VIII International Conference on Computational Plasticity
COMPLAS VIII
E. Oñate and D. R. J. Owen (Eds)
© CIMNE, Barcelona, 2005

APPLICATIONS OF PHENOMENOLOGICAL FAILURE MODELS IN AUTOMOTIVE CRASH SIMULATIONS

H. Werner*, H. Hooputra*, S. Weyer*, H. Gese†

* BMW AG, Forschungs- und Innovationszentrum
Knorrstrasse 147, D-80788 München, Germany
e-mail: heinrich.werner@bmw.de, web page: http://www.bmwgroup.com

†MATFEM Partnerschaft Dr. Gese & Oberhofer
Nederlingerstrasse 1, D-80638 München, Germany
Email: helmut.gese@matfem.de - Web page: http://www.matfem.de

Key words: Crash Simulation, Failure Model.

1 INTRODUCTION

In the automotive industry, an ongoing trend towards mixed material concepts in the body in white has been established. Components made of high- and ultra-high strength sheet steels, extruded and casted aluminium alloys, non-reinforced as well as reinforced thermoplastics, curable plastics like sheet moulding compound (SMC) are an integral part of innovative design concepts, see Grünn et al.[1]. Therefore, crash simulations have to be able to describe the vastly different behaviour of these materials across the whole range of deformations − from elastic deformations up to more or less large deformations at failure. In addition, the mechanical behaviour of an increasing number of design materials is strongly influenced by the production process. Incorporating these effects in an industrially applicable manner to material models for crash simulations as well as modelling the behaviour of joints (spotwelds, linewelds, rivets, adhesive joints, etc.) is of primary importance for crash simulations.

2 PHENOMENOLOGICAL FAILURE MODELLING

The basis for a successful failure modelling is a correct simulation of macroscopic stresses and strains in a crash simulation. The main features of the material models used for metals and short-fibre reinforced or non-reinforced plastics are:

- isotropic/orthotropic linear-elastic behaviour up to the onset of yielding
- a stress state dependent criterion for the onset of yield (yield locus), see figure 1.
- a strain rate dependent hardening rule
- criteria for the onset of failure depending on the loading condition (stress triaxiality η and a parameter θ characterizing the shear loading, see table 1) and the material specific dependencies affecting the failure process (strain rate, orthotropy, porosity, fibre orientation, etc.). Three different mechanisms leading to failure are taken into consideration:
    - Plastic **I**nstability leading to the formation of a neck in thin sheet metals loaded in the membrane plane. The onset of necking is immediately

followed by fracture. Therefore, it can be utilized as a somewhat conservative failure criterion in structures discretized with shell elements.

- **D**uctile fracture based on the growth, nucleation and coalescence of microvoids.
- **S**hear fracture induced by a localization of shear bands.

As shown in table 1, the equivalent strain $\varepsilon_{eq.}^{**}$ is used to indicate the onset of failure for each criterion. The curves shown have to be interpreted as master-curves for an integral accumulation of damage, see Hooputra et al.[2]. Onset of instability is determined as a function of an arbitrary nonlinear strain path – resulting for example from a forming process simulation and a subsequent crash simulation – by means of a theoretical model incorporated in the algorithm CRACH. The phenomenological modelling of ductile fracture depends on stress triaxiality η. The parameters d_0, d_1 and c of the function in the centre of table 1 are determined by suitably chosen experiments. Depending on the particular material, they may be a function of orientation (this is indicated in the figure in table 1), strain rate, fibre orientation, porosity distribution, etc. The latter case is presented in a companion paper of Leppin et al.[3]. Shear fracture, depending on the parameter θ, is handled in an analogous way. To account for arbitrary nonlinear strain paths, a tensorial fracture criterion is used for ductile and shear fracture. Both fracture criteria are calculated separately, assuming no interaction between both fracture mechanisms. The IDS criteria are a comprehensive tool for predicting the onset of fracture initiation. A physically based crack propagation criterion in combination with a numerically robust and discretisation independent formulation is a still missing link in the simulation process.

3 APPLICATION OF IDS FAILURE MODEL TO AN AXIALLY COMPRESSED EXTRUSION COMPONENT

The effectiveness of the failure criteria based on the evaluation of instability, ductile and shear fracture is demonstrated by comparing numerical results with test data of an axially compressed double chamber extrusion component, see figure 2. For static and dynamic impact conditions, the folding and fracture pattern from the test is in good agreement with the simulation results using the IDS failure criteria. The predominating fracture modes occurring in this test case are shear and ductile fracture. Shear fracture mainly occurs at the T-joint between the middle wall and the outer walls and at the corner of the wall segments of the double chamber profile. Ductile fracture occurs in the severely bent folds in the middle of the wall.

