Journal of the Mechanics and Physics of Solids 90 (2016) 124–141

Contents lists available at ScienceDirect

Journal of the Mechanics and Physics of Solids

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

Framework for non-coherent interface models at finite displacement jumps and finite strains

Niels Saabye Ottosen [a,*], Matti Ristinmaa [a], Jörn Mosler [b]

[a] Division of Solid Mechanics, Lund University, SE-22100 Lund, Sweden
[b] Institute of Mechanics, TU Dortmund, D-44227 Dortmund, Germany

ARTICLE INFO

Article history:
Received 14 August 2015
Received in revised form
26 February 2016
Accepted 26 February 2016
Available online 3 March 2016

Keywords:
Interface model
Non-coherent interfaces
Cohesive zone
Large displacements
Angular momentum
Dissipation inequality
Objectivity
Principle of frame indifference

ABSTRACT

This paper deals with a novel constitutive framework suitable for non-coherent interfaces, such as cracks, undergoing large deformations in a geometrically exact setting. For this type of interface, the displacement field shows a jump across the interface. Within the engineering community, so-called cohesive zone models are frequently applied in order to describe non-coherent interfaces. However, for existing models to comply with the restrictions imposed by (a) thermodynamical consistency (e.g., the second law of thermodynamics), (b) balance equations (in particular, balance of angular momentum) and (c) material frame indifference, these models are essentially fiber models, i.e. models where the traction vector is collinear with the displacement jump. This constraints the ability to model shear and, in addition, anisotropic effects are excluded. A novel, extended constitutive framework which is consistent with the above mentioned fundamental physical principles is elaborated in this paper. In addition to the classical tractions associated with a cohesive zone model, the main idea is to consider additional tractions related to membrane-like forces and out-of-plane shear forces acting within the interface. For zero displacement jump, i.e. coherent interfaces, this framework degenerates to existing formulations presented in the literature. For hyperelasticity, the Helmholtz energy of the proposed novel framework depends on the displacement jump as well as on the tangent vectors of the interface with respect to the current configuration – or equivalently – the Helmholtz energy depends on the displacement jump and the surface deformation gradient. It turns out that by defining the Helmholtz energy in terms of the invariants of these variables, all above-mentioned fundamental physical principles are automatically fulfilled. Extensions of the novel framework necessary for material degradation (damage) and plasticity are also covered.

© 2016 Elsevier Ltd. All rights reserved.

1. Introduction

Material interfaces play a major role in materials science and engineering. Ultrafine grained steels or the so-called TRIP- and TWIP-steels are well-known examples for the importance of material interfaces in materials science. In such materials, the properties of the involved interfaces significantly influence the resulting macroscopic properties due to the high

* Corresponding author.
E-mail addresses: niels_saabye.ottosen@solid.lth.se (N.S. Ottosen), Matti.Ristinmaa@solid.lth.se (M. Ristinmaa), joern.mosler@tu-dortmund.de (J. Mosler).

http://dx.doi.org/10.1016/j.jmps.2016.02.034
0022-5096/© 2016 Elsevier Ltd. All rights reserved.

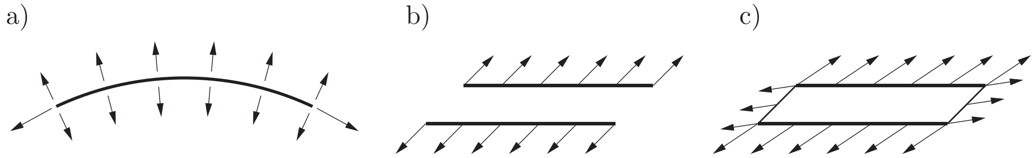

Fig. 1. Three types on interfaces: (a) coherent interface with membrane forces, (b) classical cohesive model (non-coherent interface) which acts as a fiber model and (c) generalized cohesive model (non-coherent interface) with membrane forces and out-of-plane shear forces.

interface area to bulk volume ratio. With respect to engineering applications, cracks are probably the best known example for the importance of material interfaces.

Material interfaces can be categorized by means of different criteria. One such possible criterion is the coherence of certain variables at the interface. Focusing on a mechanical setting, the displacement field is continuous in the case of coherent interfaces, while it shows a displacement jump for non-coherent interfaces.

