EXTENDED GURSON-TYPE YIELD CRITERIA FOR STRAIN RATE SENSITIVE MATERIALS

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1. Introduction

The nucleation and growth of microvoids that ultimately link to form cracks are the dominant ductile failure mechanism of metallic materials. One way to predict the behaviour of a material during the fracture process consists on using mathematical models which take into account the effect of porosity through constitutive laws applied in a homogenous medium. The most employed analytical model is the one proposed by Gurson in 1977 [1], where it was presented a yield function for perfectly plastic ductile materials. However, if the yield stress is not constant, the Gursons yield function prediction became inaccurate. In the present work, an analytical extension of Gursons model is proposed explicitly by introducing the strain-rate dependence of the material into the yield locus.

2. Problem formulation

It is considered an axisymmetric ideally plastic solid containing a single void, thus representing a material with a periodic array of voids. The void grows as remote axisymmetric loadings are applied to the cell.

The matrix material follows the Huber-Mises associated flow rule and it is considered as incompressible. For sake of simplicity, for a rate-dependent material, the Mises stress $\bar{\sigma}$ is defined by a power-type hardening formulation as:

$$\bar{\sigma} = \sigma_0 \left(\dot{\bar{\varepsilon}}\right)^m \tag{1}$$

being m the strain rate sensitivity parameter and σ_0 a reference yield stress.

In order to obtain a yield surface Φ, the exact analytical solution of the resultant equations, to the best of our knowledge, does not exist if $m \neq 0, 1$. In this work, various approaches are made in order to give accurate approximated solutions of the yield criteria for rate sensitive materials. It has been done by making various mathematical assumptions, and based on Taylor - series expansions.

The usefulness of the proposed analytical approximation methods have been explored within the range of triaxialities from 0 (pure torsion) up to $T = 3$. The porosities and strain rate sensitivity parameters are within the intervals $0 \leq f \leq 0.3$, $0 \leq m \leq 0.1$. The proposed ranges are thought to be sufficient to cover the main range of applications of rate sensitive ductile metals.

Therefore, it could be obtained a new expresion for the Gurson yield function for strain rate dependent materials given in the form:

$$\Phi = \left((K_F)^m \, \widehat{\Sigma}_{eq} \right)^2 + +2f \cosh\left(\sqrt{3}((K_F)^m \cdot \widehat{\Sigma}_1) - mG'(0) \right) - (1 + f^2) = 0 \tag{2}$$

which is a function of the macroscopic dimensionless stresses, the porosity, the strain rate sensitivity parameter and two approximated variables $G'(0)$ and K_f:

$$G'(0) = A_1 \cdot Log_{10} \left(\frac{1 - f - \widehat{\Sigma}_{eq}}{A_2 \left(B_1 f + B_2 f^2 \right)} + 1 \right), \quad K_F = \left(1 - \frac{1 - f - \widehat{\Sigma}_{eq}}{\sqrt{3} \left(B_1 + B_2 f \right)} \right) \tag{3}$$

where A_1, A_2, B_1 y B_2 are material independent parameters.

3. Validation of the proposed yield functions

First, and with the aim to validate the aproximations made in the analytic evaluation of the macroscopic yield surface, it has been made a comparison between the proposed closed yield criteria and the *"exact"* solution obtained by numerically integrating the equations. Second, and in order to assess the approximations, it is also presented a comparison between the derived approximate yield criteria and the results obtained by numerical calculations using a commercial finite element code.

Numerical finite-element calculations are made considering the yield locus originally proposed by Gurson and taking into account the strain-rate dependence is taken into account solely in the flow stress of the matrix material.

4. Remarks

For the large range of porosities and triaxialities analized, it can be noted that the presented yield function approach has the important quality to better predict the behavior of rate sensitive materials than the classical Gurson model and also can be easily implemented into finite element codes.

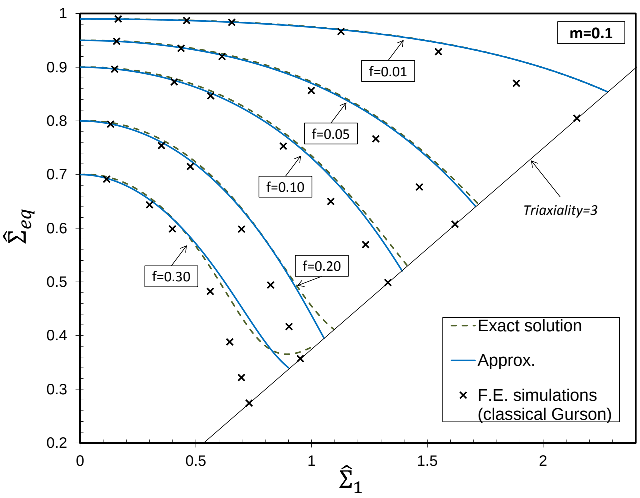

Figure 1. Comparison of model, numerical finite element and exact $\widehat{\Sigma}_{eq} - \widehat{\Sigma}_1$ results considering the approach for porosities $f = 0.01, 0.05, 0.1, 0.2, 0.3$ and a strain rate sensitivity parameter $m = 0.1$.

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6. References

[1] A.L. Gurson (1977). Continuum theory of ductile rupture by void nucleation and growth: Part I. Yield criteria and flow rules for porous ductile media, *Journal of Engineering Materials and Technology*, **99**, 2-15.