DISCUSSIONS OF THE MODEL FOR THE VOID GROWTH

X.M. Kong*, D. Holland* and W.Dahl*, Z.X. Guan** and N.S. Yang**

The growth of voids is the most important process of a ductile fracture. In order to model the growth of voids, a simplified model in which a large enough spherical body with a spherical void is subjected to a stress field and a corresponding strain rate field is adopted. It is assumed that the void grows steadily and maintains the spherical shape under the stress field. Based on the continuum plasticity theory, the relation between the growth rate of void and the corresponding triaxial stress is discussed. The agreement between model based predictions and real fracture tests has been checked.

INTRODUCTION

The nucleation of the growth and the coalescence of voids are the dominating steps in a ductile fracture of material. Rice and Tracey [1] had developed a theory for the growth of an isolated spherical void in matrix material. Gurson [2] had given a plastic flow equation for ductile porous materials. After this, Tvergaard and Needleman [3,4] had done a lot of research work on this way by finite element method and given a modified plastic flow equation. Hancock and Mackenzie [5] had shown the relations between the effective plastic strain to failure initiation and the triaxial stress.

In this paper a relation equation between the growth rate of a spherical void and the triaxial stress is presented. Further a relation equation between the effective plastic strains to failure initiation and the triaxial stress is established.

* Institute of Ferrous Metallurgy, Technical University of Aachen, Aachen, F.R.G.

** P.O. Box 169, Northwestern Polytechnical University, Xian, P.R.C.

A MODEL OF THE GROWTH RATE FOR A SPHERICAL VOID

It is assumed that a large enough spherical body with boundary surface Sbo and radius R containing a spherical void with boundary surface Svo and radius Ro to be subjected to a stress field and a corresponding strain rate field (Fig. 1) and the stress field makes the void grow steadily and maintain the spherical shape.

According to Fig. 1, the void volume fraction f can be given by

$$f = \left(\frac{R_o}{R}\right)^3 \tag{1}$$

The increment of the current void volume fracture is expressed by

$$\dot{f} = (1 - f)\dot{\varepsilon}^p_{KK} = 3f\left(\frac{\dot{R}_o}{R_o}\right)(1 - f) \tag{2}$$

The plastic incompressible matrix and the steady growth of void make the volume increment of whole body equal the volume increment of void. So one can describe the plastic strain rate $\dot{\varepsilon}^p_{KK}$ of volume as

$$\dot{\varepsilon}^p_{KK} = 3f\frac{\dot{R}_o}{R_o} \tag{3}$$

Gurson (2) had given the plastic flow potential equation that is suitable for the material including voids:

$$\Phi = \frac{\sigma_e^2}{\sigma_m^2} + 2f\cosh\left(\frac{\sigma_{KK}}{2\sigma_m}\right) - (1 + f^2) = 0 \tag{4}$$

where σ_m is micro-effective stress, σ_e is macro-effective stress and σ_{KK} is macro-dilatational stress.

For the condition of a large enough spherical body containing a spherical void, the void volume fraction is very small and the macro-effective stress is approximately equal to the micro-effective stress.

A relation equation between the radial growth rate of a spherical void and the hydrostatic stress is obtained:

$$\frac{\dot{R}_o}{R_o} = 0.5\,\mathrm{sh}\left(\frac{3\bar{\sigma}}{2\sigma e}\right)\dot{\varepsilon}_v^p \qquad (5)$$

where $\bar{\sigma}$ is mean stress. The results from the equation (5) will be further discussed in section 4.

EXPERIMENTS If the growth of a void reaches a critical value, macrocrack coalesce with a void near the macrocrack tip. We can take the critical radius Rc of void as a material constant. From the equation (5) the fracture initiation strain of material can be described by

$$(\varepsilon_v^p)_f = \frac{C}{\mathrm{sh}\left(\frac{3\bar{\sigma}}{2\sigma e}\right)} + \varepsilon_n \qquad (6)$$

Where C is a material constant, and ε_n is the void nucleation strain.

The equation (6) shows the relation between the fracture initiation strains and the triaxial stress. It is used to predict the fracture initiation strains under different triaxial stress by determining the material constants C and ε_n from experimental results.