General frameworks for coherent interfaces can be found in Gurtin and Murdoch (1975), Gurtin (1995, 2000), Steinmann (2008), Javili et al. (2012), Kaessmair et al. (2014) and references cited therein. A coherent interface with existence of membrane forces is illustrated in Fig. 1a. Although the incorporation of inelastic effects, like material degradation in the sense of quasi-brittle damage models, follows identical lines as for bulk models, hyperelasticity is considered in most papers, cf. Steinmann (2008). Without going too much into detail, such models can be derived by postulating a surface-specific Helmholtz energy depending on a surface deformation gradient associated with membrane-like deformations, cf. Gurtin and Murdoch (1975), Steinmann (2008), Javili et al. (2012) as well as Kaessmair et al. (2014). The effect of coherent interfaces on the response of nano-structures is reviewed, for instance, by Mura et al. (1996) and the influence of eigenstrained inhomogeneities is analyzed by Sharma et al. (2003)

Non-coherent interfaces, i.e., those exhibiting displacement jumps, are of main interest here and they are often described by means of so-called cohesive zone models, also known as traction separation laws. In contrast to classical continuum models, the traction vector acting at the material interface is related to its energetically dual variable being the displacement jump, cf. Hillerborg et al. (1976), Armero and Garikipati (1996), Fagerström and Larsson (2008), Mosler and Scheider (2011), Vossen et al. (2013), Ottosen and Ristinmaa (2013) and references cited therein. Although cohesive zone models indeed represent one of the workhorses whenever non-coherent material interfaces such as cracks are to be analyzed, they are often derived in an ad hoc manner, i.e. fundamental principles in continuum mechanics such as thermodynamical consistency, balance equations (in particular, balance of angular momentum) and material frame indifference are often not considered, cf. Mosler and Scheider (2011), Vossen et al. (2013), and Ottosen et al. (2015). While in a geometrically linearized framework, such an ad hoc derivation does not necessarily lead to physical inconsistencies, this is not the case in a geometrically exact setting (finite deformations), cf. Ottosen et al. (2015). For instance and as shown in Mosler and Scheider (2011), the classical cohesive zone framework applied to anisotropic hyperelasticity leads to non-vanishing dissipation. Equally important, anisotropic cohesive zone models usually violate balance of angular momentum, cf. Ottosen et al. (2015). Indeed, it turns out that for elasticity, only isotropic models which may include isotropic damage fulfill all aforementioned fundamental physical requirements. Essentially, to be consistent classical cohesive zone theory implies that the traction vector is collinear with the displacement jump and they may therefore be viewed as fiber models, cf. Fig. 1b. This severely restricts the freedom to simulate shear response and, as discussed by Ottosen et al. (2015), to fulfill objectivity and balance of angular momentum, the plastic part of the displacement jump must be chosen collinear with the total displacement jump. A novel extended cohesive zone framework was recently proposed in Ottosen et al. (2015). While in the classical cohesive zone framework, the displacement jump is defined by two points on each side of the interface having the same material coordinates, this assumption is relaxed so that during plastic development the two points that define the displacement jump refer to different material coordinates which change as a result of the evolution of plasticity. Although the framework presented in Ottosen et al. (2015) indeed extends the classical formulation and it is also consistent with the fundamental physical principles enumerated before, it does not allow in its original form to capture an anisotropic hyperelastic non-coherent interface. Furthermore, this framework relies on a non-standard displacement jump and the generalization only applies when plasticity is encountered.

In summary, none of the existing models for non-coherent interfaces at finite strains (deformations) allows us to describe anisotropic hyperelasticity in a consistent manner, i.e., at least one of the aforementioned fundamental physical principles is violated. Moreover, the freedom to model shear is severely restricted.

The main idea here is to consider a classical cohesive zone model (based on the classical displacement jump) and to supplement this model by a traction vector related to forces acting within the interfaces. Similar ideas can also be found in Gurtin (2000) as well as Steinmann and Häsner (2005). However, the models proposed within the cited papers are based on rather restrictive assumptions concerning the displacement jump. To be more precise, they only provide general frameworks for a geometrically linearized setting as also accentuated by Javili et al. (2012). The assumption made in Gurtin (2000) and Steinmann and Häsner (2005) indeed have a strong impact on the resulting theory. For instance, the additional membrane-like stress tensor is symmetric and does not show shear components in the out-of-plane direction. In sharp contrast to the cited works, such assumptions are not made here and thus, the derived stress tensor is non-quadratic and contains membrane forces as well as out-of-plane shear forces. Moreover, in accordance with intuitive concepts for how a

Download English Version:

https://daneshyari.com/en/article/797780

Download Persian Version:

https://daneshyari.com/article/797780

Daneshyari.com