Engineering Fracture Mechanics 121–122 (2014) 28–39

Contents lists available at ScienceDirect

Engineering Fracture Mechanics

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

Analytical and numerical comparison of discrete damage models with induced anisotropy

A. Benelfellah [a,*], A. Frachon [b], M. Gratton [b], M. Caliez [b], D. Picart [c]

[a] Laboratoire de Mécanique et de Physique des Matériaux (UMR CNRS 6617), Ecole Nationale Supérieure de Mécanique et d'Aérotechnique, F-86961 Futuroscope Cedex, France

[b] Laboratoire de Mécanique et Rhéologie (E.A. 2640), ENI Val de Loire, Université François Rabelais de Tours, F-41034 Blois Cedex, France

[c] CEA, DAM, Le Ripault, F-37260 Monts, France

ARTICLE INFO

Article history:
Received 25 October 2013
Received in revised form 13 March 2014
Accepted 28 March 2014
Available online 18 April 2014

Keywords:
Damage effect
Microcracks
Induced anisotropy
Constitutive modeling
Microplane
Walpole basis

ABSTRACT

Quasi-brittle materials are modeled taking into account the anisotropic damage and its unilateral character. Among the models, proposed in the literature, a first selection has been made. The attention is thus restricted to models where the damage is managed by a discrete sum of its effects along fixed directions. The influence of the basic assumptions of the selected models are compared. Thus, models are at first expressed both into the Kunin and Walpole tensor decompositions to highlight the damage effects on each stiffness tensor component. A numerical study illustrates the effect of a damage effect on engineering parameters sensitivity and compares the versatility of those models. This work shows that the microplane framework is the most versatile, against Poisson's ratio damage, while using the Volumetric Deviatoric Tangential (VDT) decomposition.

© 2014 Elsevier Ltd. All rights reserved.

1. Introduction

The influence of microcracking on the nonlinear behavior of quasi-brittle materials is widely recognized. This leads to a damage induced anisotropy, involving a sensitivity of the response to the cracks closure, which results in an increase of the transversal to longitudinal strain ratio during compression tests, and a strong dependence on the confining pressure. Continuum Damage Mechanics was originally introduced by Kachanov [16] and Rabotnov [24]. Isotropic damage were first considered by Lemaitre and Chaboche [10], Mazars [20], then anisotropic ones were proposed [18,13,21,15]. Despite continuous improvements, inconsistencies remained, as mentioned by Chaboche [9] or Carol and Willam [8].

A consistent thermodynamic formulation requires the conservativeness and existence of the free energy, *i.e.* the symmetry of the Hessian tensor. Moreover, the stress–strain response must be continuous and must not create any spurious dissipation. However, if discontinuity is introduced into the damage tensor using the strain eigenvalues, Challamel et al. [11] showed that conservation of free energy is obtained only if the principal directions of damage tensor coincide with those of strain tensor. Likewise, a thermodynamic potential based on the positive and the negative parts of the strain tensor often results in undesirable artificial dissipation [8]. Finally, Cormery [12] shows, for a given state, an example of loss of objectivity for such formulations and thus their inability to generate a potential.

Recent studies [4,22,27,1] have proposed solution for these kind of thermodynamic inconsistencies using a formulation based on a set of predetermined directions on which crack densities are defined, in a spherical distribution. These models can

* Corresponding author. Tel.: +33 549498207.
E-mail address: benelfellah@ensma.fr (A. Benelfellah).

http://dx.doi.org/10.1016/j.engfracmech.2014.03.022
0013-7944/© 2014 Elsevier Ltd. All rights reserved.

