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Sommario

In the framework of rate-independent systems, an elastic-plastic-damage model, aimed at the description of ductile fracture processes, is proposed and investigated through a variational formulation. A cohesive, or ductile, crack occurs when the displacement field suffers a discontinuity whilst still being associated to a non-vanishing tensile stress. To predict and effectively describe ductile fracture phenomena is a crucial task for many engineering materials (metals, polymers, ...), as testified by the great interest of the scientific community on the subject. Gradient damage models have been fruitfully used for the description of brittle fractures: in such cases, once the damage level reaches its maximum value, a crack is created where the traction between the two opposite lips immediately drops to zero. On the other hand, the perfect plasticity model could describe the formation of plastic slips at constant stress level. Hence, in order to describe the typical effects of a cohesive fracture, the main idea is to couple, through a variational approach, the perfect plasticity model and a softening gradient damage model. The use of a variational approach results in a weak and derivative-free formulation, gives effective means to deal with the concepts of bifurcation and stability, is intrinsically discrete and indicates a natural and rational way to define efficient numerical algorithms.

Embedding damage effects in a plasticity model is not a new idea. Nevertheless the proposed model presents many original aspects as the coupling between plasticity and damage and the way the governing equations of the variables are found. The variational approach relies simply on three concepts: the irreversibility condition, a global, local or differential stability condition and the energy balance. The resulting model possesses a great flexibility in the possible coupled responses, depending on the constitutive parameters. These various responses are first considered by investigating in a one-dimensional quasi-static traction bar test a homogeneous evolution which highlights the main features of the model. The discussion about the stability of the homogeneous solutions leads to the existence of a critical bar length which in turn depends on the characteristic internal material length. For bars that are longer than this critical value the homogeneous response is proven to become unstable and a localization must appear. A construction of localization is then proposed which explicitly takes into account the irreversibility condition on the damage field. This allows the non-homogeneous evolution and the global response to be investigated. It turns out that in general a cohesive crack appears at the center of the damage zone before the complete rupture. At this point the plastic strain localises as a Dirac measure which becomes responsible for this cohesive crack. The associated cohesive law is obtained in a closed form in terms of the parameters of the model and it recovers the cohesive fracture law postulated by Barenblatt. Finally, a numeric resolution scheme is proposed, which is based on an alternate minimization algorithm, and implemented through a finite element library only for the one-dimensional traction bar test. Although the adopted finite element spaces do not embed discontinuities, the numeric results agree perfectly with the analytic solutions. This is due to a kind of numeric regularisation. Nevertheless, future developments aim to extend the simulations in a two/three-dimensional setting and test a generalized finite element method.

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