FITTING THE GURSON PARAMETERS BY USING A PHYSICAL VOID COALESCENCE MECHANISM

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There is a non-uniqueness problem in the common way of fitting damage parameters for the Gurson model. In this paper, a method based on the new failure criterion for the Gurson model recently introduced by the authors is proposed for fitting the damage parameters. It is proposed that the initial parameters rather than the critical parameter should be fitted. According to the method, the critical parameter is a natural result of the initial parameters assumed. By comparing the numerical and the experimental results, the "exact" initial parameters can be determined. With this method, the number of unknown parameters in the Gurson model is reduced and the non-uniqueness problem of the damage parameters can be partly solved.

INTRODUCTION

In the conventional fracture mechanics, it is supposed that the fracture parameters can be transferred from laboratory specimens to large scale components and structures. However, in the application of the elastic-plastic fracture mechanics to tough, ductile materials, it has been found that there is a strong geometry dependence of crack resistance. Now it is generally understood that the geometry dependence is attributed to different constraint levels at the crack tip. One of the reasons for the failure of the conventional fracture mechanics to handle the constraint is that it neglects the presence of the micro-damaging process at the crack tip. In the recent years, micro-mechanical models, for example the Gurson model, have been found attractive in treating the constraint effect. According to the micro-mechanical model based approach, the material failure behaviour is described by a set of micro-mechanical parameters, rather than by the pseudo macro-fracture parameters. The approach can predict the geometry dependence as long as appropriate micro-mechanical parameters are given. Because the damage evolution rule should be the same in both non-

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cracked specimens and cracked specimens, the damage parameters established from simple tensile specimens can also be used in cracked specimens. Figure 1 shows how the approach could change the transferability concept of the conventional fracture mechanics for ductile fracture. The transferability is not carried out by the conventional fracture parameters, such as the *J-R* curve, but by the micro-mechanical parameters.

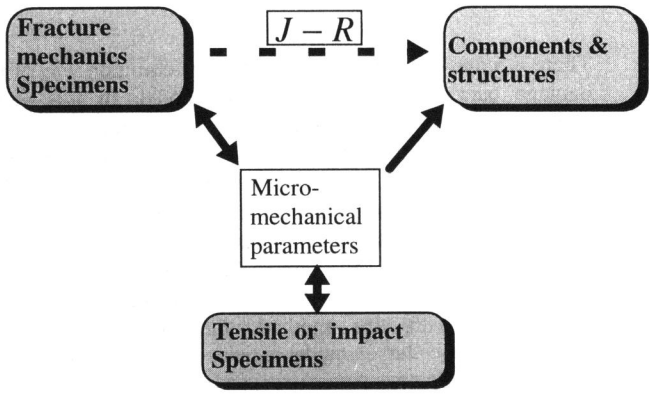

Figure 1 Transferability by the conventional fracture mechanics (dashed arrow) and by the micro-mechanical model based approach (solid arrows).

In the literature, considerable efforts have been spent on the verification of the capability of the micro-mechanical model based approach for predicting macro-fracture behaviour. In contrast, less efforts have been seen on the determination of the micro-mechanical parameters. As far as the Gurson model is concerned, there is a non-uniqueness problem in the current way of parameter fitting (1). That means different sets of parameters could yield same macro-behaviour. Therefore, even though the macro-failure behaviour can be predicted by the micro-mechanical parameters, it is not possible to classify the material toughness based on the fitted micro-mechanical parameters.

Recently, a new failure criterion for the Gurson model has been introduced by the authors (2). The criterion is based on Thomason's void coalescence mechanism (3). In this paper a method for fitting the Gurson parameters based on the new criterion is proposed. By this method, the fitted initial parameters can be used for classification of certain type of materials. In order to simplify the problem, as what has been done in the round robin (4) and the work by Xia and Shih (5), it is assumed that the material contains only one type of inclusions which nucleate at the beginning of plastic loading.

