devoted to the specific problem of quantifying micromechanical stress distributions in fibrous composites. Most of what is available deal with the simple situation of unidirectionally reinforced composites with straight fibers and subjected to static axial loads; see for example [1–5,9,10]. Further relevant references can be found in the above quoted literature.

Comparatively, much less work was carried out on similar problems involving dynamic loading. However, there exists a large body of research on wave propagation interaction with fibrous composites, the interest of which is mainly concerned with the dispersive characteristics of such classes of materials. Reviews of available literature on exact and approximate models of the interaction of elastic waves with fibrous composites can be found in [6,7,11,12].

In the present article, we extend the theoretical analyses presented in [5] for the statically loaded to the dynamically loaded fibrous composites. To understand and appreciate the underlying assumptions and approximations, we now review the levels of approximations used in our previous works on the static loading [5,9] as they have a bearing on

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