4 APPLICATION OF IDS FAILURE MODEL TO THE IMPACT OF A SPHERICAL IMPACTOR ONTO A RIBBED THERMOPLASTIC PLATE

A spherical impactor hitting the cover plate of a ribbed structure induces axial compression followed by bending and finally fracture of the ribs. As shown in figure 3 (left), the fracture initiates at rib intersections approximately at half height of the ribs. In the centre of figure 3 this characteristic feature is well reproduced by a simulation using the improved yield locus in combination with the ductile and shear failure criterion. On the other hand, the von Mises yield locus predicts the onset of fracture at the lower end of the ribs, see upper graph in the centre of figure 3. A further benefit of the improved yield locus is seen in figure 3 (right). The force displacement curve is closer to the experiment.

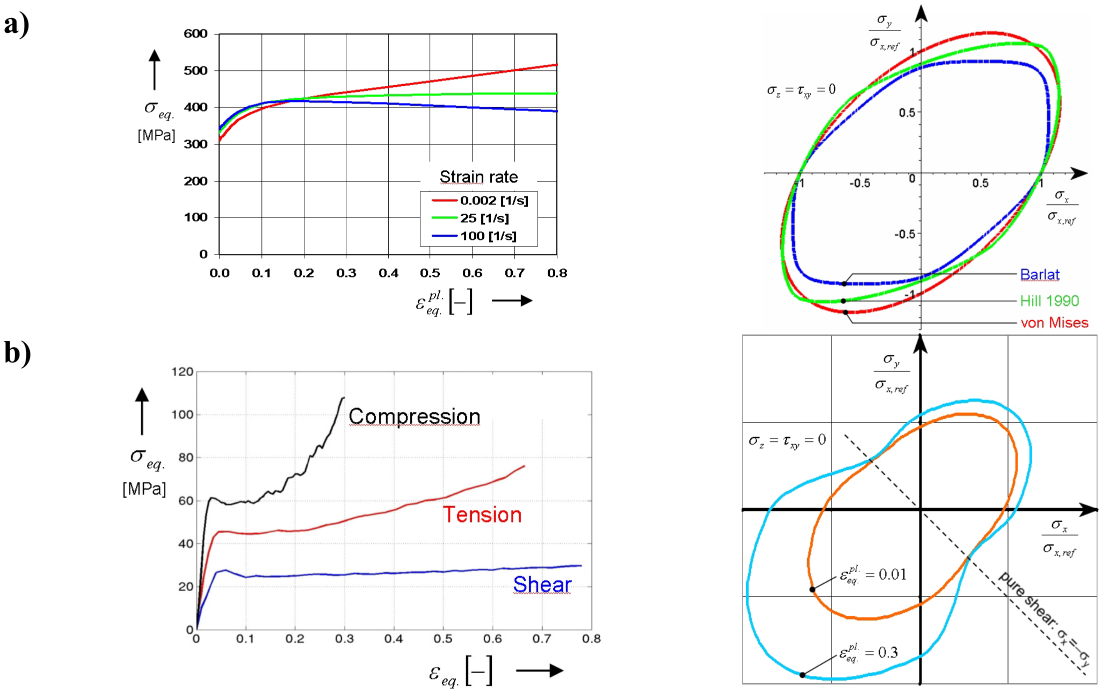
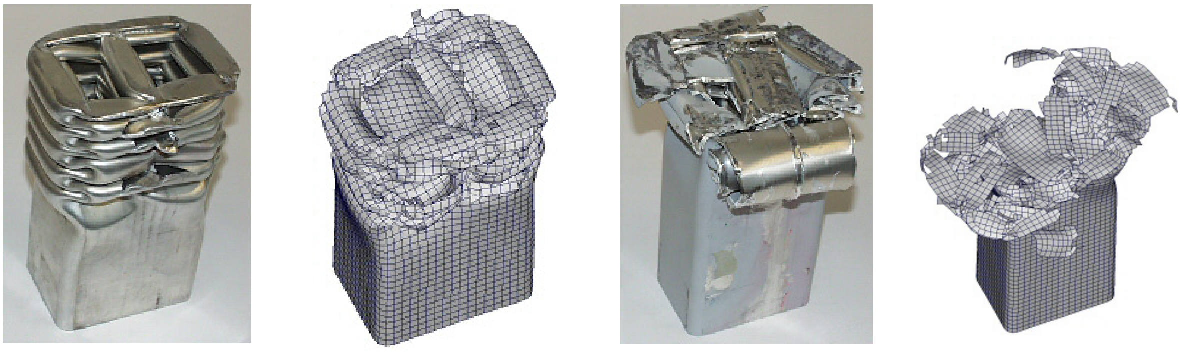


Figure 1: **a)** Left: Strain hardening for an Aluminium alloy as a function of strain rate. **a)** Right: Yield loci used for metals. **b)** Left : Strain hardening for a non-reinforced thermoplast as a function of stress state. **b)** Right : Yield locus for a non-reinforced thermoplast for two equivalent strains.



Static test Static simulation Dynamic test Dynamic simulation

Figure 2 : Experimental and simulated deformation and fracture patterns of an axially compressed extruded profile.

