Journal of the Mechanics and Physics of Solids 121 (2018) 1–22

Contents lists available at ScienceDirect

Journal of the Mechanics and Physics of Solids

journal homepage: www.elsevier.com/locate/jmps

Localization in anisotropic elastoplastic micropolar media: Application to fiber reinforced composites

A.D. Hasanyan[a], A.M. Waas[b,1,*]

[a] Department of Aerospace Engineering, University of Michigan, Ann Arbor, MI 48109-2140 2, USA
[b] Boeing-Egtvedt Chair, William E Boeing Department of Aeronautics and Astronautics, 211E Guggenheim Bldg, Seattle, WA 98195, USA

ARTICLE INFO

Article history:
Received 4 March 2018
Revised 15 May 2018
Accepted 17 May 2018
Available online 19 July 2018

Keywords:
Fiber composites
Kink banding
Micropolar theory
Compressive failure
Strength

ABSTRACT

In this paper, an anisotropic elastoplastic constitutive model is formulated for fiber reinforced composites, undergoing large geometric deformation. The composite material is modeled as a micropolar continuum, which unlike a classical or a Cauchy continuum, takes into account the higher order fiber bending and twisting modes of deformation. In micropolar theory, the rotational degree of freedom is independent of the displacement field. This is utilized to express the microrotation tensor that represents the rotation of the fibers. An anisotropic micropolar yield criterion is introduced by extending Hill's criterion in classical elastoplasticity and including couple-stresses. The geometric and materially nonlinear theoretical model is derived. The corresponding updated Lagrangian (UL) finite element formulation is discussed. In literature, micropolar theory has been applied to problems associated with localized deformation, where classical theories fail to capture this phenomenon due to the loss of ellipticity of the governing equations. These previous analyses have been done on isotropic micropolar media, and in order to initiate the onset of localization, a softening relationship between the equivalent stress and strain has been introduced. Since the introduction of material softening into the constitutive relation has been a topic of contention in the field of continuum mechanics, it is shown to be unnecessary. Instead, localization is induced due to geometric and material nonlinearity, along with misalignment of the principal material directions with respect to the dominant loading directions that introduce axial-shear coupling. In fiber reinforced composites, localization occurring from compressive loading is representative of fiber kink banding, which is associated with a snap-back behavior in the macroscopic stress-strain response.

© 2018 Elsevier Ltd. All rights reserved.

1. Literature review

Localized deformation is characterized by the formation of a narrow region in a material, where upon further continued loading, the deformation is limited inside this region. This phenomenon has been experimentally observed in various classes of materials, some of which include geological materials such as granular media (Aydin et al., 2006; Bernard et al., 2002) and metals (Wei et al., 2004). Understanding this form of instability is instrumental for predicting the integrity of

---

[*] Corresponding author.
E-mail address: awaas@aa.washington.edu (A.M. Waas).

[1] From 1 Sept., 2018, Richard A. Auhll, Department Chair and Felix Pawlowski Collegiate Professor, Department of Aerospace Engineering, University of Michigan, Ann Arbor, MI 48109-2140, USA.

https://doi.org/10.1016/j.jmps.2018.05.013
0022-5096/© 2018 Elsevier Ltd. All rights reserved.

a structure, as it leads to failure. For example, in the case of granular materials, it is crucial for civil engineering applications, and in ductile metals, the formation of the localized deformation (shear bands) is proceeded by fracture. Similar phenomenon is observed in fiber reinforced composites, where under compressive loading along the fiber direction, fiber kink banding is recognized as the dominant failure mechanism. With advances in computation, intensive research has been geared towards modeling this by assuming the material under consideration as a homogenized continuum (Abeyaratne and Triantafyllidis, 1981; Cervera et al., 2012; Chen and Schreyer, 1989). This has been achieved through the introduction of material nonlinearity (both hyperelastic or hypoelastic), where at a critical point, localization is obtained due to the loss of ellipticity of the governing partial differential equations.

As discussed in detail in Lasry and Belytschko (1988), the limitation of the classical continuum is that the constitutive models are local and do not possess intrinsic length scales. This leads to excessive numerical mesh dependency due to the ill-posedness of the problem at the onset of localization. It is detailed that by introducing a length scale into the continuum through the constitutive equations, which increases the order of the differentials in the governing equations, it prevents the ill-posedness associated with localization. In literature, various approaches have been employed in the recent decades for this purpose. This has been achieved through a rate dependent constitutive relationship, such as viscoelasticity (Needleman, 1988) or second gradient enhancement of the classical continuum model (Triantafyllidis and Aifantis, 1986).

