THE EFFECT OF THE MATRIX TENSION-COMPRESSION ASYMMETRY ON DAMAGE EVOLUTION IN POROUS PLASTIC SOLIDS

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Summary

In this paper, a new elastic/plastic damage model with yield criterion that depends on all stress invariants is used to investigate the influence of the tension-compression asymmetry of the incompressible matrix on void evolution of a porous aggregate. For uniaxial tensile loading conditions, it is shown that if the matrix tensile strength is higher than its compressive strength, damage distribution is similar to that in classical materials obeying Gurson's criterion while the void growth rate is faster. On the other hand, for certain porous polycrystals in which the matrix tensile strength is lower than its compressive strength, damage distribution is significantly different, the location of the zone of maximum porosity shifts from the center of the specimen outwards. Depending on the value of the parameter *k*, damage is delayed and the void growth rate is much slower. The effects of evolving microstructure are also investigated revealing new and unexpected trends.

A strength differential effect (different behavior in tension versus compression) is observed at the polycrystal level, if either twinning or non-Schmid type slip are contributors to plastic deformation at the single crystal level. Despite recent progress in modeling the asymmetry in yielding, modeling damage by void growth in such materials remains a challenge. Cazacu and Stewart [1] developed an yield criterion for voided polycrystal that incorporates the effects of the tension-compression asymmetry of the incompressible matrix on the overall dilatational plastic behavior :

$$\phi = m^2 \sum_{i=1}^{3} \left(\frac{\left|\sigma_i'\right| - k\sigma_i'}{\sigma_T} \right)^2 + 2f \cosh\left(-z_s \frac{3P}{2\sigma_T} \right) - \left(1 + f^2 \right) \tag{1}$$

where f is the void volume fraction; $\sigma_1', \sigma_2', \sigma_3'$ are the principal values of the deviator of the Cauchy stress tensor, $\boldsymbol{\sigma}' = \boldsymbol{\sigma} + \mathrm{P}\,\mathbf{I}$; and $P = -\frac{1}{3}\boldsymbol{\sigma} : \mathbf{I}$, with I being the second-order identity tensor, and ":" denoting the double-contracted product between two second–order tensors. In Eq. (1), k is a strength-differential (SD) material parameter, which is expressible only in terms of the ratio between the matrix tensile strength, σ_T , and the matrix compressive strength, σ_C ; i.e.,

$$\mathrm{k} = (1-\mathrm{h})/(1+\mathrm{h}), \qquad \text{with} \quad h = \sqrt{2-(\sigma_T/\sigma_c)^2} \,/\, \sqrt{2(\sigma_T/\sigma_c)^2 - 1} \tag{2}$$

From Eq. (2), it follows that for the material parameter k to be real, $1/\sqrt{2} \le \sigma_T/\sigma_C \le \sqrt{2}$. The material constant m in Eq. (1) is defined as

$$\mathrm{m} = 3/\sqrt{2\left(3\mathrm{k}^2 - 2\mathrm{k} + 3\right)} \tag{3}$$

The parameter z_s involved in the expression of the criterion (1) depends on the sign of the pressure. Its expression is

$$z_s = \begin{cases} 1 & \text{if} \quad P \ge 0, \\ \sqrt{\dfrac{3k^2 + 2k + 3}{3k^2 - 2k + 3}} & \text{if} \quad P < 0. \end{cases} \tag{4}$$

In this paper, the yield criterion (1) is used to investigate the influence of the tension-compression asymmetry of the matrix on void evolution for uniaxial tensile loading conditions. It is shown that if the matrix tensile strength is higher than its compressive strength (see Fig. 1), damage distribution is similar to that in classical materials obeying Gurson's [2] criterion while the void growth rate is faster (see Fig.2). On the other hand, for certain porous polycrystals in which the matrix tensile strength is lower than its compressive strength, damage distribution is significantly different, the location of the zone of maximum porosity shifts from the center of the specimen outwards (see Fig. 3). Depending on the value of the parameter *k*, damage is delayed and the void growth rate is much slower.

