A micromechanical model for ductile damage

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Introduction

During the forming of a metal the initial material is damaged.

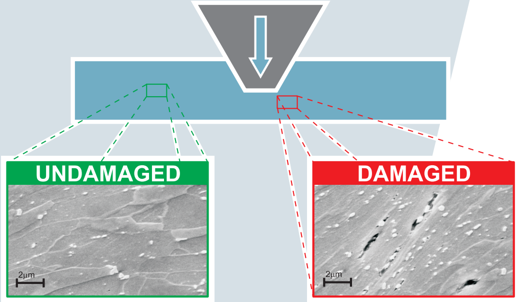

Figure 1 *Material degradation due to microvoids during a forming process.*

The material degradation determines both the quality/shape (*e.g.* cutting) and the residual properties (*e.g.* forging) of the final product. A good understanding and accurate modelling of the underlying micromechanical processes allows for an accurate prediction of the evolution of ductile damage.

Micromechanical model for void growth

Geometry

The void is represented by an elliptical shape that is surrounded by a ring of matrix material.

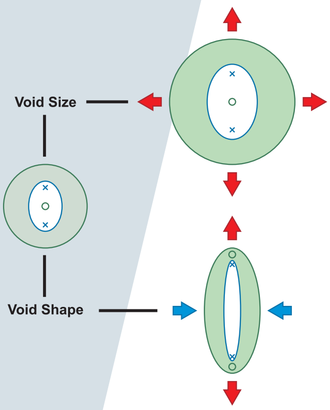

Figure 2 *Geometrical representation of the micromechanical model for void growth.*

The deformation is characterised by two damage parameters, *i.e.* the void volume fraction f and the void shape S:

$$f = \frac{V_{\text{void}}}{V_{\text{cell}}} \quad \wedge \quad S = \ln\left(\frac{a_{\text{void}}}{b_{\text{void}}}\right)$$

It is asumed that the void is aligned with the pricipal directions of the imposed deformation.

Kinematics

The change in size and shape of the void due to the applied loading on the outer boundary is governed by

- ☐ $V_{\text{cell}} - V_{\text{cell}} = V_{\text{matrix}}$ (constant matrix volume)
- ☐ $\sinh(S_{\text{void}}) = \dfrac{\sinh(S_{\text{outer}})}{\sqrt{f}}$ (non-confocal deformation)

Evolution of damage

From these kinematics the following evolution laws can be derived for both damage parameters

$$\dot{f} = [1 - f]\,\text{tr}(D) = [1 - f]\,D_{\text{v}}$$

$$\dot{S} = F_{\text{d}}(S, f; c_1, c_2)\,D_{\text{d}} + F_{\text{v}}\big(S, f; c_3, c_4\big)\,D_{\text{v}}$$

Unit cell simulations

Acquiring quantitative experimental data of ductile damage is quite intricate and the numerical verification of the evolution laws is utilised instead. Only two specific loading cases are sufficient to determine a parameter set c_i that shows a quantitative agreement with the unit cell simulations.

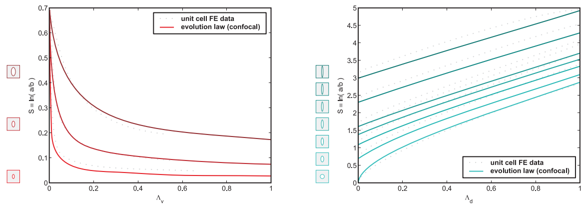

Figure 3 *Comparison of analytical and numerical damage evolution; influence of initial void size (left) and shape (right).*

It has been verified that a quantitative agreement is also achieved for an arbitrary initial void size, void shape and loading of the unit cell.

Homogenisation

For a rigid ideally-plastic von Mises material the average plastic dissipation of the unit cell reads

$$\dot{W} = \frac{1}{V}\int_V \sigma_{\text{o}}\, d_{\text{eq}}\, \text{d}V$$

A pressure-sensitive yield surface is obtained from the principle of maximum plastic dissipation and normality of plastic flow

$$\Sigma_{\text{d}} = \frac{\partial \dot{W}}{\partial D_{\text{d}}} \quad \wedge \quad \Sigma_{\text{v}} = \frac{\partial \dot{W}}{\partial D_{\text{v}}}$$

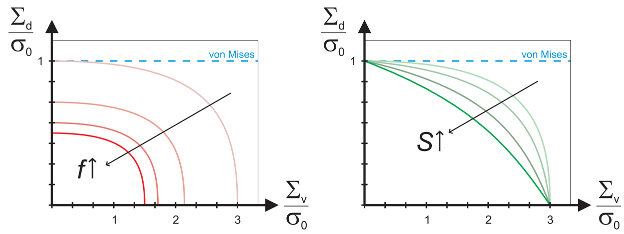

Figure 4 *Schematic representation of the non-isochoric yield surface; influence of void size (left) and shape (right).*

References:

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