Ductile failure modes in plasticity

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Ductile Failure Modes in Plasticity

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Introduction

Besides the final product shape, the accumulation of damage in regions of localised plastic deformation also affects the product quality and efficiency of the forming process.

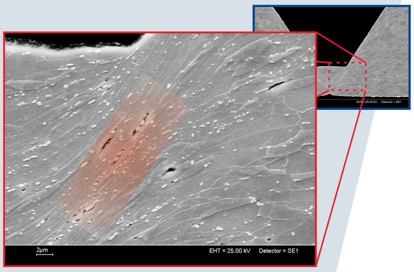


Figure 1 *Damage accumulation during the score forming determines the ease with which the lid of a can can be opened [Corus 2001].*

A continuum plasticity-damage model is being developed which represents the micromechanical initiation and evolution of ductile damage to a satisfactory extent.

Plasticity-Damage Model

plasticity

The rate-independent hyperelastic J_2-plasticity framework due to Simo [1] with an isochoric plastic flow.

ductile damage

The ductile damage parameter that gradually reduces the yield strength [2] is added to the Huber–Mises yield condition.

$$\Phi = \sigma_e - [1 - \omega_p]\, \sigma_y(\varepsilon_p) \leq 0$$

non-locality

The well-posedness of the mathematical problem in case of material softening is ensured by adopting the non-local field variable $\bar{\varepsilon}_p$ as the damage-driving variable, which is determined by solving the following additional PDE:

$$\bar{\varepsilon}_p - \ell^2 \nabla^2 \bar{\varepsilon}_p = \varepsilon_p \qquad \text{BC}: \vec{\nabla}\bar{\varepsilon}_p \cdot \vec{n} = 0 \text{ on } \Gamma$$

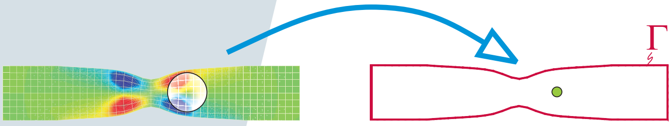


Figure 2 *Schematic representation of the non-local interactions.*

The internal length ℓ controls the degree of non-locality.

Numerical Framework

The set of governing equations (force equilibrium and non-locality) are discretised in the following manner:

$$\begin{bmatrix} K_{uu} & K_{u\bar{\varepsilon}_p} \\ K_{\bar{\varepsilon}_p u} & K_{\bar{\varepsilon}_p\bar{\varepsilon}_p} \end{bmatrix} \begin{bmatrix} \delta u \\ \delta\bar{\varepsilon}_p \end{bmatrix} = \underset{\sim}{f}_{res}$$

requiring only C^0-continuous shape functions and one additional degree of freedom aside from the usual displacements. The consistent tangent operator ensures a quadratic convergence of the Newton-Raphson method.

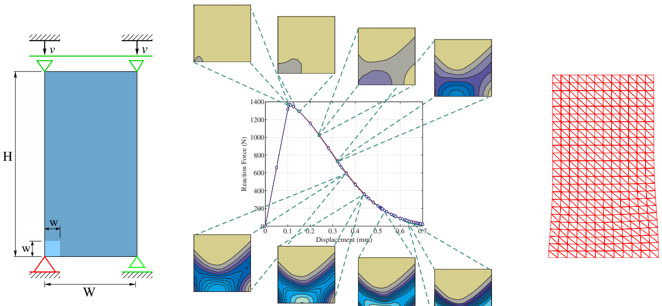


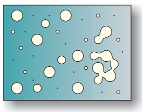
Figure 3 *Bi-axial compression test; localisation of deformation.*

The model exhibits a mesh-independent response for material softening and copes with the intense localisation.

Micromechanical Failure Modes

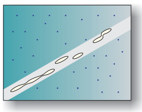
Polycrystalline metals exhibit the following distinctive ductile failure modes on the micromechanical level [3]:

☐ hydrostatic failure



hydrostatic stresses cause nucleation and growth of voids that eventually coalesce due to impingement.

☐ shear failure



localised plastic strains give rise to nucleation and extension of voids, which coalesce due to instabilities.

FE simulations are performed on a voided unit-cell with a controllable deviatoric and volumetric part of the deformation:

$$\boldsymbol{\varepsilon} = \boldsymbol{\varepsilon}_{dev} + \boldsymbol{\varepsilon}_{vol}$$

The numerical response is homogenised in order to determine relevant damage measures for the failure modes.

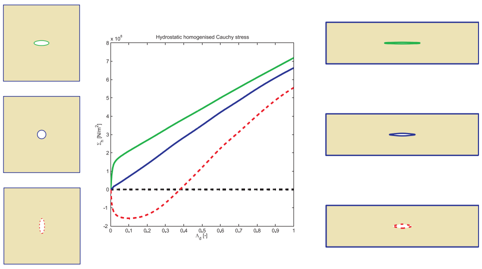


Figure 4 *Influence of void shape and orientation on the homogenised response (hydrostatic Cauchy stress).*

Eventually, a more realistic ductile damage evolution law can be obtained by fitting with the homogenised response.

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[3] Orsini, V. C., and Zikry, M. A.: *Int J Plasticity* **17**(10): 1393–1417 (2001)

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