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Micromechanics based framework with second-order damage tensors

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Abstract

The harmonic product of tensors—leading to the concept of harmonic factorization—has been defined in a previous work (Olive et al, 2016). In the practical case of 3D crack density measurements on thin or thick walled structures, this mathematical tool allows us to factorize the harmonic (irreducible) part of the fourth-order damage tensor as an harmonic square: an exact harmonic square in 2D, an harmonic square over the set of so-called *mechanically accessible directions for measurements* in the 3D case. The corresponding micro-mechanics framework based on second—instead of fourth—order damage tensors is derived. An illustrating example is provided showing how the proposed framework allows for the modeling of the so-called hydrostatic sensitivity up to high damage levels.

Keywords: anisotropic damage, crack density, harmonic decomposition
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1. Introduction

The damage anisotropy encountered in quasi-brittle materials is induced by the loading direction and multiaxiality. From a micro-mechanics point of view, it is the consequence of an oriented microcracking pattern. From the Continuum Damage Mechanics (CDM) point of view, the anisotropic damage state is represented by a tensorial thermodynamics variable, either an eight-order tensor (Chaboche, 1978, 1979), a fourth-order damage tensor $\mathbf{D}$ (Chaboche, 1978, 1979; Leckie and Onat, 1980; Chaboche, 1984; Lemaitre and Chaboche, 1985; Andrieux et al., 1986; Ju, 1989; Kachanov, 1993; Zheng and Collins, 1998; Cormery and Welemane, 2010; Dormieux and Kondo, 2016) or a symmetric second-order damage tensor $\mathbf{d}$ (Vakulenko and Kachanov, 1971; Murakami and Ohno, 1978; Cordebois and Sidoroff, 1982; Ladevèze, 1983; Murakami, 1988).

There exist many second-order anisotropic damage frameworks (Murakami, 1988; Kattan and Voyiadjis, 1990; Ramtani et al., 1992; Papa and Taliercio, 1996; Halm and Dragon, 1998; Steinmann and Carol, 1998; Lemaitre et al., 2000; Carol et al., 2001; Menzel and Steinmann, 2001; Menzel et al., 2002; Brunig, 2003; Lemaitre and Desmorat, 2005; Desmorat et al., 2007; Badel et al., 2007; Desmorat and Otin, 2008; Desmorat, 2016), as their unification into a single model is partial (Ladevèze, 1983, 1995). A link with the theory of second order fabric tensors has been made in (Zysset and Curnier, 1995; Voyiadjis and Kattan, 2006). From a theoretical point of view (Leckie and Onat, 1980; Onat, 1984), second order damage frameworks are usually seen to be restrictive compared to the fourth-order tensorial one. Nevertheless, the interpretation of a damage variable being simpler when a second-order tensor is considered (the three principal values d_i of $\mathbf{d}$ naturally correspond to 3 orthogonal families of microcracks), less damage parameters are introduced and the second-order frameworks have been widely used for either ductile or quasi-brittle materials.

The recent analysis of 2D cracked media with both open and closed microcraks has shown that the so-called irreducible (harmonic) part $\mathbf{H}_{2D}$ of the damage tensor can be decomposed by means of a second-order damage tensor (Desmorat and Desmorat, 2016). More precisely, the standard second-order crack density tensor of Vakulenko and Kachanov (1971) still represents the open cracks contribution when a novel (deviatoric) second-order damage tensor represents the closed—sliding—cracks (previously represented by a fourth-order tensor, Andrieux et al. (1986); Kachanov (1993)). This can be achieved using Verchery's polar decomposition of 2D fourth-order tensors (Verchery, 1979; Vannucci, 2005), which includes both (Desmorat and Desmorat, 2015):

– the harmonic decomposition of considered tensor;

– the harmonic factorization of its fourth-order irre-

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