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Theoretical and Numerical Analysis of Void Coalescence in Porous Ductile Solids under Arbitrary Loadings

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Abstract

Micromechanics-based constitutive relations are developed to model plasticity in solids with relatively high levels of porosity. They are especially appropriate to model void coalescence in ductile materials. The model is obtained by limit analysis of a cylindrical cell containing a coaxial void of finite height with plastic flow confined to the ligaments, and loaded under combined tension and shear. Previously obtained analytical estimates were not upper-bound preserving when shear was present and, in addition, were assessed against numerical results obtained for different cell geometries. Here, a rigorous upper-bound model is developed and its predictions are consistently compared with finite-element based estimates of limit loads on the same cylindrical unit cell exploiting quasi-periodic boundary conditions. The numerical results are used to guide a heuristic modification of the model in order to capture the behavior for extremely flat or extremely elongated voids.

Key Words: Ductile fracture; Low triaxiality; Internal necking; Internal shearing; Homogenization; Upper-bound.

1 Introduction

Void coalescence is known to be the last elementary stage of ductile failure (Pineau et al., 2016). That is, as soon as the first few largest voids approach each other within a fraction ($\sim$0.3–0.5) of the intervoid distance, yet long before they link up, the stress carrying capacity *abruptly* drops, and this upheaval continues to failure at the material point level (Koplik and Needleman, 1988, Benzerga, 2002). This sudden change is associated with strain concentration in the intervoid ligament (a form of micro-scale strain localization). Prior to this, void deformation occurs by diffuse plasticity, the distorsion being due to void enlargement, change of shape, rotation or all (Benzerga and Leblond, 2010, Benzerga et al., 2016). Ultimate failure of a test piece can thus occur if plastic flow successively localizes in intervoid ligaments thereby leading to macroscopic ductile crack growth. This mechanism prevails unless failure occurs by some plastic instability at the scale of many-void populations.

As a precursor to void coalescence, the process of micro-scale strain concentration should thus be modeled for predicting ductile fracture. This involves developing constitutive relations for voided solids in a