Effects of Lode-dependent matrix behaviour on the macroscopic yielding and ductile failure in isotropic porous plastic solids

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ABSTRACT

Many metal alloys used in structural applications, such as aluminium alloys that are increasingly applied by the automotive industry, exhibit a dependence upon the third deviatoric stress invariant (or, equivalently, the Lode parameter). Still, the majority of porous plasticity models are governed by an underlying matrix constitutive formulation described by J_2 flow theory. Benallal [1] proposed a porous plasticity model incorporating first-order effects of the Lode parameter based on an upper-bound limit analysis of a spherical representative volume element. An alternative porous plasticity model was used by Dæhli et al. [2], referred to as the heuristic model, in which the original Gurson model is modified by simply replacing the usual von Mises equivalent stress by a non-quadratic equivalent stress [3]. This work is dedicated to (i) assess the performance of these two different porous plasticity models that include Lode-dependent material behaviour and (ii) to examine the influence of Lode-dependent material behaviour on ductile failure. First, numerical limit analyses of a spherical representative volume element using finite element simulations are conducted to obtain macroscopic yield limits for the porous ductile solid under a wide range of imposed loading conditions. The numerical results are then used to evaluate the performance of the two porous plasticity models. The results show that the upper-bound model [1] correctly describes the shape transformation of the macroscopic yield surface with increasing levels of stress triaxiality; from a hexagonal shape under low stress triaxiality to a rounded triangular shape for increasing stress triaxiality. The heuristic model [2] provides reasonably accurate results for lower porosities, which are realistic values for the content of potentially void-nucleating particles in many structural aluminium alloys. However, the heuristic model fails to predict the shape transformation of the macroscopic yield surface due to its very simple formulation, which deteriorates the predictions for intermediate and high stress triaxiality ratios, especially when the porosity increases. Second, since the heuristic model was found to be in good agreement to the numerical limit analyses for lower porosities, this model is employed in strain localization analyses based on the imperfection band approach [4]. The strain localization analyses show that the ductile failure (taken to coincide with the onset of localized deformation) is greatly affected by including a Lode-dependent matrix behaviour, and the trend is that the ductility decreases when the yield surface has sharper corners. These results are corroborated by result from strain localization analyses using unit cell finite element simulations.

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