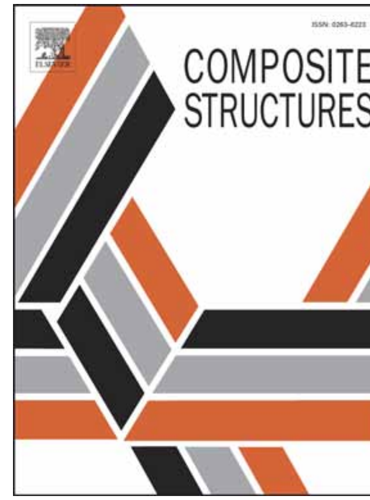

Finite-strain laminates: bending-enhanced hexahedron and delamination

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Finite-strain laminates: bending-enhanced hexahedron and delamination

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Abstract

With a new finite strain anisotropic framework, we introduce a unified approach for constitutive modeling and delamination of composites. We describe a finite-strain semi-implicit integration algorithm and the application to assumed-strain hexahedra. In a laminate composite, the laminae are modeled by an anisotropic Kirchhoff/Saint-Venant material and the interfaces are modeled by the exponential cohesive law with intrinsic characteristic length and the criterion by Benzeggagh and Kenane for the equivalent fracture toughness. For the element formulation, a weighted least-squares algorithm is used to calculate the mixed strain. Löwdin frames are used to model orthotropic materials without the added task of performing a polar decomposition or empirical frames. To assess the validity of our proposals and inspect step and mesh size dependence, a least-squares based hexahedral element is implemented and tested in depth in both deformation and delamination examples.

Keywords: Anisotropy, delamination, Löwdin frame, Assumed-strain hexahedron, Finite strains

1. Introduction

Mechanical and structural components built of unidirectional fiber-reinforced laminates are increasingly common. Laminates can have the direction of fibers tuned for specific applications making the components very optimizable [26]. In contrast with classic isotropic materials, delamination is a particularly important failure mechanism [15, 30] and the theme of this and many previous works. Delaminations occur due to lack of fiber reinforcement in thickness direction, although stitching has been proposed as a solution (cf. [25]). Without the stitching technique, which is far from established, an in-depth understanding of delamination is necessary. Since classical fracture mechanics (cf. [18]) does not include damage initiation and needs the existence of cracks, cohesive zone models (which are available for decades, cf. [12]) have been recently popularized with success for laminates (see, e.g. [15]). Cohesive zone models are specially convenient if the crack path is known or can be reliably predicted, since it determines the location of the cohesive elements. In contrast with classical fracture mechanics, cohesive models can predict both initiation and propagation by means of a single stress-displacement law. A cohesive zone model can easily be incorporated in a finite element code by either implementing zero-thickness elements [15] or, alternatively, using continuum elements with small thickness (e.g. [32]). Continuum elements are used herein, using a mixed 3D formulation. Continuum elements are kinematically convenient, since no additional considerations are needed in a standard finite element code (e.g. [3]). However, due to requirements of bending and twisting performance, high performance continuum