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A semi-analytical model for the behavior of saturated viscoplastic materials containing two populations of voids of different sizes

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ABSTRACT

This paper presents a micromechanical model for a porous viscoplastic material containing two populations of pressurized voids of different sizes. Three scales are distinguished: the microscopic scale (corresponding to the size of the small voids), the mesoscopic scale (corresponding to the size of the large voids) and the macroscopic scale. It is assumed that the first homogenization step is performed at the microscopic scale, and, at the mesoscopic scale, the matrix is taken to be homogeneous and compressible. At the mesoscopic scale, the second homogenization step, on which the present study focuses, is based on a simplified representative volume element: a hollow sphere containing a pressurized void surrounded by a nonlinear viscoplastic compressible matrix. The nonlinear behavior of the matrix, which is expressed using the results obtained in the first homogenization step, is approached using a modified secant linearization procedure involving the discretization of the hollow sphere into concentric layers. Each layer has uniform secant moduli. The predictions of the model are compared with the more accurate numerical results obtained using the finite element method. Good agreement is found to exist with all the macroscopic stress triaxialities and all the porosity and nonlinearity values studied.

1. Introduction

The aim of this study was to develop a micromechanical model for the behavior of porous viscoplastic media containing two populations of pressurized voids.

The problem of modeling the behavior of viscoplastic materials containing voids is not new. Since the seminal work by Budiansky et al. (1982) on the deformation of a spherical void in an infinite block of nonlinear viscous matrix, several studies have been devoted to this subject. Duva and Hutchinson (1984) proposed an explicit form for the effective potential of nonlinear materials containing voids at dilute volume fractions and Cocks (1989) assessed this potential in a material with an arbitrary void volume fraction, based on variational principles.

More rigorous methods based on variational principles have been developed by Ponte Castañeda (1991), Willis (1991) and Michel and Suquet (1992) to obtain rigorous bounds for the effective potential of porous isotropic materials. These results are less accurate in the case of the composite-sphere assemblage subjected to purely hydrostatic loadings, and Michel and Suquet (1992) therefore proposed a correction of the bounds at high stress triaxialities (a similar correction was proposed independently by Sofronis and McMeeking (1992)), which, in the limit case of a rigid-plastic matrix, leads to the Gurson yield criterion (Gurson, 1977). Suquet (1995) has shown that these variational estimates are equivalent to the secant approach using the secant moduli of the phases evaluated at the second order moments of the fields in the phases.

Generalizing the notion of optimally selected linear comparison composite, Ponte Castañeda (1996) proposed an alternative approach whereby the tangent moduli of the phases are evaluated at the phase averages of the fields (first order moments) using a self-consistent scheme. Nebozhyn and Ponte Castañeda (1999) subsequently proposed improved estimates for nonlinear porous materials taking the effect of the third invariant of the macroscopic stress tensor into account. The latter authors also pointed out that in some cases, this method, can violate rigorous bounds or lead to nonconvex effective energy functions. In order to address this problem, Ponte Castañeda (2002) proposed a new second-order method in which the second-order moments of the local fields in the linear comparison composite are used to evaluate the tangent moduli of the phases. This new method was an improvement on the earlier method and gives more accurate estimates for the effective behavior of isotropic porous nonlinear media, but as Pastor and Ponte Castañeda (2002) noted, these estimates are too stiff

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