A new finite element framework for the modeling of ductile fracture mechanisms in heterogeneous microstructures

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Ductile fracture has been studied for many years and has given rise to number of damage theories and failure criteria. However, predicting ductile fracture under complex loading path remains challenging, in particular for advanced heterogeneous materials for which failure mechanisms depend on microstructural properties such as particle characteristics (nature, shape and distribution), grains, and texture. Modeling failure at a mesoscale would help in the understanding of the role of these microstructural properties on ductile fracture mechanisms. Such a modeling requires an accurate numerical framework accounting for heterogeneous microstructure definition and meshing capabilities under large plastic strain as well as numerical methods for the modeling of failure events such as void nucleation – by interface debonding or particles failure – and coalescence.

In this work, a micromechanical approach is developed in order to conduct realistic full field finite element (FE) simulations of ductile fracture at the microscale. Meshing and remeshing methods relying on the use of Level-Set functions are proposed to discretize the microstructure and its behavior under large plastic strain [1, 2]. These numerical methods are extended to account for cracks and model the microstructure failure mechanisms: void nucleation, growth and coalescence. This new FE approach is used to study the influence of multiaxial and non-monotonic loading on ductile failure mechanisms. It is shown that different loading paths leading to the same final macroscopic strain activate different nucleation mechanisms and consequently different final void volume fraction.

These full field FE simulations can also be used to calibrate nucleation or coalescence failure criteria. This is done here thanks to the combination of Synchrotron Radiation Computed Laminography (SRCL) experiments and observations [3], Digital Volume Correlation (DVC) [4] and FE simulations [1, 2]. Thanks to SRCL images at the initial state, a representative volume element (RVE) representing the exact microstructure is meshed using the body-fitted immersed method presented in [2]. The DVC also uses SRCL images at different stages of the mechanical test in order to extract the exact boundary conditions that need to be applied on the RVE. These boundary conditions play an important role on void growth as detailed in [5]. The FE framework enables the modeling of void nucleation growth and coalescence with criteria parameters that can be identified by comparison with SRCL images. The whole methodology ([6]) is carried out on nodular cast iron and comparisons with experimental observations are discussed.

References

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