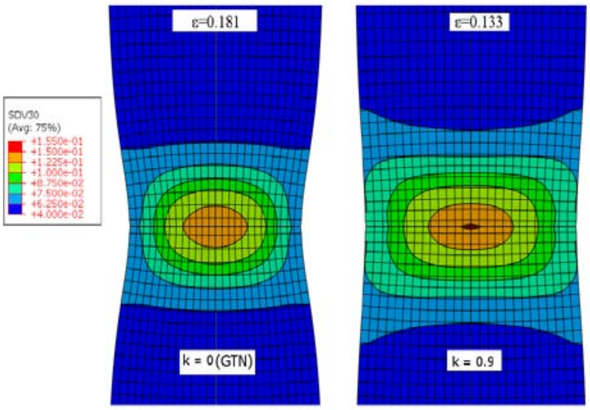

Figure 1: Contours of constant void volume fraction, f, for material with matrix having the yield in tension larger than the yield in compression k = 0.9 (σ_T/σ_C = 1.41), in comparison with a GTN material (k = 0).

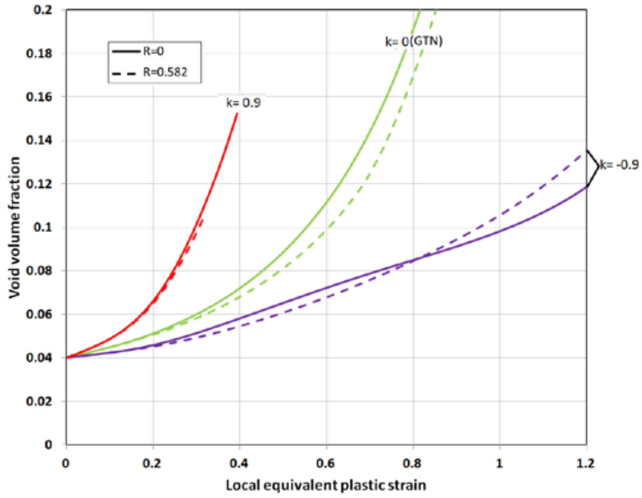

Figure 2: Evolution of the void volume as a function of the local plastic strain at the center of the specimen (R = 0) and at R/R0=0.582 for different materials: k = 0 (GTN material), k=0.9 (σ_T/σ_C = 1.41) k=-0.9 (σ_T/σ_C = 0.71).

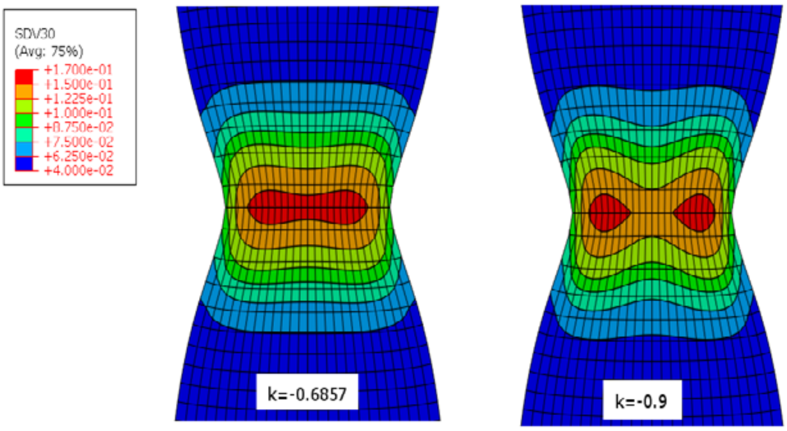

Figure 3: Contours of constant void volume fraction, f, for materials with matrix having the yield in tension less than the yield in compression : k=-0.686 (σ_T/σ_C = 0.72) and k=-0.9 (σ_T/σ_C = 0.71) corresponding to the end of the test (i.e. for fmax= 17%).

Furthermore, the influence of the evolving microstructure on void growth is studied. For this purpose, simulations are carried out by considering an evolving strength differential ratio for the matrix. It is shown that void growth and damage distribution are significantly affected by the rate of change of the strength differential ratio with plastic strain.To illustrate the unusual features of the damage growth to be expected in such materials, simulations are presented for a high-purity alpha titanium material. The trends predicted may provide guidance for a systematic experimental investigation on damage by void growth in this material and others hexagonal materials as well.

References

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