A UNIFIED NONLINEAR XFEM-CZM BASED METHODOLOGY TO DEAL WITH DUCTILE FRACTURE

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Abstract

The numerical treatment of the whole process of ductile fracture remains a challenging task, particularly when FEM is employed. The main issue regards pathologically mesh dependence of the numerical results, not only in the softening regime but also in the stages of strain localization and further crack propagation. In the literature, non-local approaches are adopted to mitigate these effects but they require a calibrated length scale and mesh refinement, thus being time consuming. This work focuses on the numerical treatment of ductile fracture in metal materials via a three-dimensional unified methodology that combines (*i*) the GTN model to describe diffuse damage using the standard FEM, the (*ii*) XFEM to represent the crack and (*iii*) the coupling of the XFEM with a cohesive zone model to account for the intermediate localization phase. We rely upon the Updated Lagrangian formulation to include large strains and rotations. The methodology, implemented in Abaqus commercial code as a user finite element (UEL), is capable of reproducing numerically the overall response of structures until rupture.

1. Introduction

Ductile metals and alloys are the most widely 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 consecutives steps that lead to fracture. In the literature, there is a consensus about the different steps leading to ductile fracture (e.g. [1]), namely: void nucleation and growth, void coalescence into thin bands creating meso-cracks and finally macro-cracking. The problem of mesh dependence of the numerical results is well-known when the standard finite element method is adopted with a constitutive model involving ductile damage induced softening (like e.g. GTN model). Regularization methods present in the literature are mainly based on non-local methods [2] that require a fine meshing, therefore presenting a high computational cost when the response of large-dimension structures is investigated. We develop here a three-dimensional numerical methodology that accounts for the physics of the mechanisms leading to the progressive failure. To numerically 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).

2. Application

The passage from standard FEM (diffuse damage) to cohesive XFEM (localization band) is triggered by a phenomenological criterion in terms of critical porosity/equivalent plastic strain 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. The orientation of the localization plane is controlled by the local stress triaxiality and the transition between Mode I and Mode II is treated with a mode mixicity law. To numerically integrate the XFEM we use a volume averaging based integration (VAI) method (see [3]) which allows mitigating 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 methodology has been implemented in Abaqus as user finite element

(UEL). We consider a mild steel flat tension test specimen. Hexahedral full integration finite elements are used. The value of the initial porosity is $f_0 = 0.1\%$ while the value of critical porosity is $f_c = 3\%$.

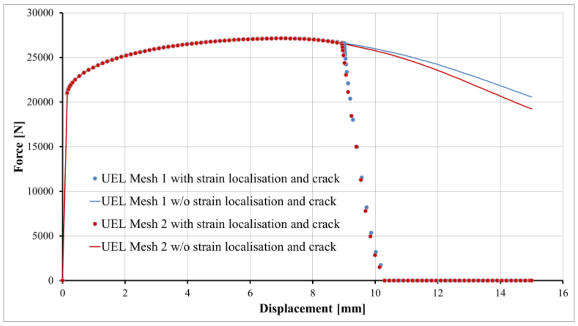

Fig.1 – Reaction force in terms of displacement for flat tension test specimen.

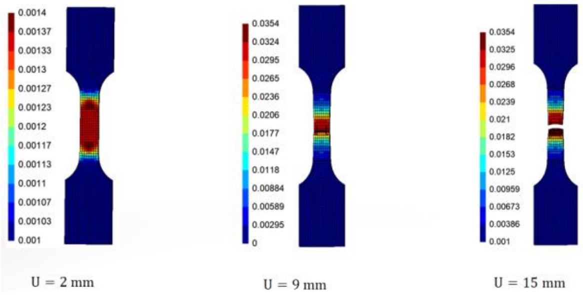

Fig.2 – Porosity map for various values of imposed displacement.

We observe in Figure.1 the reaction force in terms of the displacement, for the same specimen but with two different mesh sizes. Namely Mesh 1 has around 2000 elements with 3 through thickness, and Mesh 2 has around 5000 elements with 4 through thickness. Curves with the continuous lines represent the reaction force obtained with the methodology that considers only ductile damage, while the dotted lines represent the reaction force obtained with the unified methodology, thus including strain localization and crack propagation. The unified methodology exhibits no mesh dependency during the drop-in-resistance phase. In Figure.2 the porosity evolution for three different displacement values is shown. We can observe a realistic reproduction of the fracture surface.

3. Conclusions

The unified methodology is capable to fairly reproduce all consecutive failure mechanisms and the rupture surface for large elastoplastic deformation without mesh dependence and 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. Moreover, experimental data will be collected in order to perform a parametric study and to determine the cohesive parameters that influence the response in the softening regime.

4. References

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