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Anisotropic coalescence criterion for nanoporous materials

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Abstract

Ductile fracture through void growth and coalescence depends significantly on the plastic anisotropy of the material and on void size, as shown by experiments and/or numerical simulations through several studies. Macroscopic (homogenized) yield criteria aiming at modeling nanoporous materials have been proposed only for the growth regime, *i.e.* non-interacting voids. The aim of this study is thus to provide a yield criterion for nanoporous materials relevant for the coalescence regime, *i.e.* when plastic flow is localized between voids. Through homogenization and limit analysis, and accounting for interface stresses at the void-matrix interface, analytical coalescence criterion is derived under the following conditions: axisymmetric loading, orthotropic material obeying Hill's plasticity, cylindrical voids in cylindrical unit-cell. Incidentally, an orthotropic extension of the existing isotropic modeling of interface stresses through limit analysis is described and used. The proposed coalescence criterion is then extended to account for combined tension and shear loading conditions. Numerical limit analyses have been performed under specific conditions / materials parameters to get supposedly exact (up to numerical errors) results of coalescence stress. A good agreement between the analytical coalescence criteria derived in this study and numerical results is found for elongated spheroidal voids, making them usable to predict the onset of void coalescence in ductile fracture modeling of nanoporous materials.

Keywords: Ductile fracture, Coalescence, Nanoporous material, Homogenization, Limit analysis

1. Introduction

Early experimental investigations have suggested [1] and shown [2, 3] that ductile fracture of structural materials occurs by void nucleation, growth and coalescence. The physical mechanisms and associated micromechanical models have then been described (*e.g.* [4, 5, 6] for seminal contributions), while imaging techniques allow recently to assess experimentally voids evolution in porous materials in astonishing details [7]. Following the pioneering works of Gurson [8] for void growth and Thomason [9] for void coalescence leading to macroscopic yield criteria, homogenized models have been proposed and subsequently improved to describe porous materials at the macroscopic scale, considering the presence of voids with additional state variables, leading to ductile fracture modeling. The reader is referred to the recent reviews on this topic [10, 11, 12, 13].

Assuming classical continuum plasticity (see *e.g.* [14] for a recent advanced model) for the behavior of the matrix surrounding the voids, most of the ductile fracture models are strictly valid only when the matrix material can be considered *homogeneous* at the scale of the void. Same requirement is also necessary for models developed using crystal plasticity (see *e.g.* [15, 16, 17]), although such models allow in principle to better represent the plastic anisotropy inherent to slip systems activity for voids in single crystals (or voids smaller than grain size in polycrystalline materials), as observed by lower-scale simulations [18]. From a simple perspective[1], material homogeneity is assumed to be

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[1] A refined perspective would be to consider additional lengthscale, *e.g.* set by mobile/immobile dislocations, distances between dislocations sources.