PAMM · Proc. Appl. Math. Mech. **14**, 161 – 162 (2014) / **DOI** 10.1002/pamm.201410068

Three-dimensional cell model analysis of ductile damage under dynamic loading condition

Steffen Gerke[1,*], **Kevin Kuhnt**[1], and **Michael Brünig**[1]

[1] Institut für Mechanik und Statik, Universität der Bundeswehr München, Werner-Heisenberg-Weg 39, 85579 Neubiberg, Germany

The paper deals with the damage and fracture behavior of ductile metals under dynamic loading conditions. The in [1–3] presented phenomenological continuum damage and fracture model, which takes into account the rate- and temperature-dependence of the material, provides reasonable results of experiments with high strain rates while the identification of the corresponding material parameters results difficult from the available experimental data. This lack of information can be resolved by micro-mechanical numerical simulations of void containing unit-cells. In this context results of dynamic micro-mechanical simulations are presented which can be used to study the damage effects on the micro-scale and to validate the rate-dependent continuum damage model.

1 Introduction

The description of the material behavior under general, especially including dynamic loading conditions becomes increasingly evident with the need to activate its inelastic resources. Thus a detailed knowledge of this inelastic behavior including the deterioration of the material on the micro-scale is crucial. Figure 1 illustrates the microstructure of a ductile metal plate which was impacted in thickness direction [4]. The simulation of these processes is usually realized with the finite element method using a phenomenological material model, i.e. the behavior of the damaged material is reflected by a continuous material while the ongoing damage is described by corresponding damage rules. The micro-mechanisms leading to the final failure of the material primarily depend on the stress state, but it is not an easy task to develop experiments and corresponding specimens which can be tested at various stress states under well controlled conditions. To overcome these experimental difficulties, frequently micro-mechanical simulations with void containing cells are used to study the damage behavior under general loading conditions [5, 6]. Micro-mechanical simulations under static loading conditions have been successfully used to gain additional information with respect the ongoing damage processes [7] while under dynamic loading conditions only two-dimensional studies have been presented [8].

2 Numerical analysis

The present micro-mechanical studies under dynamic loading conditions focus on void growth of uniaxially loaded micro-cells. Numerical calculations have been performed using the finite element program LsDyna enhanced by a user-defined material subroutine [3]. The numerical model consists of three sections having a length of $60\,\mu\mathrm{m}$ in each direction which reflects realistic physical dimensions. Following the ideas of Benson [8], only the central part of the model, where the damage processes are studied, contains micro-pores, Fig. 2a, while the left and right parts are homogeneous, allowing an undisturbed wave propagation. Moreover the model is loaded by a trapezoidal tension pulse in x-direction. Concerning the boundary conditions the nodes on the loaded surface as well as on the opposite side have been coupled in loading direction while on the surfaces perpendicular to the loading direction zero displacements are applied. These constraints conditions reflect the conditions at the central part of a bigger sample most appropriate. The simulations with pre-damaged material are realized with a constant initial porosity of 3% in relation to the volume of the central part. For this purpose the central part is overlaid

* Corresponding author: e-mail steffen.gerke@unibw.de, phone +49 89 6004 3422, fax +49 89 6004 4549

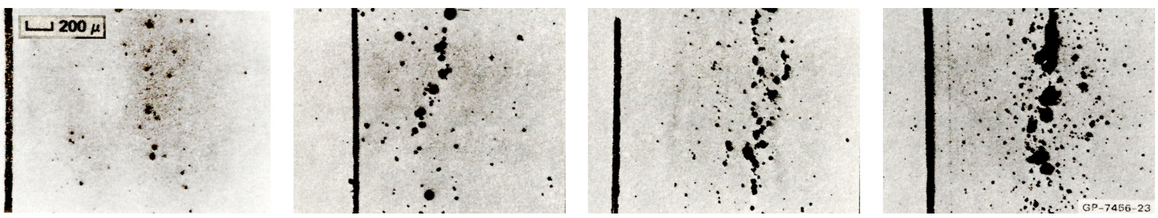

Fig. 1: Ductile damage under dynamic loading; Micro structure after impact, impact velocities, left to right: 433 fps, 468 fps, 506 fps and 688 fps; cut-outs from Barbee et al. [4]

