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Macroscopic yield criteria for plastic anisotropic materials containing spheroidal voids

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Abstract

The combined effects of void shape and matrix anisotropy on the macroscopic response of ductile porous solids is investigated. The Gologanu–Leblond–Devaux's (GLD) analysis of an rigid-ideal plastic (von Mises) spheroidal volume containing a confocal spheroidal cavity loaded axisymmetrically is extended to the case when the matrix is anisotropic (obeying Hill's [Hill, R., 1948. A theory of yielding and plastic flow of anisotropic solids. Proc. Roy. Soc. London A 193, 281–297] anisotropic yield criterion) and the representative volume element is subjected to arbitrary deformation. To derive the overall anisotropic yield criterion, a limit analysis approach is used. Conditions of homogeneous boundary strain rate are imposed on every ellipsoidal confocal with the cavity. A two-field trial velocity satisfying these boundary conditions are considered. It is shown that for cylindrical and spherical void geometries, the proposed criterion reduces to existing anisotropic Gurson-like yield criteria. Furthermore, it is shown that for the case when the matrix is considered isotropic, the new results provide a rigorous generalization to the GLD model. Finally, the accuracy of the proposed approximate yield criterion for plastic anisotropic media containing non-spherical voids is assessed through comparison with numerical results.

Keywords: A. Yield condition; B. Anisotropic material; B. Porous material; B. Ideally plastic material; A. Microstructures

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Nomenclature

a	scalar
$\underline{a}$	vector
$\boldsymbol{a}$	second order tensor
$\mathbb{A}$	fourth order tensor
$\mathbf{1}$	second order unit tensor
$\mathbb{J}$	$= \frac{1}{3}(\mathbf{1} \otimes \mathbf{1})$
$\overline{\boldsymbol{A}}$	deviator of a second order tensor $\boldsymbol{A}$;
.	simple contraction of two tensors
:	double contraction of two tensors
$\otimes$	tensorial product
$\overset{s}{\otimes}$	symmetrized tensorial product
$\mathbb{I}$	$= \mathbf{1}\overline{\underline{\otimes}}\mathbf{1}$ symmetric fourth order unit tensor
$\mathbb{K}$	$= \mathbb{I} - \mathbb{J}$
A_h	hydrostatic part of $\boldsymbol{A}$

1. Introduction

During deformation, voids are nucleated in metals, mainly by decohesion at the hard particle-matrix interfaces. These voids grow in the matrix until coalescence, phenomenon that triggers ductile fracture. In the opposite direction, in the consolidation of metallic powders, plastic collapse of voids occurs when the material is compacted at certain rates and temperatures, to reduce porosity (Hom and McMeeking, 1989). The evolution of a single void in an infinite isotropic rigid-perfect plastic matrix subjected to axisymmetric loading at the remote boundary was investigated by McClintock (1968) for the case of cylindrical voids and Rice and Tracey (1969) for spherical voids. However, voids in metallic alloys are often ellipsoidal. They are either prolate ellipsoids if they are nucleated around inclusions previously elongated during rolling (see for e.g. Benzerga et al., 2004) or oblate ellipsoids if they grow from cleavage cracks in the hard phase of a dual-phase structure (see for e.g. Son and Kim, 2003). Lee and Mear (1992) extended the pioneering works of McClintock (1968) and of Rice and Tracey (1969) to ellipsoidal cavities embedded in an infinite viscous medium (obeying Norton's power law) and subjected to axisymmetric deformation. Key in their analysis is the solution of a kernel problem that provides the deformation fields (strain rates) in the matrix.

Based on the limit-analysis of a cavity embedded in a finite volume of an ideal rigid-plastic material obeying von Mises yield criterion and subjected to axisymmetric deformation, Gurson (1977) has proposed analytical overall yield criteria for porous solids. Both spherical and cylindrical void geometries were considered. Despite the simplicity of the conceptual framework of limit-analysis methods, the yield surface obtained by Gurson constitutes an upper bound for porous media of the Hashin's "composite spheres assemblage" type (see (Perrin, 1992)). An heuristic extension of the Gurson model has been