GURSON MODEL AND THE COMMON WAY OF PARAMETER FITTING

The Gurson model referred here is written as (6):

$$\phi(\sigma, f, \bar{\sigma}) = \frac{q^2}{\bar{\sigma}^2} + 2q_1 f \cosh\left(\frac{3q_2\sigma_m}{2\bar{\sigma}}\right) - 1 - (q_1 f)^2 = 0 \qquad (1)$$

where constants q_1 and q_2 were introduced by Tvergaard (7), σ_m and q are the mean normal and effective part of the average macroscopic Cauchy stress σ, $\bar{\sigma}$ is the yield stress of the matrix material, f is the current void volume fraction.

It is well known that the Gurson model itself can not predict void coalescence. An extra criterion should be incorporated into the model to manage the void coalescence. Practically, the treatment of void coalescence becomes the determination of the "critical void volume fraction". A function has been introduced by Tvergaard and Needleman (8) to model the post-coalescence behaviour (rapid-decay of the load carrying capacity) of the Gurson model,

$$f^* = \begin{cases} f & for \quad f \le f_c \\ f_c + \dfrac{f_u^* - f_c}{f_F - f_c}(f - f_c) & for \quad f > f_c \end{cases}. \qquad (2)$$

Here, f_c is the so-called critical void volume fraction at which voids coalesce, f_F is the void volume fraction at final failure of the material, and $f_u^*=1/q_1$. It should be mentioned that the absolute value of f_F does not play a significant role in the numerical modelling once f_c is determined (1). In the following discussion, f_F is ignored. In the numerical examples reported in this study, $f_F=0.2$ with $q_1=1.5$ and $q_2=1.0$ have been used.

The damage parameters involved in the Gurson model can be classified as the initial damage parameter, f_0, which is the void volume fraction at the beginning of plastic deformation, and the critical damage parameter, f_c.

In the common way of parameter fitting, no void coalescence mechanism is used. By selecting the initial parameter (f_0) and comparing the numerical prediction of the Gurson model with experimental result, the critical parameter (f_c) is fitted (4,9). According to this way of parameter fitting, the fitted f_c is a function of f_0, the experimental failure behaviour ($F_{exp.}$) and the loading (L)

$$f_c = f_c(f_0, F_{exp.}, L). \qquad (3)$$

For the same given $F_{exp.}$, different f_0 will result different values of f_c. In other words, different sets of parameters (f_0,f_c) could correspond to the same

material failure behaviour. One example of this non-uniqueness problem is shown in Fig. 2. In Fig. 2, a notched round bar has been analyzed with the stress-strain curve used in (4). The notch radius is 0.785 mm and the smallest diameter of the bar is 4 mm. Fig. 2 shows as long as the parameters are small and have the approximate relation $f_c = 2.9 f_0 + 2200 f_0^2$, they all correspond to the same failure behaviour. In the common way of parameter fitting where no void coalescence mechanism is used, the numerical failure behaviour can be generally described,

$$F_{numer.} = F(f_0, f_c, L). \tag{4}$$

Equation (4) indicates that there are two unknowns in the failure equation and it is not possible to determine the "exact" parameters from the given experimental result.

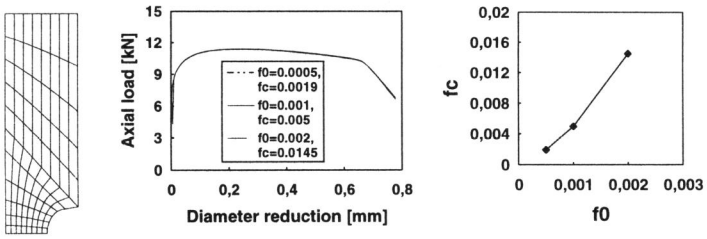

Figure 2 The non-uniqueness problem in the Gurson model: different sets of parameters (f_0, f_c) correspond to nearly identical material failure behaviour.

