THE EFFECT OF NON-SPHERICAL VOID SHAPE ON THE EVOLUTION OF DUCTILE DAMAGE

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The evolution of ductile damage in smooth and notched axisymmetric tensile specimens of an extruded AlMgSi alloy has been studied. Experimental testing was combined with detailed finite element analyses of the applied specimen geometries. The damage evolution was evaluated both by means of the classical Gurson model and by cell models of isolated voids. The main objective was to investigate the effects of non-spherical void shapes, and in particular, whether such effects will influence the transferability of the micromechanical parameters related to the Gurson model.

INTRODUCTION

During the last years, Gurson's constitutive model for an isotropically voided solid (1) has become increasingly popular in the study of ductile damage. Despite the many simplifications assumed in the model, numerous investigations have demonstrated its capability to quite accurately predict the ductility limits in structural components.

The Gurson model describes the damage by means of one single scalar variable; namely the void volume fraction. Such an approach neglects many effects related to the individual voids, such as size, shape, orientation, distribution, etc.

Recently, the author has been examining the growth of spheroidal voids by means of extensive finite element analyses of elementary volume elements containing isolated voids (2). The work clearly showed that the shape of the

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voids may have a significant effect on both void growth rate and coalescence strain. At low stress triaxialities, prolate voids generally grow slower than spherical voids of the same volume fraction. Oblate voids, however, grow faster than the corresponding spherical ones. In the case of high stress triaxialities, the opposite effect was observed. But the effect of void shape is generally significantly less at high triaxialities.

The main objective of the present work is to investigate whether the observed void shape effect has any significance for practical applications of the Gurson model. In particular, focus will be put on the transferability of micromechanical parameters from one stress state to another.

The fracture behaviour of smooth and notched axisymmetrical tensile specimens is investigated. The notched specimens comprised notch radii of 2, 0.8 and 0.4 mm, respectively.

In the present work an inplementation by Zhang (3) of Gurson's constitutive model into the general purpose FEM code ABAQUS has been used.

DETERMINATION OF MICROMECHANICAL PARAMETERS

A commonly applied procedure for determining micromechanical parameters is based on a dual approach involving experimantal testing as well as FE analyses of axisymmetric tensile specimens (see e.g. Sun et al. (4)). The FE analyses calculate the macroscopic response of the specimens using the constitutive equations of the Gurson model. The choise of nucleation parameters (and the q_1 and q_2 parameters) is either arbitrary or based on metallographical examinations. The final step is to compare the experimentally observed response with the numerical calculations and adjust the coalescence parameters so that the fulfilment of the chosen coalescence criterion coincides with failure in the tested specimens.

In Fig. 1 is shown an example of such adjustment of parameters. The initial void volume fraction is assumed to be 0.1 % . Neglecting void nucleation, a good prediction of failure strain for the smooth specimen (TSS) is obtained with a critical void volume fraction (f_c) of 0.3 %. For simplicity, it is assumed that fracture occurs immediately after the void volume fraction has exceeded f_c in one of the integration points.

The results in Fig. 1 illustrate a common problem with the Gurson model, namely the lack of transferability of micromechanical parameters between different stress states. For another choise of parameters the transferability may be improved, but there appears to be no general guidelines for how to select the optimal parameters.

VOID SHAPE EFFECTS

In order to study the 'real' evolution of voids for the different specimen geometries, a cell model of an isolated void were made. For details about this cell model, it is referred to (2). The cell model was subjected to four different loading histories, see Fig. 2. These histories correspond to the most severly damaged point in the four geometries studied, and were determined by FE analyses of the actual specimens. For the smooth specimen (TSS) and that with a notch radius of 2 mm (TSR2), the highest void growth rate occured in the centre of the specimens. For the two geometries with the sharpest notches (TSR08 and TSR04), the corresponding point was in front of the notch root. The vertical arrows in Fig. 2 corresponds to the fracture strains as observed in the experiments.

Fig. 3 shows the void growth corresponding to the four stress histories (solid lines). Also shown are the curves corresponding to the standard Gurson model (dot-dashed lines). It is evident from this figure that the evolution of the initially spherical voids into elongated spheroids, significantly affects the void growth rate.

In order to assess possible implications of this difference in predicted void growth between the cell model and the Gurson model, we can see how the corresponding choises of f_c will affect the predicted failure strains. The two horizontal lines in Fig. 3 correspond to the f_c that fits the failure strain of the smooth specimen in the two cases. The intersections of these lines with the other void growth curves will thus give the predicted failure strains for the corresponding specimens.

Comparing with the experimental failure strains (indicated with vertical arrows on the abscissa), it is quite clear that in this particular case the modified void growth curves do not give any better predictions of failure in the notched specimens than do the Gurson model.

In establishing the void growth curves in Fig. 3 it was assumed that the voids were present (and thus started to deform) from the very onset of deformation. In most engineering alloys, however, the voids are formed from inclusions and/or second phase particles. For this void nucleation to take place, a certain amount of plastic deformation is required. Such a delayed nucleation will of course affect the predicted failure strains. Fig. 4 shows void growth curves in the case where the voids (0.1 %) nucleate instantaneously at 10 % effective strain. The predicted failure strains have now shifted toward higher strains, but even if the failure strain of TSR2 now is well predicted, the failure strains for TSR04 and TSR08 are still underpredicted by about 13 and 10 %, respectively.