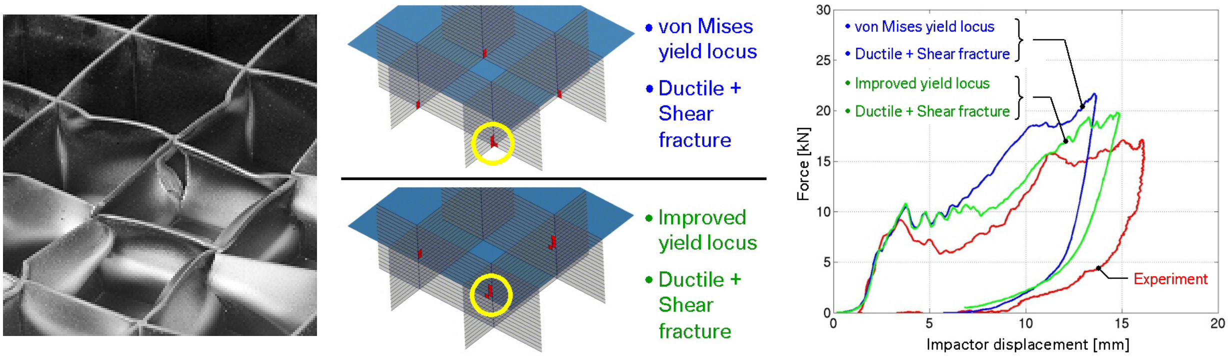


Figure 3 : Left: Experimental failure pattern of a ribbed plate impacted by a sphere. Centre: Simulation results of crack initiation site marked by red elements. Right: Comparison of force vs. displacement curves.

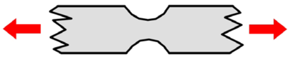
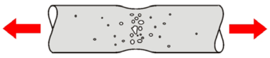
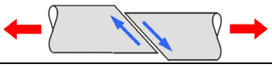
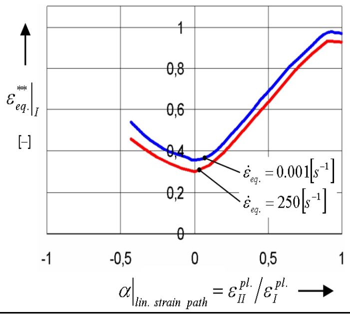
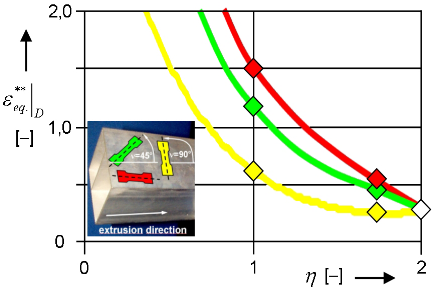
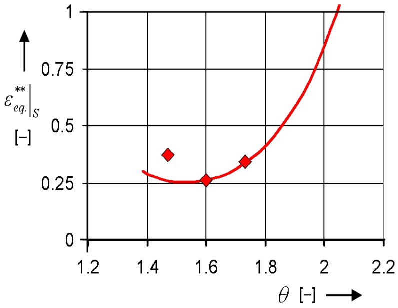
Instability	**D**uctile fracture	**S**hear fracture
		
$\varepsilon^{**}_{eq.}\Big\vert_I = g\left(\underbrace{\frac{d\varepsilon^{pl.}_{II}}{d\varepsilon^{pl.}_{I}}}_{\alpha},\ \dot{\varepsilon}^{pl.}_{eq.}\right)$	$\varepsilon^{**}_{eq.}\Big\vert_D = d_0\exp(-c\eta) + d_1\exp(c\eta)$ $\eta = \dfrac{\sigma_1+\sigma_2+\sigma_3}{\underbrace{\sqrt{\dfrac{(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2}{2}}}_{\sigma_{eq.}}}$	$\varepsilon^{**}_{eq.}\Big\vert_S = d_2\exp(-f\theta) + d_3\exp(f\theta)$ $\theta = \dfrac{\sigma_{eq.}}{\tau_{\max}}(1-k_s\eta)$
		

Table 1 : Overview of the IDS failure criteria. Symbols ◆ indicate experimentally determined sampling points, used to fit the parameters.

REFERENCES

[1] R. Grünn, J. Schönberger, G. Kettner, R. Zeller, O. Schreyer, J. Korzonnek, *The new BMW 6-Series: The Art of Body Building – Intelligent and Innovative*, ATZ MTZ extra, May 2004, pp. 16–20.

[2] H. Hooputra, H. Gese, H. Dell, H. Werner, *A comprehensive failure model for crashworthiness simulation of aluminium extrusions*, Int. J. of Crashworthiness, Vol. 9, No. 5, 2004, pp. 449–463.

[3] C. Leppin, H. Hooputra, H. Werner, S. Weyer, R.V. Büchi, *Crashworthiness simulation of aluminium pressure die castings including fracture prediction*, VIII International Conference on Computational Plasticity, COMPLAS VIII, Barcelona, 5-8 September 2005.