A gradient-enhanced model for ductile damage and failure of steels based on an engineering approach

Andreas Seupel and Meinhard Kuna

Institute of Mechanics and Fluid Dynamics
TU Bergakademie Freiberg
Lampadiusstrasse 4, 09599 Freiberg, Germany
e-mail: Andreas.Seupel@imfd.tu-freiberg.de
e-mail: Meinhard.Kuna@imfd.tu-freiberg.de

ABSTRACT

We present recent enhancements of an engineering concept, which was introduced by Lian et al. [1], to model ductile failure. The concept consists of using an appropriate plasticity model, an uncoupled indicator of damage initiation, and a simple model of damage evolution which is fully coupled to the constitutive equations leading to material softening. We focus on the following improvements which have been recently published [2]: 1) In order to account for the impact of hydrostatic stress on macroscopic plasticity due to the evolution of damage (nucleation and growth of voids), an elliptic yield function in terms of hydrostatic and equivalent stress is proposed. The plastic yielding deviates from J_2-plasticity in case of damage onset only. Damage is driven by the additive combination of equivalent and volumetric plastic strain leading to a triaxiality dependent damage evolution law similar to the one suggested by Mediavilla et al., [3]. 2) The important issue of spurious mesh dependency is handled by incorporating an implicit gradient-enhancement, see [4]. The non-local counterpart of the previously mentioned damage driving strain is used to formulate the damage law. The model is efficiently implemented into the FE-code ABAQUS, utilizing the similarities between the field equations of the implicit gradient-enhancement and the equation of heat conduction, see [5]. A convergence study is performed to show the mesh-independence and other features of the enhanced damage model. Finally, the proposed model is exemplarily applied to experimental data of a pressure vessel steel (18Ch2MFA) at moderate to high stress triaxialities. It is shown that groups of model parameters can be calibrated independently. The calibration has been performed using a crack growth resistance curve of a SENB-test and results from notched tensile tests. The numerical prediction of a small punch test shows good agreement compared to experiments. Additional numerical examples are performed to discuss further applications, restrictions, and open issues of the model.

REFERENCES

[1] Lian, J., Sharaf, M., Archie, F., Münstermann, S. A hybrid approach for modelling of plasticity and failure behaviour of advanced high-strength steel sheets. *Int. J. Damage Mech.* (2013) **22**:188–218.

[2] Seupel, A. and Kuna, M. A gradient-enhanced damage model motivated by engineering approaches to ductile failure of steels. *Int. J. Damage Mech.* (2019), https://doi.org/10.1177/1056789518823879

[3] Mediavilla, J., Peerlings, R. H. J. and Geers, M. G. D. A nonlocal triaxiality-dependent ductile damage model for finite strain plasticity. *Comput. Methods Appl. Mech. Engrg.* (2006) **195**:4617–4634.

[4] Peerlings, R. H. J., de Borst, R., Brekelmans, W. A. M. and de Vree, J. H. P. Gradient enhanced damage for quasi-brittle materials *Int. J. Numer. Meth. Eng.* (1996) **39**:3391–3403.

[5] Seupel, A., Hütter, G. and Kuna, M. An efficient FE-implementation of implicit gradient-enhanced damage models to simulate ductile failure. *Engng. Fract. Mech.* (2018) **199**:41–60.