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CONTINUUM MULTI-SCALE (FE^2) MODELING OF MATERIAL FAILURE

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Two-scale computational modelling of materials is a subject of increasing interest in computational mechanics. When dealing with materials displaying a spatially smooth behaviour there is some consensus, and some suitable mechanical approaches to the problem are available in the literature. For instance, the so-called FE2 methods, based on the hierarchical, bottom-up one-way coupled, description of the material using the finite element method in both scales, and computational homogenization procedures at the low scale, is nowadays one of the most popular approaches. At the heart of the direct computational homogenization procedure lies the notion of representative volume element (RVE) defined as the smallest possible region representative of the whole heterogeneous media on average.

Alternatively, two-scale computational modelling of *material failure* is more controversial, and exhibits additional complexity. Either if discrete approaches (based on non-linear softening cohesive models), or continuum approaches (strain localization-based or regularized models) are used at the lower scale, the kinematic description of some, or both, scales cannot be considered smooth anymore, and the existence of the RVE can be questioned arguing that, in this case, the material loses the statistical homogeneity. A crucial consequence of this issue is the lack of objectivity of the results with respect to the size of the RVE. In (Nguyen, Lloberas-Valls et al. 2010) a recent attempt to overcome this flaw, for regularized non-local models, can be found.

This work is an attempt to address this issue in the setting of the Continuum Strong Discontinuity Approach (CSDA) to material failure, developed by the authors in the past (Oliver, Huespe et al. 2002). The essentials of the method are:

1) At the macroscopic level, material failure is captured via strain-localization and finite elements with embedded regularized strong discontinuities.

2) The microstructure of the smooth-strain part of the body is represented by a classical RVE, whose size is associated to standard statistic representativeness concepts.

3) A failure-cell at the microscopic scale, with the same size and topological properties than the RVE is associated to material points at the strain-localizing part of the macrostructure. This failure-cell is enriched with appropriated material failure mechanisms with, apparently, no restriction on their type. Though, for the sake of simplicity, cohesive-bands with a predefined position have been used in this work, there is no “a priori” limitation on using more sophisticated material failure mechanisms, e.g. arbitrarily propagating cracks or strong discontinuities. In contrast, this failure-cell is not claimed to be a RVE, in the sense of being statistically representative of any part of the macrostructure, although standard homogenization procedures are applied to it.

4) It is proven that homogenization of the RVE and failure-cell returns a macroscopic constitutive model (stress vs. strain) with the same format than classical inelastic-strain-based phenomenological models. A set of macroscopic inelastic-strain-like internal variables emerge naturally, whose evolution equation is ruled by the activation of material non-linearities and failure mechanisms at the failure-cell. In addition, a internal-length arises from that homogenization procedure, and it is naturally determined by the size of the chosen RVE and the amount of activated material failure mechanisms at the microstructure. This internal length is of the same order then the RVE and, determines the bandwidth of the macroscopic regularized strain-localization or displacement-discontinuity bands.

5) Based on this internal length, imported from the microstructure, the macrostructure is equipped with finite elements with embedded regularized strain-localization and displacement-discontinuities. Through this method, complete insensitivity of the structural response, with respect to the RVE size, and the macroscopic and microscopic finite element meshes is achieved, and material failure properties, like the fracture energy, are consistently up-scaled.

The result is a multiscale approach, that preserves the correct dissipation and objectivity, with respect both the macroscopic size of the finite element mesh and the size of the failure cell, which, in turn, can be readily connected with recent proposals for similar purposes (Sánchez, Blanco et al. 2013).The proposed approach is tested with a number of representative examples.

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