Implementation of a shear-modified Gurson-Model into the FE-Program Abaqus

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Introduction

The Gurson model and its modified version (GTN model) are widely used for the simulation of ductile failure in porous metals. It is known, that the effective plastic strain at fracture increases dramatically when the stress triaxiality $T=P/Q$ decreases [1]. However, experimental observations [2] have shown a different behavior in range of low stress triaxiality. However, the GTN model is not able to predict failure behavior in this range but it performs well under medium and high triaxiality. That’s why the GTN model can predict failure for axisymmetric tension when stress triaxiality has a value greater than 1/3 but there is no damage prediction under pure shear.

Yield condition of the GTN model:

$$\Phi = \left( \frac{Q}{\Sigma_y} \right)^2 + 2q_1 f^* \cosh \left( -\frac{3}{2} q_2 \frac{P}{\Sigma_y} \right) - \left( 1 - (q_1 f^*)^2 \right) = 0$$

$q_1$, $q_2$: Fitting parameters
$Q$: Equivalent stress
$P$: Hydrostatic stress
$\Sigma_y$: Yield stress
$f^*$: Modified void volume fraction
$f_c$: Critical void volume fraction
$f_f$: Final void volume fraction
$f_{\omega} = \frac{1}{q_1}$

Shear-modified Gurson model

Due to the rotation of voids under shear, damage occurs in the material. Different approaches have been proposed for incorporating the shear failure in the GTN model. The method introduced by Nahshon and Hutchinson [3] is widely used, since this model contains a limited number of parameters for modeling the shear driven damage. On the other hand, it gives reliable outputs which can be compared to experimental data with sufficient accuracy. The original GTN model is not able to describe localization and damage for low stress triaxiality. Nahshon and Hutchinson [3] included a phenomenological damage term into the GTN model which represents void deformation and reorientation in shear dominated stress states. The modified expression of void evolution is given by:

$$\dot{f} = \dot{f}_{\text{growth}} + \dot{f}_{\text{nucleation}} + \dot{f}_{\text{shear}}$$

$$\dot{f}_{\text{shear}} = \kappa \omega(\sigma) \frac{\Sigma_j^2 E_{ij}^p}{Q}$$

The original GTN model is governed by the 1st and 2nd stress invariants. The void shearing mechanism is affected by the 3rd invariant $J_3$, so the modified GTN model incorporates the following dependency on $J_3$:

$$\omega(\sigma) = 1 - \left( \frac{27 J_3}{2Q^2} \right)^2$$

$\omega(\sigma)$ is a dimensionless parameter which becomes 0 for all axisymmetric and 1 for pure shear stress states, respectively. $\kappa_{\omega}$ is a new parameter which sets the rate of damage development in shear. It has to be fitted for experimental data in the same way as $q_1$ and $q_2$.

Simulation of shear experiments

Nodular cast iron is a complex alloy with a ferritic matrix material and embedded nodular graphite particles. Due to its high porosity, the material exhibits at room temperature a ductile behavior with a very high value of elongation. The matrix material follows a Ramberg-Osgood stress-strain relationship and with a yield stress of $\Sigma_y=240\text{MPa}$, a strain hardening exponent of $N=0.15$, Young’s modulus $E=181\text{GPa}$ and Poisson’s ratio $\nu=0.27$. The material parameters for the GTN model are listed in the table below.

<table>
<thead>
<tr>
<th>$q_1$</th>
<th>$q_2$</th>
<th>$q_3$</th>
<th>$f_0$</th>
<th>$f_c$</th>
<th>$f_f$</th>
<th>$\Sigma_N$</th>
<th>$f_N$</th>
<th>$\Sigma_N$</th>
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<td>0.11</td>
<td>0.35</td>
<td>0.4</td>
<td>0.2</td>
<td>0.1</td>
<td>0.3</td>
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</tr>
</tbody>
</table>

The shear-modified Gurson model is employed to simulate a shear test of a thin plate made of nodular cast iron. The FE-model of the shear specimen and the microstructure of nodular cast iron are shown below.

The results of the simulations are compared with the experimental data in the figure below by variation of the shear damage coefficient $\kappa_{\omega}$ from 0.0 to 2. It is obvious that the damage coefficient $\kappa_{\omega}$ has a strong influence on the prediction of the shear failure.