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Void shape effects and voids starting from cracked inclusion

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ABSTRACT

Numerical, axisymmetric cell model analyses are used to study the growth of voids in ductile metals, until the mechanism of coalescence with neighbouring voids sets in. A special feature of the present analyses is that extremely small values of the initial void volume fraction are considered, down to 10^{-10}, which means that the metal undergoes huge strains before coalescence. This is accounted for in the present analyses by using remeshing techniques. The evolution of the void shape during the large deformations is a natural outcome of the numerical analysis. Also the effect of different initial void shapes is considered, as well as the effect of different spacings between the voids in the axial and transverse directions. While these first analyses are carried out for voids in a homogeneous metal, a second set of cell model studies are carried out for voids that initiate from a crack in a hard second phase particle. As the particle deforms relatively little the void growth is here dominated by strong blunting of the metal at the tip of the initial penny-shaped crack. These analyses are used to estimate how well the void shape evolution would be approximated by assuming that the presence of the particle in the material adjacent to the void can be neglected.

1. Introduction

The early analyses by Rice and Tracey (1969) for the growth of a single spherical void in an infinite ideally plastic solid led to the development of a constitutive model (Gurson, 1977), which allowed for studies of the effect of a certain void volume fraction on the development of ductile fracture. Subsequently, the effect of the void volume fraction has been studied in a number of analyses for cell models containing a single spherical void, as *e.g.* Tvergaard (1982) or Koplik and Needleman (1988), who focused on determining the critical value of the void volume fraction at which the process of coalescence with neighbouring voids would initiate. It has also been shown (Huang et al., 1991) that voids under sufficiently high stress triaxiality grow in an unstable manner. Such numerical cell model analyses naturally account for the evolution of the void shape during straining, but efforts to develop constitutive models that account for void shape effects came later (Gologanu et al., 1997; Danas et al., 2009a,b), and these studies also focused on the influence of an initial void shape that differs from spherical. Early insight in void shape effects had been obtained by Budiansky et al. (1981) for viscous solids. The work of Gologanu et al. (1997) was extended by Pardoen and Hutchinson (2000) to account for strain hardening, and many numerical cell model studies analogous to those of Koplik and Needleman (1988) were carried out to determine the critical void volume fraction for the initiation of void coalescence. Koplik and Needleman (1988) considered initial void volume fractions down to 0.0013, while the smallest void volume fractions studied by Pardoen and Hutchinson (2000) were 1.96×10^{-6}. Cell model studies for much smaller initial void volume fractions have been carried out by Tvergaard (1997, 2000), considering highly constrained plastic flow in thin metal layers bonded to ceramics. In these cases, where also cavitation instabilities are an issue, the use of remeshing techniques has made it possible to follow growth from the initially tiny void to the final stage of ductile failure by coalescence with neighbouring voids.

In the present paper axisymmetric cell models are analyzed under specified stress triaxiality, as in the studies of Koplik and Needleman (1988) and Pardoen and Hutchinson (2000), thus representing ductile metals with a periodic distribution of voids. As remeshing is used here, it is possible to study void growth to failure for much smaller initial void volume fractions than those considered in the previous two papers. The influence of void shape evolution is automatically accounted for in the numerical cell model analyses, and also the effect of initially prolate or oblate void shapes are considered here, as well as the effect of different initial void spacings in the axial and transverse directions.

In applications to materials where voids nucleate by cracking of hard particles, the approximation has been made (*e.g.* see Nielsen et al., 2010) that the shape evolution from the initial penny-shaped crack is described as that of an oblate void in a homogeneous matrix material. In reality the mode of deformation is very different, more like that at fibre breakage in a metal matrix composite

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