Nomenclature

Abbreviations

DM	Discrete Model
EM	Eshelby Model
RVE	Representative Volume Element
VD	Volumetric Deviatoric
VDT	Volumetric Deviatoric Tangential

Tensor notations

n	scalar
$\mathbf{n}$	vector
$\mathbf{N}$	second-order tensor
$\mathbb{N}$	fourth-order tensor
$\mathbf{1}$	second-order unit tensor
$\mathbb{I}$	fourth-order unit tensor
σ	Cauchy stress tensor
$\tilde{\sigma}$	effective stress tensor
η	strain tensor
$\mathbb{C}^{el}$	elastic stiffness tensor
$\mathbb{C}^{ed}$	elastic stiffness damaged tensor
$\mathbb{I}_V$	volumetric part of fourth-order identity tensor $\mathbb{I}$
$\mathbb{I}_D$	deviatoric part of fourth-order identity tensor $\mathbb{I}$

Tensor operations

$\cdot$	dot product
$:$	double dot product
$\otimes$	tensor product $(a \otimes b_{ijkl}) = a_{ij}b_{kl}$ $(a \underline{\otimes} b_{ijkl}) = a_{il}b_{jk}$ $(a \overline{\otimes} b_{ijkl}) = a_{ik}b_{jl}$ $(a \overline{\underline{\otimes}} b_{ijkl}) = \frac{1}{2}(a_{ik}b_{jl} + a_{il}b_{jk})$
$H\ (X)$	Heaviside function $H(x) = \frac{x+\lvert x\rvert}{2\lvert x\rvert}$

be classified into two categories: (1) phenomenological macroscopic constitutive laws, (2) macroscopic laws obtained from an homogenization process and assumptions at the mesoscale. This article proposes a method to compare formulation which describe the behavior of quasi-brittle materials, initially isotropic, satisfying thermodynamic requirements. Analysis of the damage effect highlights the differences between these models.

2. Selected models

In the selected models, microcracks fall into N sets, characterized by their density and normal orientation $\mathbf{n}_i$ which is described and fixed. The condition for opening/closure of crack can thus be postulated in these directions avoiding a spectral decomposition of the strain tensor. Considering the assumption of non-interacting microcracks, both behavior and closure effects are treated in each direction. The effect of several microcracks on the stiffness of an initially isotropic material is the sum of the contributions of each set of microcracks. A set of randomly distributed microcracks characterized by a common normal orientation induces a transverse isotropic behavior. The following models meet the requirements of the thermodynamics of irreversible processes framework. The Young's, shear and bulk moduli and the Poisson's ratio of the material are respectively $E,\ \mu,\ k$, and ν. For each direction, the second-order tensor $\mathbf{N}_i$ is defined as the tensor product $\mathbf{n}_i \otimes \mathbf{n}_i$ and the scalar angular weighting coefficient as w_i. $\otimes$ denotes the tensor product, and $\overline{\underline{\otimes}}$ the symmetrized tensor product.

2.1. Discrete approach

Discrete Model (DM) is based on a previous model proposed by Halm and Dragon [15]. The damage tensor has been replaced by sets of microcracks with densities ρ_i^{Dis} associated with prescribed directions [1]. The resulting damaged stiffness tensor $\mathbb{C}^d$ is given in the Kunin [17] formalism by:

$$\mathbb{C}^d(\rho_i, \mathbf{N}_i) = \left(k - \frac{2}{3}\mu\right)\mathbf{1} \otimes \mathbf{1} + 2\mu\ \mathbf{1} \overline{\underline{\otimes}} \mathbf{1} - \sum_{i=1}^{N} \rho_i^{Dis} \{\alpha[2\ \mathbf{1} \overline{\underline{\otimes}} \mathbf{1} - \mathbf{1} \otimes \mathbf{1} + \mathbf{1} \otimes \mathbf{N}_i + \mathbf{N}_i \otimes \mathbf{1}] + 2\beta[\mathbf{1} \overline{\underline{\otimes}} \mathbf{N}_i + \mathbf{N}_i \overline{\underline{\otimes}} \mathbf{1}] - (3\alpha + 4\beta)H(-tr(\boldsymbol{\varepsilon} \cdot \mathbf{N}_i))\mathbf{N}_i \otimes \mathbf{N}_i\} \quad (1)$$

Download English Version:

https://daneshyari.com/en/article/770300

Download Persian Version:

https://daneshyari.com/article/770300

Daneshyari.com