International Journal of Solids and Structures 48 (2011) 1255–1267

Contents lists available at ScienceDirect

International Journal of Solids and Structures

journal homepage: www.elsevier.com/locate/ijsolstr

Failure by void coalescence in metallic materials containing primary and secondary voids subject to intense shearing

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ARTICLE INFO

Article history:
Received 8 October 2010
Received in revised form 22 December 2010
Available online 11 January 2011

Keywords:
Voids
Shear deformation
Plasticity
Low triaxiality
Extended Gurson model

ABSTRACT

Failure under intense shearing at close to zero stress triaxiality is widely observed for ductile metallic materials, and is identified in experiments as smeared-out dimples on the fracture surface. Numerical cell-model studies of equal sized voids have revealed that the mechanism governing this shear failure mode boils down to the interaction between primary voids which rotate and elongate until coalescence occurs under severe plastic deformation of the internal ligaments. The objective of this paper is to analyze this failure mechanism of primary voids and to study the effect of smaller secondary damage that co-exists with or nucleation in the ligaments between larger voids that coalesce during intense shearing. A numerical cell-model study is carried out to gain a parametric understanding of the overall material response for different initial conditions of the two void populations, subject to shear dominated loading. To account for both length scales involved in this study, a continuum model that includes the softening effect of damage evolution in shear is used to represent the matrix material surrounding the primary voids. Here, a recently extended Gurson-type model is used, which represents the effect of the small secondary voids under the low triaxiality loading conditions considered. This work suggests a failure mechanism for materials that contain voids on two different length scales, subject to intense shearing, in terms of; (i) the interaction of the primary voids, and (ii) the material softening of the ligaments due to the evolution of secondary damage. It is found that coalescence of primary voids under shear loading is severely affected by the presence of smaller secondary voids or defects in the ligaments. The change in overall ductility is presented for a wide range of initial material conditions, and an empirical correlation with the peak load is reported.

1. Introduction

Ductile material behavior and failure at loading conditions dominated by shearing, where the hydrostatic tension is zero or even negative, have received a great deal of attention in recent years. In particular due to the lack of micro-mechanics based models that can describe failure under such conditions (Barsoum and Faleskog, 2007a,b; Scheyvaerts, 2008; Leblond and Mottet, 2008; Nahshon and Hutchinson, 2008; Tvergaard, 2008, 2009; Xue et al., 2010; Jodlowski, 2009; Tvergaard and Nielsen, 2010). Barsoum and Faleskog (2007b) presented a full 3D numerical analysis of double notched specimens under combined twist and tension with focus on matching their experimental findings (Barsoum and Faleskog, 2007a). The use of a simple shear deformation criterion to determine failure was demonstrated and its physical relevance discussed. The shape evolution of primary voids and their rotation in a shear field have been analyzed by Scheyvaerts (2008) in a numerical cell-model study in full 3D. The first stage of the void deformation was of particular interest and their analysis contributed to a further extension to the coalescence criterion by Thomason (1990), Pardoen and Hutchinson (2000). Leblond and Mottet (2008) proposed a theoretical approach to account for coalescence by void growth as well as by the void sheet mechanism. A comparison with 3D numerical cell-model predictions showed a good agreement. The micro-mechanism governing ductile shear failure was brought out in a recent study by Tvergaard (1982a, 2009) using a 2D plane strain numerical cell-model of a single row of equal sized circular cylindrical voids under shearing. As a first, Tvergaard (2008) demonstrated that a maximum load carrying capacity for a ductile material is attained in a shear field due to micro-voids interaction. It was shown that during shearing the voids are flattened out to micro-cracks, which rotate and elongate until interaction with neighboring micro-cracks gives coalescence (Anderson et al., 1990). The failure mechanism in shear is thereby very different from that at moderate or high stress triaxiality, where the voids grow until necking of the internal ligaments between neighboring voids gives coalescence. The contact problem arising as the discretely modeled voids are flattened to micro-cracks

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doi:10.1016/j.ijsolstr.2011.01.008