Finite Element Modeling of Void Nucleation, Growth and Coalescence for Large Plastic Strain and Complex Loading Paths

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Ductile damage prediction is still an important issue in the mechanical industry. Ductile failure criteria as well as coupled damage models were enhanced in the last decade by accounting for the influence of stress triaxiality ratio and Lode angle. For the Gurson-Tvergaard-Needleman (GTN) model, these improvements were essentially made for the growth and coalescence stages based on unit-cell models in which the behavior of a single ellipsoidal void is studied under various loading conditions [1]. In the present work, the stage of nucleation is also addressed in addition to void growth and coalescence for large plastic strain and different particle/void morphologies.

- Microstructure representation

Heterogeneous microstructures with particles and voids in a metallic matrix are considered. This heterogeneous microstructure is meshed using level-set functions - to define interfaces between matrix, inclusions and voids - and anisotropic mesh adaptation. This anisotropic mesh adaptation is particularly well suited for macroscopic [2] and microscopic [3] ductile damage problems.

- Mechanical failure criteria

Nucleation starts either by particle failure or by debonding at particle-matrix interfaces. For debonding nucleation (respectively particle failure), the failure criterion is based on interfacial normal and tangential stresses (respectively maximum principal stress in particles). The void growth stage is based on plastic strain around void during the deformation stage. Finally coalescence is activated when a critical plastic strain value is reached between two growing voids. It has to be noticed that this coalescence criterion can be easily transformed in a criterion based on the distance between neighbouring voids.

- Numerical failure techniques

Once the failure criterion is reached, two different numerical techniques can be used to model failure:

- Germ-based method: a void germ, represented by a new level-set function, is created at the location for which the failure criterion was reached. The interface between this void and the matrix (or particle) is well described thanks to the anisotropic mesh adaptation.

- Failure plane method: an instantaneous failure plane, modelled by a level-set function, is created once the critical failure criterion is reached. For good accuracy, particular attention has to be paid to the mesh refinement in the area in which this failure plane is created.

The two methods are compared and their advantages and drawbacks are presented in terms of numerical accuracy and physical representation of ductile failure mechanisms.

- Applications

Several 2D and 3D applications are presented. The influence of failure parameters and loading conditions are studied for simple microstructures and for real microstructures coming from scanning electron microscopy (SEM) images.

References

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