Another intriguing approach is by modeling the material as a micropolar continuum, which is based on the generalization of the classical (Cauchy) continuum theory. It has been shown to introduce an internal length scale by increasing the order of the Laplacian of the governing equations. Some of the notable works in this area include (Alsaleh et al., 2006; De Borst, 1991; Khoei et al., 2010). In this theory, the central assumption is that each point in the material can rotate independently. For example, in 3D space, every particle has 3 rotational and 3 translational degrees of freedom. With the generalization of the kinematics of the continuum, this brings about higher order stresses and strains, such as curvature strains and couple-stresses (moment stress). Their presence results in the classical stress and strains to be asymmetric. In addition to fiber reinforced composites, which is the topic of interest, these higher order effects are also applicable to cellular solids, where at the microscale, the cellular microstructure is viewed to be assembled by beams, with bending and twisting mechanisms (Hasanyan and Waas, 2016; Rueger and Lakes, 2018).

Although the origin of micropolar theory can be traced to the work of the Cosserat brothers in 1909 (Cosserat and Cosserat, 1909), the modern version of micropolar theory saw its development by Eringen and Suhubi (1964a,b), with the introduction of a more general micromorphic theory. The reason for the limited application of these higher order theories for wider application has primarily been twofold: (1) the difficulty to determine the additional constitutive parameters that are introduced, and (2) the complications associated with the extension to finite deformation. The recent works by Forest and Sab (1998); Onck (2002) have addressed the former by introducing methods for determine the additional micropolar material constants. For fiber reinforced composites, an approach based on the concentric cylinder model (CCM) was introduced by Hasanyan and Waas (2018). In addition, the latter has been discussed by Hasanyan and Waas (2015), where by considering the general geometric nonlinear micropolar equations, an analytical solution to the buckling of a micropolar strip under compression loading was derived. It was concluded that the micropolarity has a stabilizing effect on problems associated with buckling. Further discussion of the complexity associated with the general finite micropolar theory, such as the irreducibility to the finite classical theory from micropolar theory has been analyzed in Neff (2006), and Neff and Münch (2009). To avoid the issues presented with the geometrically exact equations discussed in these studies, a simplified finite micropolar theory is considered in this paper, under the assumption of first order (linear) curvature strains. This has been shown to capture the salient features of localization in Alsaleh et al. (2006), and Alshibli et al. (2006). Based on this assumption, which was earlier applied to study isotropic granular media, we seek to extend this simplified geometric nonlinear model to anisotropic fiber reinforced composites.

In the recent decades, fiber reinforced composites have been applied to various industrial applications, most notably in the aerospace industry as lightweight material. These composites have been shown to exhibit physically nonlinear behavior. A common approach to characterizing this has been through the flow rule. As a result, numerous anisotropic yield criteria have been developed and extensively used for these materials (Sun and Chen, 1989). One in particular is the pressure independent Hill criterion, which effectively captures the nonlinear behavior of an orthotropic composite along different loading directions (Prabhakar and Waas, 2013b). The extension of classical von Mises criterion to an isotropic micropolar continuum has been shown in De Borst (1991), and Alsaleh et al. (2006). In the present study, a similar extension of Hill's anisotropic criterion will be discussed.

By modeling fiber reinforced composites using micropolar theory, another advantage is the ability to quantify local fiber rotation, curvature, and bending and twisting at the continuum scale. In literature, some notable works in this area include (Fleck and Shu, 1995), where by studying fiber kinking, it was shown that the governing equations correspond to the micropolar equations. In addition, a continuum model for fiber-reinforced composites, with fiber bending and twisting effects included, was discussed by Steigmann (2012). More recently, this has been extended to derive the general nonlinear continuum equations of fiber composites based on the assumption that the fibers behave as Kirchhoff rods (Steigmann, 2015). In the following analysis, a similar, simplified nonlinear micropolar model is proposed. To demonstrate the utility of the theory, it is applied to model fiber kinking, or localization at the continuum scale. In literature, a common approach to modeling localization has been through the introduction of a softening relation into the constitutive model, which is in violation of the classical Drucker stability criteria for nonlinear materials. Although this is sufficient to induce localization, it will be

Download English Version:

https://daneshyari.com/en/article/7177324

Download Persian Version:

https://daneshyari.com/article/7177324

Daneshyari.com