



A damage model with evolving nonlocal interactions

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ABSTRACT

We present a damage model for softening materials with evolving nonlocal interactions. The thermodynamic implications and the material stability issue are addressed. The proposed nonlocal averaging scheme provides the obtained constitutive models with an evolving nonlocal interaction which is activated only when damage occurs. In the analysis of structures made of quasi-brittle materials, this feature helps not only to overcome some issues with the incorrect initiation of damage but also to better control the evolving size of the active fracture process zone. This is an essential feature that is usually not considered in depth in many existing nonlocal approaches to the continuum modelling of quasi-brittle fracture. Numerical examples are given to demonstrate features of the proposed modelling approach.

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1. Introduction

Material stability is an issue one should always consider when developing constitutive models for softening materials. One of the effective techniques to deal with the issue of material stability is the nonlocal regularisation technique (Pijaudier-Cabot and Bazant, 1987). The key idea of this regularisation is to introduce into constitutive models a characteristic length representing the heterogeneity of the evolving material micro-structure. Considering the richness of the evolving micro-structure of quasi-brittle materials, the introduction of a single length parameter can be seen as an over simplified process aiming at reducing the complexity of the constitutive models and also the numerical implementation. This however has been proved to be sufficient for several practical applications.

Due to the heterogeneity of quasi-brittle material (e.g. concrete, rocks), diffuse micro-cracking over a certain volume is usually observed at early stages of the fracturing process (Haidar et al., 2005; Grassl and Jirásek, 2010). This volume, where micro-cracks develop, is called fracture process zone (FPZ) in the literature. It has been experimentally observed that the size of the active FPZ is evolving with the fracturing process (Jankowski and Styś, 1990; Otsuka and Date, 2000). This zone expands once micro-cracks start to grow, and then reduces to a zero-volume (macro) crack. During this fracturing process, many micro-cracks in the FPZ are deactivated,

while some continuously develop, propagate, and coalesce with other to form a final macro crack.

In the modelling of quasi-brittle fracture using nonlocal damage models, several outstanding issues in the development and application of nonlocal regularisation techniques have not been given adequate treatments. The source of nonlocality, as proved by Bazant (1991, 1994), are due to micro-crack interactions. Since the FPZ, where micro-cracking occurs, is evolving, the nonlocal interaction of the nonlocal continuum models cannot be fixed. However, the issue of evolving FPZ is usually not discussed at length in the literature of constitutive modelling, since most nonlocal damage models are formulated on the basis of fixed nonlocal interaction, e.g. fixed nonlocal weight scheme. Although these models can characterise the evolving (active) damage zone to some extent, they still suffer from the incorrect initiation and propagation of damage (Simone et al., 2004).

The motivation of this paper is to enhance existing nonlocal models with features and capabilities that allow capturing the evolving nature of the FPZ more faithfully. This will hopefully help overcome unwanted issues (e.g. incorrect initiation of damage) associated with models employing fixed nonlocal interactions. We also note here that although the issue of continuum–discontinuum transition has been tackled in some research (e.g., Simone et al., 2003; Comi et al., 2007; Jirasek and Marfia, 2008), it is not covered within the scope of this study. In the literature, the enhancement to fixed internal length nonlocal models may lie in employing an evolving internal length (Geers et al., 1998, 2000; Pijaudier-Cabot et al., 2004), or using a variable mixing between local and nonlocal quantities (Bui, 2010). Both types of

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