International Journal of Plasticity 53 (2014) 206–227

Contents lists available at ScienceDirect

International Journal of Plasticity

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

Evolution of elliptic-cylindrical and circular-cylindrical voids inside power-law viscous solids

Ming-Song Chen [a,b,c], Y.C. Lin [a,b,*], Kang-Hua Chen [c]

[a] School of Mechanical and Electrical Engineering, Central South University, Changsha 410083, China
[b] State Key Laboratory of High Performance Complex Manufacturing, Changsha 410083, China
[c] Powder Metallurgy Research Institute, Central South University, Changsha 410083, China

ARTICLE INFO

Article history:
Received 15 May 2013
Received in final revised form 5 August 2013
Available online 22 August 2013

Keywords:
A. Void
B. Viscoplastic material
C. Finite elements
C. Representative volume element model

ABSTRACT

The evolution of voids inside power-law viscous solids is investigated. A representative volume element (RVE) model of an infinite matrix containing an isolated void is applied. In the RVE model, the void is assumed to be elliptic-cylindrical or circular-cylindrical, and the matrix is considered as the isotropic and incompressible power-law viscous material. To obtain the velocity field of RVE, a Ritz procedure is developed using the method proposed by Lee and Mear (1992). Moreover, the results obtained from the Ritz procedure are verified by the finite element simulations. Based on the data obtained from RVE models, the effects of material Norton exponent, remote stress field and void aspect ratio on the changing rate of void aspect ratio are discussed. Especially, when the void's principal axes are parallel to the principal axes of the remote stress, the mathematical models are proposed to relate the changing rate of void aspect ratio to the void aspect ratio and material Norton exponent. The results show that the material Norton exponent, remote stress field and void aspect ratio have a great influence on the changing rate of void aspect ratio. For the remote shear stress and uniaxial compression stress fields, the changing rate of void aspect ratio increases with the increase of void aspect ratio and material Norton exponent. Furthermore, the relationships between the changing rate of void aspect ratio and the void aspect ratio can be represented as the parabolic function and linear function for the remote shear stress field and uniaxial compression stress field, respectively. While the relationships between the changing rate of void aspect ratio and material Norton exponent can be expressed as the first order exponential function for these two remote stress fields. Besides, the changing rate of void aspect ratio can also be expressed as a unified function of void aspect ratio and material Norton exponent. For the remote biaxial compression stress field, the relationships between the changing rate of void aspect ratio and the void aspect ratio can be represented as the parabolic function, in which the coefficients can be expressed as functions of material Norton exponent and remote stress field. The findings of this study can be mainly used to evaluate the aspect ratio of voids inside large ingots during hot working, as well as to model the final densification stage of powder metal compacts.

© 2013 Elsevier Ltd. All rights reserved.

1. Introduction

As the billets of heavy forgings, large ingots often contain some voids or defects. The voids or defects inside heavy forgings will severely deteriorate their mechanical properties, especially the fatigue fracture resistance. Therefore, eliminating the

---

[*] Corresponding author at: School of Mechanical and Electrical Engineering, Central South University, Changsha 410083, China. Tel.: +86 013469071208.
E-mail addresses: yclin@csu.edu.cn, linyongcheng@163.com (Y.C. Lin).

0749-6419/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ijplas.2013.08.005

voids inside large ingots is one of important tasks of hot forging. Generally, the elimination of voids contains two stages: void closure and welding of the closed void surfaces (Park and Yang, 1997). The void closure process aims at the contact of the void internal surface, which is one of most important issues to be investigated (Zhang et al., 2009).

A considerable amount of work on the void closure has been done in recent decades. Ståhlberg et al. (1980) investigated the closure of artificial voids during the plastic deformation, and found that the rate of void closure increases with the increase of deformation degree. The upsetting process of a cylinder with a void was studied by Tanaka et al. (1987). Their results showed that the effective strain and hydrostatic stress around the void are the main factors for void closure. Sun and Guo (1987) investigated the closure of voids inside the large ingot during hot forging by finite element method, and introduced a parameter called shrinkage energy as a criterion to evaluate the void closure. Dudra and Im (1990) simulated the deformation of a solid cylinder pressed with flat dies, V-shaped dies and FML dies, and found that the V-shaped dies are the most effective to close the internal voids. Wang and Ren (1993) investigated the mechanism of void closure and optimized the forming procedure of large forgings. The effect of the cooling of steel ingot surfaces on the closure of the internal voids were investigated by Ono et al. (1994) and Park and Yang (1997). Their results showed that the pre-cooling can increase the hydrostatic stress at the central zone of the ingot and contribute to the void closure. Pietrzyk et al. (1995) developed a finite element model to simulate the closure of a single void in a matrix during the plastic deformation, and investigated the influence of stress state on the void closure. More recently, Banaszek and Stefanik (2006) studied the effects of the anvil shape and the critical forging process parameters on the elimination of metallurgical defects. Nakasaki et al. (2006) chose the integration of the hydrostatic stress, G_m, as a parameter to describe the closure of center voids, and found that the cross-sectional area of void is in proportion to G_m in single-pass rolling. Li et al. (2008) simulated the closure of voids in the cylindrical forging during the upsetting process, and obtained the critical deformation degree for the void closure. Zhang et al. (2009) proposed a criterion for void closure in large ingots during hot forging by a cell model. Kakimoto et al. (2010) calculated the closing evaluation value of internal voids, and quantified its limit value for completely closing the void. Chen et al. (2010) studied the evolution of different void defects during the hot forging, and found that the closure of tetrahedral void is most difficult. Kim et al. (2011) carried out a numerical analysis of the upsetting and cogging processes, and proposed an efficient forging process to eliminate void defects. Chen et al. (2011) developed a comprehensive procedure to predict the void closure degree by finite element and neural network models.