CONCLUSIONS

The present work has clearly shown that the evolution of voids into elongated spheroids may significantly alter their growth rates. It has been demonstrated that these effects also most likely will contribute to a lack of transferability of micromechanical parameter between diferent stress states. However, to properly account for the observed void shape effects will require a good knowledge of the nucleation behaviour, and as long as this cannot be provided, there seems to be little to gain by including such an account of void shape. An apparent way to reduce the void shape effects would be to base the determination of micromechanical parameters on testing of specimens with high stress triaxialities in the most severely damaged area (cfr. specimen TSR2 in the present study).

In a separate investigation by the author (4), the effects of void shape in combination with a 'physical' void coalescence model have been utilized in an attempt to predict the void nucleation behaviour.

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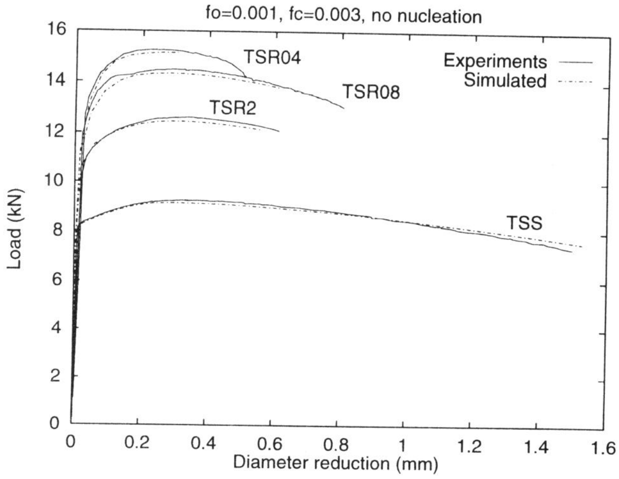

Figure 1: Experimental (solid lines) and predicted (dot-dashed lines) load vs. diameter reduction curves.

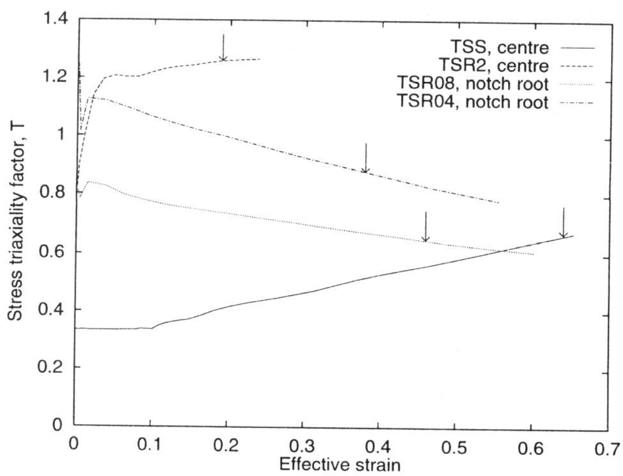

Figure 2: Development of stress triaxiality in the four specimens. The arrows indicate the occurence of fracture

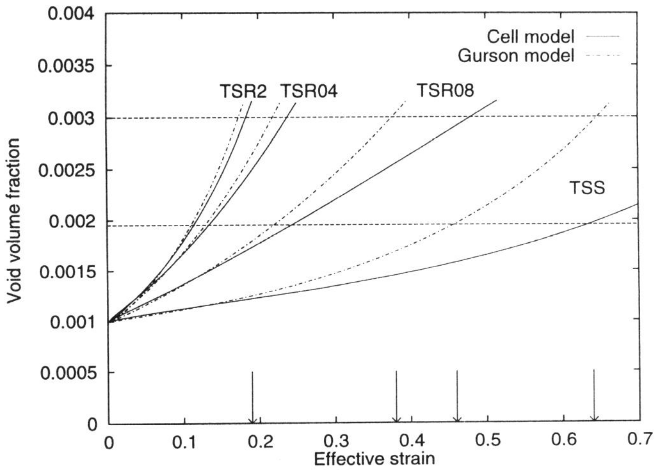

Figure 3: Comparison of growth rates of spheroidal (solid line) and spherical (dot-dashed line) voids. Voids present from onset of deformation.

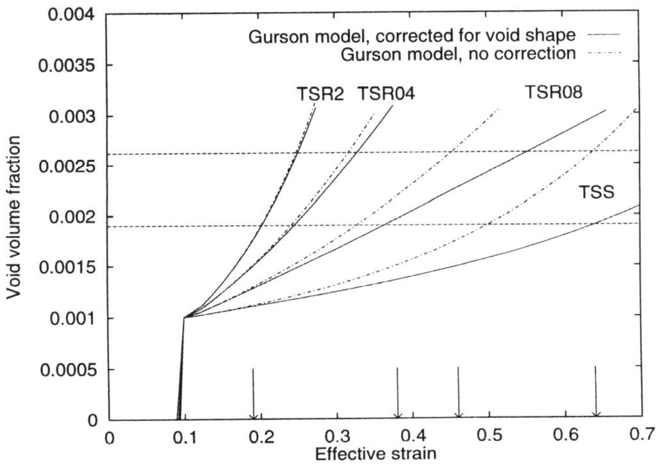

Figure 4: Comparison of growth rates of spheroidal (solid line) and spherical (dot-dashed line) voids. Voids nucleated instantaneously at 10 % strain