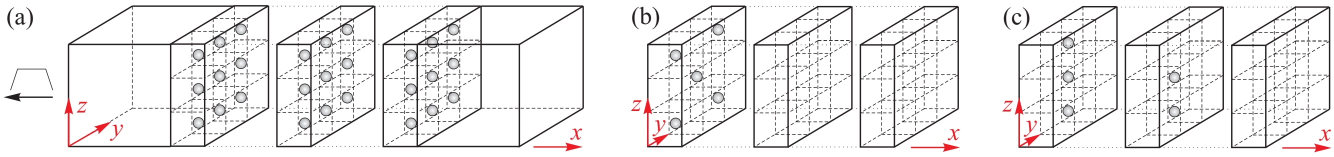

Fig. 2: Numerical model with micro-pores

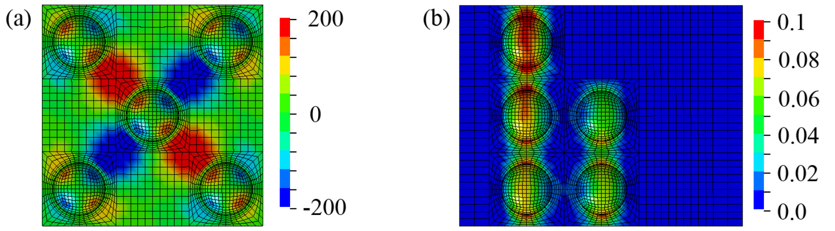

Fig. 3: Shear stresses of pore distribution as displayed in Fig. 2b (cut in y/z-plane) and equivalent plastic strains of pore distribution as displayed in Fig. 2c (cut in x/z-plane)

with a 3 by 3 by 3 raster (Fig. 2a) where each cell can contain one spherical void at its center while all voids are assumed to have the same radius. Hence, if not all cells contain pores, the pore radius of the remaining voids increases. This approach allows to study the behavior of homogeneously distributed pores (Fig. 2a) and influences of different pore distributions (Fig. 2b and c).

Simulations with homogeneous pore distributions as displayed in Fig. 2a indicate that the pores within the first layer enlarge remarkably before the wave propagates further while the undamaged initial part only deforms elastically. Obviously within this pore layer already pore coalescence, which is not considered here, would take place and a study with a reduced number of pores, which can be distributed in several ways, seems to be evident. For this study a total of 5 pores has been chosen which are collocated in several different ways; amongst others as displayed in Fig. 2b and c. The crosswise distribution perpendicular to the loading direction (Fig. 2a) may facilitate shear mechanisms as indicated for instance in Fig. 3a. This shear stress concentration is an indicator for pore interaction which can lead finally to coalescence. Furthermore the distribution indicated in Fig. 2c leads to a concentration of plastic deformations where no pore is remarkably collocated in the second layer (Fig. 3b), i.e. a micro crack is induced here, while the pores in the second layer reduce the plastic strain concentration. It is important to notice that different pore distributions may lead to different fracture mechanisms and thus have to be studied in more detail.

3 Conclusions

With the presented numerical analysis it was possible to study the damage process under dynamic loading conditions in detail. Appropriate boundary conditions, which reflect the material behavior at the center of an extensive sample, have been discussed. In this connection it was found that the pore distribution has a significant influence on the resulting deformation and thus on the stress state of the material which will lead to significantly different micro-failure mechanisms. Hence, further studies to identify critical pore distributions and to identify the corresponding failure processes are necessary. Furthermore it can be noted that a straight forward approach from static loading [7] to dynamic loading is not possible. Especially the definition of the appropriate boundary conditions, the controlled generation of stress states, which will become even more critical for three-dimensional loading, and the definition of a micro-fracture criterion will need special attention.

References

[1] M. Brünig, int. j. plast. **19**, 1679–1713 (2003).
[2] M. Brünig, acta mech. **186**, 37–53 (2006).
[3] M. Brünig and S. Gerke, int. j. plast. **27**, 1598–1617 (2011).
[4] T. W. Barbee, L. Seaman, R. Crewdson, and D. Curran, j. mat. **7**,**3**, 393–401 (1972).
[5] A. Needleman, j. appl. mech. **4**, 964–970 (1972).
[6] M. Kuna and D. Sun, int. j. frac. **81**(3), 235–258 (1996).
[7] M. Brünig, S. Gerke, and V. Hagenbrock, int. j. plast. **50**, 49–65 (2013).
[8] D. J. Benson, j. mech. phys. sol. **41**, 1285–1308 (1993).

