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G. Royer Carfagni

REDUCTIO AD UNUM PHASE-FIELD APPROACH TO FRACTURE, DAMAGE AND PLASTICITY

University of Parma, Italy

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Abstract. Phase-field models have been successfully used to predict crack propagations through the minimization of an energy functional, establishing an energetic competition between elastic release (bulk term) and material damage (surface term). The matching conditions at the interfaces are substituted by the evolution of an auxiliary (phase) field, which is unitary for the sound phase and null for the damaged phase. Here, two generalizations of this approach are presented. In the first one, the bulk term of the energy is modified to represent that, when the material microstructure is loosened and damaged, peculiar inelastic (structured) deformations may occur in the representative volume element at the price of surface energy consumption. This approach unifies various theories of failure because, by simply varying the admissible class of structured deformations, different-in-type responses can be captured, incorporating the peculiarities of cleavage, deviatoric, combined cleavage-deviatoric and "masonry-like" fractures. Remarkably, this latter formulation rigorously avoid material overlapping in the cracked zones. The model is numerically implemented using a standard finite-element discretization and adopts an alternate minimization algorithm, adding an inequality constraint to impose crack irreversibility (fixed crack model). Numerical experiments for some paradigmatic examples are presented and compared for various possible versions of the model. In the second proposal, the surface energy term is modified to account for cohesive stresses bridging the crack lips. This is a particular type of Dugdale–Barenblatt cohesive-crack that can interpret the response of a perfectly plastic body, for which inelastic deformations are associated with displacement jumps along slip surfaces at constant yielding stress. The flow is driven by the transformation of elastic strain energy into inelastic work, once that an energetic barrier for slip activation has been overcome. The resulting deformation is structured since it involves supplementary kinematical variables (the plastic slips), governed by an evolution law. We show that the glide surfaces diffuse in bands, whose width depends upon a material length-scale parameter: as this goes to zero, the energy functional Gamma-converges to a free-discontinuity problem, set in the space of SBV functions. The distinction of the elastic strain energy into spherical and deviatoric parts can also be used to incorporate in the model the idea of von Mises plasticity and isochoric plastic strain. Numerical experiments provide solutions with striking similarities with the classical slip-line field theory of plasticity, but the proposed model is much richer because, accounting for elastic deformations, it can describe the nucleation, propagation and widening of slip bands.