Because the nucleation, growth and coalescence of voids are well known mechanisms in the ductile fracture of materials, the void growth has been investigated during the past decades (Khan and Liu, 2012a,b; Lubarda, 2011; Voyiadjis et al., 2011). McClintock (1968) investigated the expansion of a long cylindrical void in an ideally plastic solid under the imposed axial strain rate and the transverse stress. Rice and Tracey (1969) studied the growth of an isolated spherical void in an ideally plastic solid under a remote uniform stress and strain rate fields. Budiansky et al. (1982) analyzed the growth of an isolated spherical void in an infinite block of linearly or nonlinearly viscous material under the remote axisymmetric stress, and established the famous BHS model (Budiansky, Hutchinson, Slutsky). Following the work, Duva and Hutchinson (1984) derived the constitutive relations for the incompressible power-law material containing a concentration of spherical void. Fleck and Hutchinson (1986) developed the analogous constitutive potentials for solids containing a dilute concentration of cylindrical void. Yee and Mear (1996) investigated the macroscopic response of an infinite incompressible power-law matrix containing aligned spheroidal voids. Chew et al. (2006) examined the effects of void shape and microvoid interaction in pressure-sensitive materials. Keralavarma et al. (2011) presented the large strain finite element calculations of unit cells subjected to triaxial axisymmetric loadings for plastically orthotropic materials containing periodic distributed spheroidal voids. For porous ductile materials, Gurson (1977) developed an approximate yield criteria (Gurson model) and flow rule. Gurson model deals with the growth of an initially spherical void in a rigid-perfectly plastic matrix, and assumes that the void remains spherical throughout the entire loading history. Later, Gurson model was widely employed and improved by some researchers (Gao et al., 2011; Gologanu et al., 1993; Hsu et al., 2009; Flandi and Leblond, 2005; Leblond et al., 1995; Li et al., 2011; Li and Huang, 2005; Malcher et al., 2012; Monchiet et al., 2008; Monchiet and Kondo, 2013; Pardoen and Hutchinson, 2000; Tvergaard, 1982; Wen et al., 2005; Zaïri et al., 2011). Recently, the growth of voids in some important engineering materials were investigated by finite element method or theoretical analysis (Borg et al., 2008; Chung et al., 2011; Kadkhodapour et al., 2011; Keralavarma et al., 2011; Fritzen et al., 2012; Lecarme et al., 2011; Li et al., 2000, 2003; Sabnis et al., 2012; Segurado and LLorca, 2010; Shanthraj and Zikry, 2012; Tvergaard and Niordson, 2004; Yerra et al., 2010).

The plane strain deformation of a power-law material containing randomly oriented elliptical voids was investigated by Lee and Mear (1992). Because their study is for small deformation, the evolution of the shape and orientation of voids is negligible. Lee and Mear (1999) also investigated the evolution of an isolated elliptic-cylindrical void contained in a power-law viscous matrix. The evolution of the shape and orientation of the voids was considered. For linearly viscous materials, the history of shape, orientation and volume of the void as a function of time or remote strain was determined by Eshelby's equivalent inclusion method. For non-linearly viscous matrix materials, a Ritz procedure developed by Lee and Mear (1992) was utilized to simulate the finite deformations of voids. The history of the relative void volume and the aspect ratio under different remote stress field was presented in graphical form.

This main purpose of this study is to establish the mathematical models to evaluate the changes of void aspect ratio for the voids inside the large ingots during the hot forging. Generally, the voids inside large ingots are mainly deformed under the remote compressive stress or shear stress during the hot forging. Therefore, the void evolution under these particular remote stresses is discussed in detail. The methods proposed by Lee and Mear (1992, 1999) are applied. Some new findings are obtained comparing with the works done by Lee and Mear (1999). Especially, the mathematical models are proposed to

Download English Version:

https://daneshyari.com/en/article/786202

Download Persian Version:

https://daneshyari.com/article/786202

Daneshyari.com