International Journal of Solids and Structures 48 (2011) 925–938

Contents lists available at ScienceDirect

International Journal of Solids and Structures

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

# Micromechanical analysis on the influence of the Lode parameter on void growth and coalescence

Imad Barsoum [a,*], Jonas Faleskog [b]

[a] Department of Mechanical Engineering, The Petroleum Institute, P.O. Box 2533, Abu Dhabi, United Arab Emirates

[b] Department of Solid Mechanics, Royal Institute of Technology, SE-100 44 Stockholm, Sweden

ARTICLE INFO

*Article history:*
Received 1 December 2009
Received in revised form 31 October 2010
Available online 8 December 2010

*Keywords:*
Micromechanics
Localization
Ductile failure
Void coalescence
Void growth
Lode parameter

ABSTRACT

A micromechanical model consisting of a band with a square array of equally sized cells, with a spherical void located in each cell, is developed. The band is allowed a certain inclination and the periodic arrangement of the cells allow the study of a single unit cell for which fully periodic boundary conditions are applied. The model is based on the theoretical framework of plastic localization and is in essence the micromechanical model by Barsoum and Faleskog (Barsoum, I., Faleskog, J., 2007. Rupture mechanisms in combined tension and shear—micromechanics. International Journal of Solids and Structures 44(17), 5481–5498) with the extension accounting for the band orientation. The effect of band inclination is significant on the strain to localization and cannot be disregarded. The macroscopic stress state is characterized by the stress triaxiality and the Lode parameter. The model is used to investigate the influence of the stress state on void growth and coalescence. It is found that the Lode parameter exerts a strong influence on the void shape evolution and void growth rate as well as the localized deformation behavior. At high stress triaxiality level the influence of the Lode parameter is not as marked and the overall ductility is set by the stress triaxiality. For a dominating shear stress state localization into a band cannot be regarded as a void coalescence criterion predicting material failure. A coalescence criterion operative at dominating shear stress state is needed.



## 1. Introduction

It is a well known fact that the stress triaxiality has a significant influence on void growth and coalescence and hence on the ductility of materials. This has been demonstrated by several authors in the past, both experimentally, theoretically and numerically. The classical work by Hancock and Mackenzie (1976), where they perform experiments on notched round bar specimens, show that ductility increases with decreasing stress triaxiality. These experimental findings are annotated by the use of the theoretical void growth models by McClintock (1968) and Rice and Tracey (1969). Recently, Weck et al. (2006) perform an experimental study on void coalescence in voided layers and observe that the voids grow until a critical spacing between them is reached, which corresponds to the onset of coalescence. Beyond this point two different ductile failure mechanisms leading to final rupture are observed. One is void shearing due to that the deformation becomes concentrated into a narrow shear band between the larger voids leading to micro-void nucleation at second phase particles (Cox and Low, 1974; Faleskog and Shih, 1997). The other mechanism is referred to as void coalescence by internal necking, where the ligament between the voids necks down to a point. This event is studied extensively numerically e.g. by Koplik and Needleman (1988), Pardoen and Hutchinson (2000) and most recently by Scheyvaerts et al. (2010), who investigate the influence of the stress triaxiality on void growth and coalescence under axisymmetric conditions by the use of a cell model. However, it has been observed in recent experimental studies by Wierzbicki et al. (2005) and Barsoum and Faleskog (2007a) that the stress triaxiality is insufficient to characterize the stress state in ductile failure. A deviatoric stress measure is also needed and the stress state is hence characterized by the stress triaxiality and the Lode parameter.

Zhang et al. (2001) and Gao and Kim (2006) perform systematic numerical analysis on a cell model with straight boundaries subjected to different macroscopic stress states characterized by the Lode parameter and stress triaxiality. They find that the Lode parameter has a strong influence on the stress carrying capacity of the material and the onset of void coalescence, which they define as the shift to an uniaxial straining mode. As a consequence of the constraint on the cell not allowing for shear deformation, the uniaxial straining mode is the only mode of localization that will occur in their model. Other cell studies by Tvergaard (1981), Tvergaard (1982), Pijnenburg and Van der Giessen (2001) and

* Corresponding author. Tel.: +971 2 6075273; fax: +971 2 6075194.
*E-mail address:* ibarsoum@pi.ac.ae (I. Barsoum).

0020-7683/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ijsolstr.2010.11.028