On damage initiation and evolution

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Introduction
Industrial applications like deep drawing and blanking are characterised by the presence of small zones where damage accumulates and plastic deformation localises.

Figure 1 Zones of damage accumulation and intense localisation of plastic deformation; Corus 2001.

These zones determine not only the product quality, the efficiency of the process, but they are also responsible for the vast majority of engineering problems.

Objective
The development of a continuum plasticity framework, which represents the micromechanical behaviour during ductile damage to a satisfactory extent and which is able to handle both finite strains and localised deformations.

Methods
Plasticity
Starting point is the rate-independent hyperelastic $J_2$-plasticity framework introduced by Simo (1988) with a corrected kinematic constraint for isochoric plastic flow.

Ductile Damage
A ductile damage parameter gradually reduces the yield strength $\sigma_y$ through an enriched Huber–Mises yield condition

$$\Phi = \sigma_e - [1 - \omega_p] \sigma_y = 0$$

Non-locality
The damage driving variable is the non-local field of the effective plastic strain $\bar{\varepsilon}_p$, which is determined using an implicit gradient PDE. The solution $\bar{\varepsilon}_p$ is fully non-local from a mathematical point of view

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

Figure 2 Schematic non-local material interactions.

In addition, the non-locality regularises the mathematical framework in case of material softening.

Results
Besides the expected mesh independence, simulations reveal that the model is well able to cope with highly localised deformations.

Figure 3 Localised deformations in compression
These simulations reveal two deformation stages:
- expansion of the plastic zone
- further localisation within this zone

Discussion
On the micromechanical scale of polycrystalline metals two characteristic modes of ductile damage are observed.

Ductile fracture
Typically occurs due to coalescing voids that grow in the presence of hydrostatic stresses

Figure 4 Hydrostatic stresses cause nucleation and growth of microvoids; coalescence by impingement

Shear cracks
Instable fracture between extended microvoids within a region with high (localised) plastic deformation

Figure 5 Localised plastic strains cause nucleation and extension of microvoids; coalescence by instability

The presented framework is suited to display the global behaviour of both the above failure modes, e.g. if the influence of the hydrostatic stress is accounted for.

References: