A MODIFIED GURSON MODEL TO ACCOUNT FOR THE INFLUENCE OF THE LODE PARAMETER AT HIGH TRIAXIALITIES

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1. Introduction

The ductile fracture phenomenon in metals and alloys usually follows a failure mechanism involving nucleation, growth and coalescence of voids. To analyze the ductile failure of porous materials, the Gurson's damage model [1] is the most widely used approach. Tvergaard [2] modified the Gurson model by introducing the q_1 and q_2 parameters to more accurately describe the void growth kinetics observed in unit cell computations.

The effect of the Lode parameter on ductile failure cannot be properly accounted for with the classical GT model. In the present work, an improvement of the Gurson-Tvergaard model that accounts for the influence of the Lode parameter at high triaxiality stress states is presented. The modification consists on incorporating the Lode parameter effect into the GT yield surface through q_1 and q_2 parameters, which depend not only of the stress triaxiality T, but also on the third invariant of the deviatoric stress tensor J_3. The convexity of the yield surface is assured with this new term . The integration of the new constitutive equations has been implemented using a full implicit Euler-backward scheme combined with the return mapping algorithm. Additionaly, the consistent tangent modulus has been formulated. For validation purposes, a 3D extension of a computational cell model has been developed prescribing both macroscopic triaxiality and Lode parameter. Numerical simulations using the Finite Element code ABAQUS/Standard are presented for Weldox 960 steel. The obtained results using the new continuum damage model are compared with those found with a J_2 voided cell for both the void growth and the stress-strain response of the material.

2. Numerical cell results for the voided J_2 and for the classical Gurson-Tvergaard model

Fig.1 compares the evolution of macroscopic stress-strain and the predicted void-volume fraction growth till coalescence using GT classical model with calibrated q_i parameters using the results of the J_2 voided cell model for $L = -1$. The studied material for the analysis is Weldox 960 [3]. The cases analyzed corresponds to f_0=0.005, $T = 1$ and $L= -1$, 0 and 1. It can be seen how the classical GT model predicts the same behavior when the triaxiality ratio is the same, meanwhile voided J_2 cell response differs when Lode parameter changes. It is also observed, for every triaxiality studied, how the difference between the two models increase when the value of the Lode parameter increases.
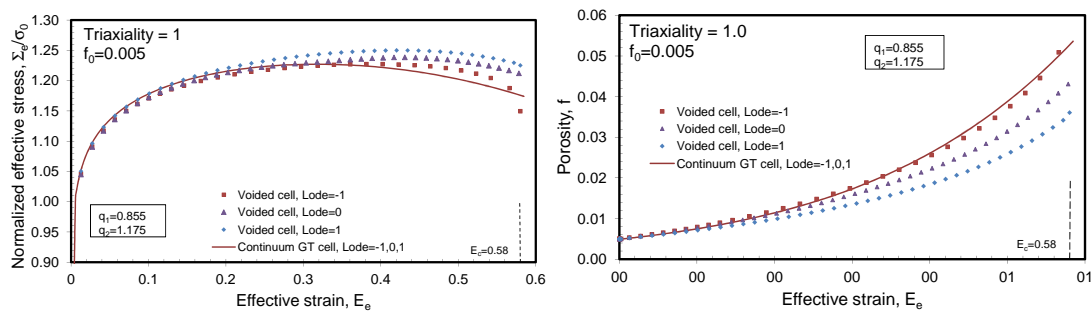

Figure 1. Comparison of Σ_e vs. E_e curve and f vs. E_e curve for a voided cell and a continuum GT cell.

3. Modified Gurson-Tvergaard model with Lode parameter dependence

In order to account for the influence of T and L on the response of the material, the main innovative feature of this work is to propose a modification of the yield function of the classical GT model introducing new dependences in q_1 and q_2 Gurson-Tvergaard parameters as functions of triaxiality and Ω. The proposed yield function has the form:

$$(1) \qquad \Phi_{mod}\left(\Sigma_e, \Sigma_h, T, \Omega, \bar{\sigma}, f\right) = \frac{\Sigma_e^2}{\bar{\sigma}^2} + 2q_{1mod} f \cosh\left(\frac{3q_{2mod}\Sigma_h}{2\bar{\sigma}}\right) - \left(1 + (q_{1mod})^2 f^2\right)$$

with q_{1mod}, q_{2mod}, for the sake of simplicity, defined as linear functions of T and Ω as:

$$(2) \qquad q_{1mod}(T, \Omega) = q_1(T) \cdot (1 + k_\Omega \cdot \Omega); \quad q_{2mod}(T, \Omega) = q_2(T) \cdot (1 + k_\Omega \cdot \Omega)$$

$\Omega = \frac{27 J_3}{2\Sigma_e^3} - 1$, function of the effective stress Σ_e and $J_3 = \det(\Sigma')$, lies in the range $-2 \leq \Omega \leq 0$. $\Omega = 0$ for $L = -1$, and $\Omega = -2$ for $L = 1$. The functions $q_1(T)$ and $q_2(T)$ in q_{1mod} and q_{2mod} follows a linear function with interpolated coefficients based of fitted discrete q_i values for $L = -1$. k_Ω is a proposed adjustment parameter. This modification is purely phenomenological, but formulated to retrieve the original GT formulation for $L = -1$ and T=constant. Figure 2 is an example that shows
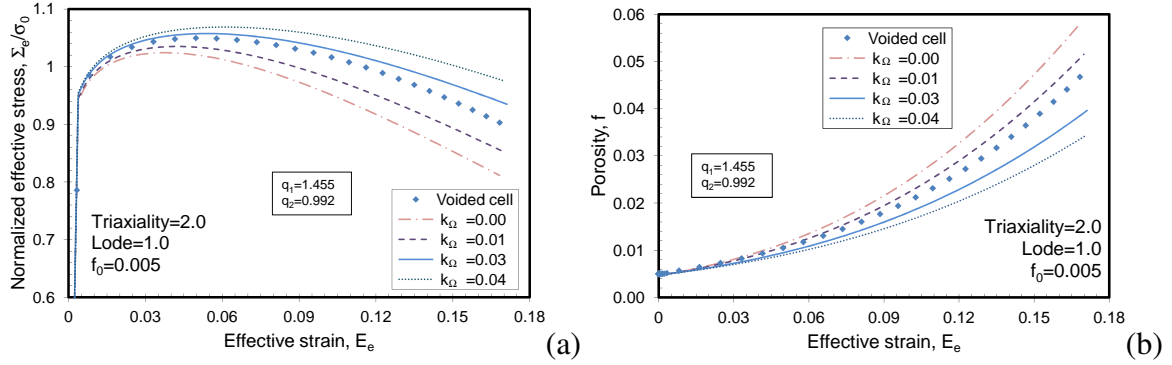

Figure 2. Σ_e versus E_e and f versus E_e for $f_0 = 0.005$, $T = 2$, $L = 1$

that the proposed model, with a proper selection of k_Ω, agrees very well with that obtained from the voided cell analysis.

4. Acknowledgement

5. References

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