A XFEM-CZM Based Methodology for Finite Strain Ductile Fracture

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Ductile metals and alloys are the most used materials for structural components in the aerospace, naval and automotive industries due to their strength and good formability. In order to determine the residual strength or/and damage tolerance of engineering structures, it is crucial to be able to reproduce qualitatively and quantitatively the consecutive steps leading to ductile fracture [1], namely: void nucleation and growth, void coalescence into thin bands creating meso-cracks and finally macro-cracking. Mesh-dependency of the numerical results is a well-known issue when the standard finite element method is employed together with a constitutive model involving ductile damage induced softening (e.g. GTN model). In the literature there are some regularization methods mainly based on non-local methods [2] that require a fine meshing, thus having a high computational cost if the response of large-dimension structures is investigated.

We present here a three-dimensional numerical methodology implemented in ABAQUS as user finite element (UEL), that phenomenologically accounts for the mechanisms leading to the progressive failure. In order to deal with large elastoplastic deformation, we adopt the Updated Lagrangian formulation. Ductile damage is treated using the standard finite element method (FEM) whereas the localization band and further crack, embedded in the finite element, are treated using the extended finite element method (XFEM). The band is treated as a cohesive crack (cohesive XFEM) and its progressive cohesion loss leads to the ultimate crack (standard XFEM). The passage from standard FEM (diffuse damage) to cohesive XFEM (localization band) is triggered by a phenomenological criterion in terms of critical porosity that leads to the formation of a damage localization band. The cohesive zone model relates the traction force vector with the equivalent relative displacement, with a power law form for the evolution of the damage-like variable. Local stress triaxiality controls the orientation of the localization plane and the transition between Mode I and Mode II is treated with a mode mixicity law. The integration of the XFEM is performed by means of a volume averaging based integration (VAI) method, already implemented by Nikolakopoulos et al. [3], which mitigates the need for the existence of integration points on both sides of the discontinuity. We also adopt the F-bar approach to deal with incompressibility. The unified methodology exhibits no mesh dependency and is capable of fairly reproducing all consecutive failure mechanisms and the rupture surface for large elastoplastic deformation without volumetric locking. Future developments include cohesive zone model improvement and other physics motivated criteria to describe the passage from diffusive damage to localization and from localization to rupture [4].

References

[1] A. Pineau, A. A. Benzerga, and T. Pardoen, Failure of metals I: Brittle and ductile fracture, Acta Materialia 107 (2016) 424–483.

[2] R. H. J. Peerlings, R. De Borst, W. A. Brekelmans, and J. H. De Vree, Gradient enhanced damage for quasi-brittle materials, International Journal for Numerical Methods in Engineering 39 (1996) 3391–3403.

[3] K. Nikolakopoulos, J. P. Crété, and P. Longère, Progressive failure of ductile metals: Description via a three-dimensional coupled CZM-XFEM based approach, Engineering Fracture Mechanics 243 (2021) 107498.

[4] J. Besson, Damage of ductile materials deforming under multiple plastic or viscoplastic mechanisms, International Journal of Plasticity 51 (2009) 2204–2221.