In order to obtain the corresponding fracture initiation strains under different triaxial stress specimens of pre-notched round bar with different geometrical sizes are tested. Steel Fe 510, steel 510 pearlite reduced, steel 510+Cer and steel 520+CaSi have been chosen as test materials for investigating the relation between the fracture initiation strain and the triaxial stress. All experiments have been performed at the temperature of 238K. For determination of strain at fracture initiation metallograpic preparation has been used. The values of the effective plastic strains and the triaxial stresses are calculated by Bridgman formulas. The corresponding material constants (Ci) are respectively calculated by the equation (6): C1 = 0.74 and ε_n = 0.05 for the steel 510; C2 = 0.64 ε_n = 0.3 for the steel 510 pearlite reduced; C3 = 0.76 and ε_n = 0.15 for the steel 510+Cer and C4 = 0.57 and ε_n = 0.05 for the steel 510+CaSi.

The predicted curves obtained from the equation (6) are compared well with the results from the experiments (Fig. 2-Fig. 5).

As shown in Fig. 2-Fig. 5 the predicted curves are good in agreement with the curves from experiments. On the other hand, the experimental results have shown that the coalescence of voids results in the fracture initiation and the developing of macrocrack (Fig. 6).

DISCUSSION For the ductile fracture of materials with the growth of voids the relation equations between the growth rate of voids and the triaxial stress and the relation between the fracture initiation strain and the triaxial stress have been given based on the theoretical analysis and the experiments.

The relation equation between the growth rate of void and triaxial stress from Rice and Tracey [1] is

$$\frac{\dot{R}_o}{R_o} = 0.283 \exp\left(\frac{3\bar{\sigma}}{2\sigma_e}\right) \dot{\varepsilon}_v^p \qquad (7)$$

The relation equation between the fracture initiation strain and triaxial stress had been given by Hancock and Mackenzie [5] based on the void growth model of Rice and Tracey [1]. The fracture initiation strain can be expressed as:

$$(\varepsilon_v^p)_f = \alpha \exp\left(\frac{-3\bar{\sigma}}{2\sigma_e}\right) + \varepsilon_n \qquad (8)$$

The reference [6] has a form similar to equation (8).

In order to compare all the results from the theories and the experiments the triaxial stress $\bar{\sigma}/\sigma_e = 1.4$ and the corresponding fracture initiation strains $(\varepsilon_v^p)_{f5} \cong 0.15$ for the material Q1(LT) and $(\varepsilon_v^p)_{f6} = 0.12$ for the material HY130(LT) are taken based on the experimental results from Hancock and Mackenzie [5]. Because the nucleation plastic strains are very small, cavities are assumed to initiate with onset of plastic deformation. The corresponding material constants are calculated by the equation (6): C5 = 0.60 for the material Q1(LT) and C6 = 0.48 for the material HY130(LT).

The comparison curves of the results from the equation (6), the results from the equation (5) and the results of the experiments from Hancock and Mackenzie [5] are given in Fig. 7 and Fig. 8.

The experimental results in Fig. 7 are from the material Q1 (LT); The experimental results in Fig. 8 are from the material HY130(LT). The chemical composition of materials Q1 and HY130 can be found in reference [5].

The results from the equation (6) and the experimental results from the reference [5] have been compared. The absolute values of the relative errors are within 15%.

Fig. 7 and Fig. 8 show that the results from the equation (6) are in good agreement with the results from the experiments of Hancock and Mackenzie.

The present work has emphasized the relations between the growth rate of void, the triaxial stress and the fracture initiation strain. The equation (5) can give a better description on this way. From the equations (6) better predicted curves about the relation between the triaxial stresses and the fracture initiation strains for ductile fracture can be obtained.

