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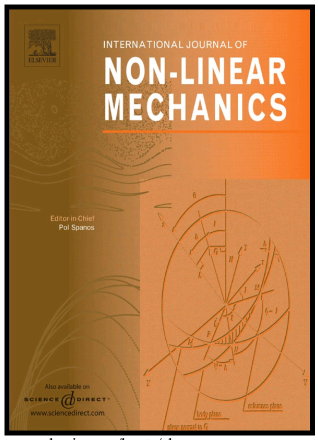

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Fibre-reinforced composites with fibre-bending stiffness under azimuthal shear – comparison of simulation results with analytical solutions

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Abstract

In [1], Spencer and Soldatos proposed an enhanced modelling approach for fibre-reinforced composites which accounts for the fibre-bending stiffness in addition to the directional dependency induced by the fibres. Although analytical solutions for simple geometries have been derived over the past years, often subject to specific assumptions such as small deformation kinematics, the application to more general and non-academic boundary value problems is desirable. Motivated by the latter, the numerical solution of the general system of partial differential equations by means of a multi-field finite element approach is proposed in [2] and the principal model properties are studied for a specific form of the elastic energy potential. In the present contribution a comparison of the numerical solution by means of the multi-field finite element approach against the analytical solution is presented for the azimuthal shear deformation of a tube-like structure. To this end, the general deformation pattern and especially the distribution of the stress and couple stress tensor are taken into account. We find that, although the analytical solution is derived subject to the assumption of small deformations, whereas the numerical solution is based on the finite strain counterpart of the theory, the simulation results are quasi identical, which verifies the numerical framework proposed.

Keywords: fibre-reinforced composites with fibre-bending stiffness, generalised continuum, multi-field mixed-type finite element approach, comparison of finite element simulations with analytical solutions

1. Introduction

In [1] an enhanced modelling approach for the simulation of fibre-reinforced composites is proposed which extends the classic modelling approach by means structural tensors, cf. [3], dropping the assumption of perfectly flexible fibres. Thus, in addition to the directional dependency induced by the fibres, the presented approach allows to account for the fibre-bending stiffness by taking into account higher-order gradients of the deformation map as additional arguments of the elastic energy potential. This further implies the usage of a polar continuum theory which is accompanied by the action of a couple-stress tensor and in general causes the Cauchy stress tensor to become unsymmetric.

Simplified versions of the general finite strain theory proposed in [1] have been analysed over the past years, cf. [4, 5, 6, 7], to gain a basic understanding of the theory. These investigations often imposed further assumptions to allow for an analytical solution of the respective boundary value problems. These comprise assumptions on the fibre-extensibility, the compressibility of the bulk or the restriction to small deformations.

The first attempt to provide an analytical solution to a boundary value problem with the fibre-bending stiffness being explicitly accounted for in accordance with the derivations presented in [1] is documented in [7]. Therein, the analysis is focused on the bending of a block and the azimuthal shear deformation of a tube-like structure for a plane strain deformation state, subject to the assumption of inextensible fibres and an incompressible matrix material, undergoing finite deformations. Motivated by the results presented in [7], the azimuthal shear deformation of the tube-like structure is discussed in [5]. To simplify the derivation of an analytical solution, the investigations are restricted to linearised kinematics, and different combinations of the constraints are imposed on the material. Finally, a detailed

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