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Plastic deformation modes in perforated sheets and their relation to yield and limit surfaces

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ABSTRACT

Construction of mechanism-based plasticity theories for the homogenized response of heterogeneous materials requires identification of plastic deformation modes as a function of loading direction relative to the microstructural details. Herein, we employ an efficient homogenization theory to identify for the first time such deformation modes in plates under plane stress with hexagonal arrays of circular holes at small and intermmediate pore volume fractions, and establish their relation to the branches of initial and subsequent yield and limit surfaces. Newly introduced maps of the intrinsic geometric features of point-wise yield surfaces provide full-field picture of the investigated microstructures' propensity for plastic strain initiation and localization. The identified characteristic plastic modes provide a rational explanation for the evolving geometric features of subsequent yield and limit surfaces whose branches represent different plastic flow mechanisms, as well as a basis for the construction of a mechanism-based homogenized plasticity theory for use in structural analysis algorithms. The results suggest the need for composite yield surfaces comprised of multiple branches in the construction of mechanism-based homogenized plasticity theory for the investigated class of porous materials.

1. Introduction

Micromechanical techniques enable calculation of the average response of heterogeneous materials based on the constituents' properties, shape and arrangement. The most advanced techniques provide detailed information on the local stress and strain fields that facilitate identification of the local deformation modes which give rise to the observed response. This is particularly important in the post-yield domain where the evolution of plasticity is governed by local stress field details.

Accurate reproduction of local stresses is necessary in constructing continuum-level, elastic–plastic constitutive theories whose macro-level parameters reflect the local deformation mechanisms. This recent trend in the micromechanics-based construction of macroscopic constitutive theories, driven by the current emphasis on the development of multiscale computational capabilities, has re-emerged after initial introduction in the mid 1970s in the context of constructing homogenized yield surfaces and flow rules for porous metals. Variational principles had been employed in the early works based on elementary kinematically admissible velocity fields in simplified representations of material microstructures containing porosities. The best known homogenized yield or limit surface in this class is the one developed by Gurson (1977) based on limit-type analysis of a rigid-perfectly plastic von Mises sphere or cylinder containing a spherical or cylindrical cavity. This model has been the subject of much attention, with a number of improvements and extensions proposed during the past 30 years, cf. Tvergaard (1982), Needleman and Tvergaard (1984), Leblond et al. (1995), Monchiet et al. (2008) and the recent review by

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