A NEW METHOD FOR THE PARAMETER FITTING

In the new method proposed here, the failure criterion for the Gurson model recently proposed by authors (2) is used. The failure criterion is based on a modification of Thomason's physical void coalescence mechanism. By observing that void coalescence appears as a result of plastic localization, the material capacity against plastic localization, the coalescence stress, $\sigma_1^{Coalescence}$, is calculated. In the beginning, the void is small and the capacity is very large. Therefore, the applied stress is not able to cause void coalescence and the material is stable,

$$\sigma_1^{Applied} < \sigma_1^{Coalescence}, \tag{5}$$

where σ_1 is the maximum principal stress. The void coalescence will occur once the following condition has reached

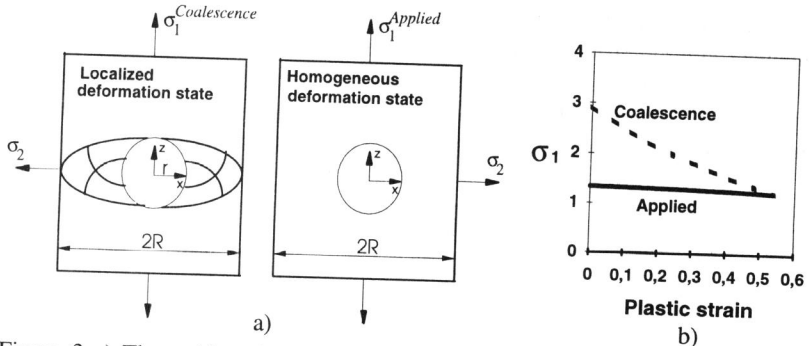

Figure 3 a) The void coalescence mechanism and b) a coalescence assessment diagram: coalescence will occur when the two curves cross each other.

$$\sigma_1^{Applied} = \sigma_1^{Coalescence}. \tag{6}$$

The coalescence mechanism is schematically shown in Fig. 3a. Fig. 3b shows that the material is stable until the two curves cross each other, where coalescence occurs. The coalescence stress, $\sigma_1^{Coalescence}$, is a function of the current void-matrix geometry and the current yield stress of the matrix material. Detailed formulations for calculating the coalescence stress and implementing the mechanism in finite element analysis can be found in (2,10). According to the mechanism, the coalescence is a natural result of the plastic deformation. Therefore, once the f_0 is given, the critical void volume fraction f_c at void coalescence can be written

$$f_c = f_c(f_0, L). \tag{7}$$

According to the mechanism, there is a one-to-one relation between the numerical failure behaviour $F_{numer.}$ and the f_0,

$$F_{numer.} = F(f_0, L). \tag{8}$$

By comparing the numerical and the experimental failure behaviour we have

$$f_0 = f_0(F_{exp.}, L). \tag{9}$$

The above equation shows that f_0 can be uniquely determined from the given loading and experimental failure behaviour.

Fig. 4 shows an example of the new way of parameter fitting. The material is the same as in Fig. 2. The diameter of the smooth bar is 4 mm. An initial imperfection of 0.005 times the diameter at the middle of the specimen

was applied. It can be seen from Fig. 4 that the numerical failure behaviour is uniquely controlled by the initial parameter f_0. By comparing the numerical prediction with the experimental result, the "exact" initial damage parameter, f_0, can be easily determined. If all the materials have only one type of inclusions, the fitted f_0 can be taken as a parameter for material classification.

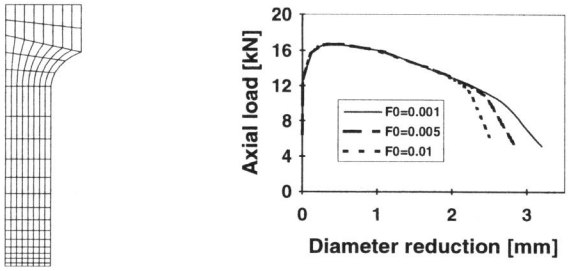

Figure 4 An example of the new method for parameter fitting: numerical prediction is uniquely controlled by f_0.

CONCLUDING REMARKS

There is a non-uniqueness problem in the current way of parameter fitting, where no void coalescence is used. By using the method proposed, this problem can be solved for materials having only one type of inclusions. For more complicated cases where nucleation of secondary voids and characteristic length parameters are involved, the non-uniqueness problem can not be completely solved by the proposed method. However, the number of unknown parameters can be reduced. Development of a methodology for fitting the Gurson parameters for the more complicated cases is currently going on.

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