The 4th Canadian Conference on Nonlinear Solid Mechanics (CanCNSM 2013)
McGill University, July 23-26, 2013
Montréal, Canada

(Extended abstract) Paper ID 756

Certain orthotropic textiles must be modeled as second gradient hyperelastic continua: modelling the onset of shear boundary layers

Manuel Ferretti, LaMCoS, Université de Lyon, INSA France & Università dell'Aquila, Italy, manuel.ferretti@insa-lyon.fr

Angela Madeo, LGCIE, Université de Lyon, INSA, France, & International research center M&MoCS, Università dell'Aquila, Italy, angela.madeo@insa-lyon.fr

Francesco dell'Isola, DISG Università di Roma "La Sapienza," & International research center M&MoCS , Università dell'Aquila, Italy, francesco.dellisola@uniroma1.it

Philippe Boisse, LaMCoS, Université de Lyon, INSA, 20 avenue Albert Einstein, 69621 Villeurbanne cedex, France, philippe.boisse@insa-lyon.fr

It has been known since the pioneering works by Piola, Cosserat, Mindlin, Toupin, Eringen, Green, Rivlin and Germain that many microstructural effects in mechanical systems can be still modeled by means of continuum theories. When needed, the placement function must be complemented by additional kinematical descriptors, called sometimes microstructural fields. In this paper, a technologically important class of textiles is considered and their mechanical behavior is described by means of a second gradient elastic continuum theory. Following Mindlin and Eringen, we consider a micromorphic continuum theory based on an enriched kinematics constituted by the displacement field and a second order tensor field describing microscopic deformations. The governing equations in weak form are used to perform numerical simulations in which a bias extension test is reproduced. The governing equations in weak form are used to perform numerical simulations in which the bias-test is reproduced. We show that second gradient energy terms allow for an effective prediction of the onset of internal shear boundary layers which are transition zones between two different shear deformation modes. The existence of these boundary layers cannot be described by a simple first gradient model and its features are related to second gradient material coefficients. The obtained numerical results seem to be in a good agreement with available experimental evidence and justify the need of a novel measurement campaigns.

Keywords : Hyperelastic continua, second gradient theories, woven fibrous composites, shear boundary layers, numerical simulations.

All materials are actually heterogeneous if one considers sufficiently small scales, but the woven composites reinforcements show their heterogeneity at scales which are significant from an engineering point of view. It is also well known that woven composites reinforcements macroscopically show strong anisotropy, since their mechanical response significantly varies if the load is applied in the direction of the fibers or in some other direction. We model the considered fibrous materials as orthotropic continua, i.e. continua which have two privileged directions in their undeformed configuration. This hypothesis can be considered to be realistic if no relative displacement between fibers occurs. In other words, we are assuming that two superimposed fibers can rotate around their contact point, while no slipping takes place. This hypothesis is often verified during experimental analyses, even at finite strains. The anisotropy of the considered reinforcements will be taken into account by introducing suitable hyperelastic, orthotropic constitutive laws which are able to characterize the behavior of considered materials also at large strains.

Nevertheless, a first gradient continuum, orthotropic model is not able to take into account all the possible effects that the microstructure of considered materials have on their macroscopic deformation. More precisely, some particular loading conditions, associated to particular types of boundary conditions may cause some microstructure-related deformation modes which are not taken fully into account in first gradient continuum theories. This is the case, for example, when observing some regions inside the materials in which high gradients of deformation occur, concentrated in those relatively narrow regions which we will call boundary layers.

Actually, the onset of shear boundary layers can be observed in some experimental tests which are used to characterize the mechanical properties of fibrous composite reinforcements. Indeed, internal boundary layers do actually arise in the so-called bias extension test, which is currently used to characterize the mechanical behavior of fibrous composites.

One way to deal with the description of such boundary layers, while remaining in the framework of a macroscopic theory, is to consider so-called “generalized continuum theories”. Such generalized theories allow for the introduction of a class of internal contact actions which is wider than the one which is accounted for by classical first gradient Cauchy continuum theory. These more general contact actions excite additional deformation modes which can be seen to be directly related with the properties of the microstructure of considered materials.

In this paper, the important class of fibrous composites described before is considered and their macroscopic mechanical behavior (i.e. at a scale relatively larger than the yarn) is described by means of a second gradient, hyperelastic continuum theory. The quoted hyperelastic, second gradient theory is obtained as the limit case of a micromorphic theory, following what done in [1,2] for the linear-elastic case. The governing equations in weak form are used as a basis for the formulation of suitable numerical codes, which allow to perform simulations in which the bias extension test is reproduced. We show that second gradient energy terms allow for an effective prediction of the onset of internal shear boundary layers which can be defined as those transition zones between two different regions exhibiting different shear deformation modes (see Fig.1).

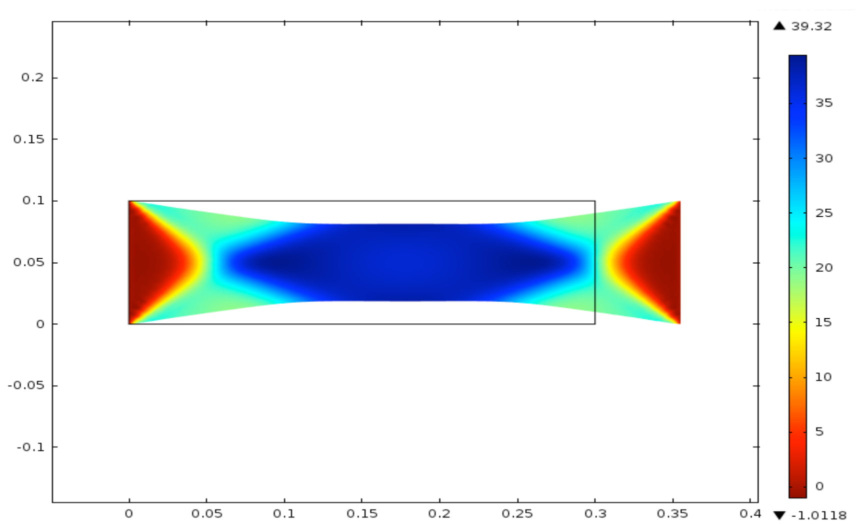

Fig.1: Shear boundary layers occurring during the bias extension test on woven composites: numerical simulations via second gradient theory.

The existence and thickness of these boundary layers cannot be described by a first gradient model and its overall features are related to the particular second gradient material coefficient introduced in this paper. The obtained numerical results seem to be in a good agreement with the already available experimental evidence and fully justify the need of a novel measurement campaign.

References

[1]Bleustein J.L., 1967. A note on the boundary conditions of Toupin's strain gradient-theory. Int. J. Solids Structures, 3, 1053-1057.

[2]Mindlin R.D. , 1964. Micro-structure in linear elasticity. Archs ration. Mech. Analysis 51-78