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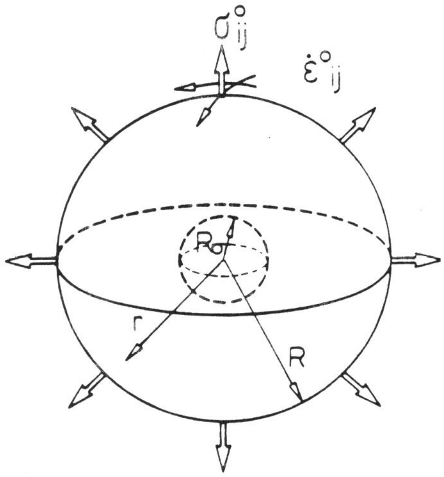


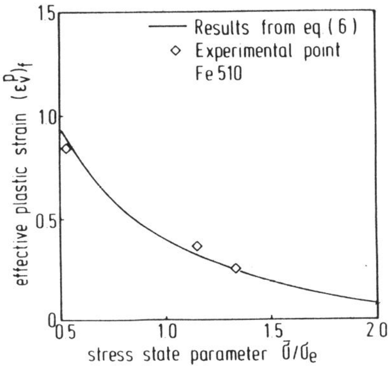
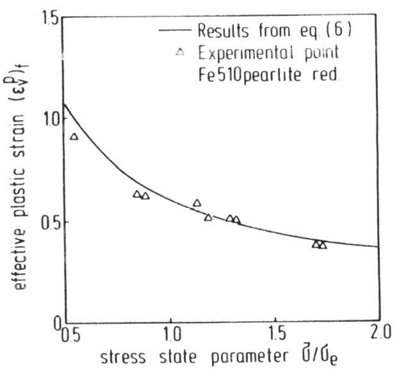


Fig. 1 The spherical body containing a spherical void.

Fig. 2 The comparison curve for the steel 510.



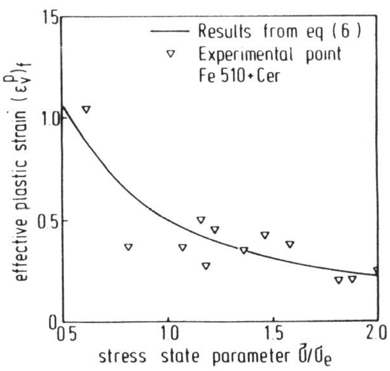


Fig. 3 The comparison curve for the steel 510 pearlite red.

Fig. 4 The comparison curve for the steel 510+Cer.

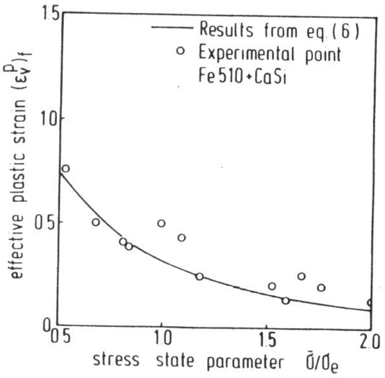


Fig. 5 The comparison curve for the steel 510+CaSi.

Fig. 6 The coalescence of voids .

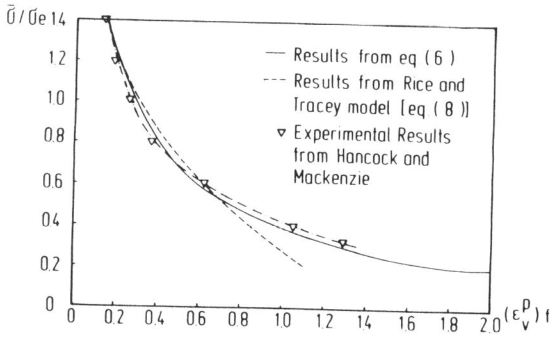


Fig. 7 The comparison curves for the Q1(LT).

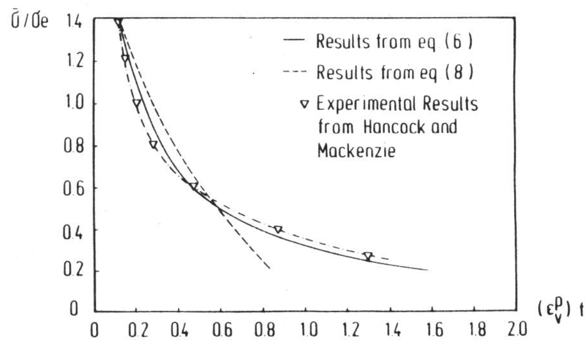


Fig. 8 The comparison curves for the HY130(LT).