Properties of a non-local locking-free GTN model within the context of small-scale yielding

Youbin CHEN*†, Eric LORENTZ* and Jacques BESSON†

* EDF R&D, 7 Boulevard Gaspard Monge, Palaiseau 91120, France
Email: youbin.chen@edf.fr, eric.lorentz@edf.fr

† Mines ParisTech, PSL Research University, Centre des Matériaux, UMR CNRS 7633, 10 rue Henri Desbrures, Evry 91000, France
Email: youbin.chen@mines-paristech.fr, jacques.besson@mines-paristech.fr

ABSTRACT

This study aims at investigating the properties of a non-local locking-free GTN ductile damage model [1] at finite strain within the framework of small-scale yielding. This model solves the problems of spurious localization and volumetric locking. The former is achieved by introducing the gradient of the hardening variable into the Helmholtz free energy (gradient plasticity). On a numerical ground, this results in spatial gradients of state variables within the constitutive relations: a decomposition-coordination techniques [2] is used to treat the corresponding term. Regarding the volumetric locking resulting from plastic incompressibility prior to damage, the Hu-Washizu mixed variational principle [3] is put in practice. An additional penalty term is also introduced into the corresponding Lagrangian in order to ensure coercivity. Finally, a new 5-field finite element is derived from the non-local locking-free variational formulation, in combination with the set of constitutive relations.

The model is applied to simulate large crack propagation under small-scale yielding and plane-strain mode I conditions. A new way to extract the crack length from the porosity field is introduced. Besides, purely numerical parameters are introduced to help convergence. An adequate range is exhibited for each of them so that their impact on the $J-\Delta a$ crack growth resistance curves be negligible. Finally, a parametric study is performed for several values of the material properties in order to estimate their influence on the crack growth resistance.

Here are the main findings:

1. A linear relationship between the non-local intrinsic length implicitly introduced by the hardening gradient terms and the width of the damage/strain localization band is established.
2. Crack tip blunting, crack initiation and large crack propagation can be well captured with the modified GTN model.
3. The numerical formulation is robust; wide ranges for the material plasticity and damage parameters can be used in a reliable way so that toughness at crack initiation as well as ductile tearing behaviour can be thoroughly studied.

REFERENCES

[1] Y. Zhang, E. Lorentz, J. Besson, “Ductile damage modelling with locking-free regularised GTN model”, International Journal for Numerical Methods in Engineering 113 (13) 1871–1903, (2018).

[2] M. Fortin, R. Glowinski, Augmented Lagrangian methods: applications to the numerical solution of boundaryvalue problems, Vol. 15, Elsevier, (2000).

[3] K. Washizu, “On the variational principles of elasticity and plasticity”, M.I.T. Aeroelastic and Structures Research Laboratory, Cambridge, (1955)