APPLICATION OF LOCAL CONCEPTS IN THE AUTOMOTIVE INDUSTRY

W. Schmitt, O. Benevolenski, H. Brehm, T. Walde
Fraunhofer-Institut Werkstoffmechanik, Freiburg, Germany

ABSTRACT

The automotive industry has been among the protagonists for the application of numerical simulation tools within the development process of new components and products for many years. Precision and quality of the simulations depend largely on the correct description of deformation and failure mechanisms of the materials under investigation. In this paper, two examples are presented which demonstrate the power of advanced simulation techniques. In the first example we focus on a concept for the evaluation of the durability of exhaust components under severe thermo-mechanical loading conditions. It is based on the application of local elastic-plastic fracture mechanics concepts to the growth of micro-cracks, the evaluation of the relevant crack tip loading requires the consideration of non-proportional, non-isothermal plastic deformations. Depending on the quality of the mechanical and thermal loading conditions implemented in the component models, not only the easy identification of weak spots in the structure is achieved, but also the calculated number of cycles to failure compare very well with results from test rigs. In the second example, the deep drawing properties of a sheet magnesium alloy at ambient and elevated temperatures are examined and applied in the forming simulation of a prototype motor hood. The appropriate modelling of the deformation and failure behaviour requires the consideration of strain rate effects and, in particular, of very complicated anisotropy effects caused by a combination of texture and twinning induced plasticity. The evaluation of those anisotropy effects is supported by using an interactive texture- and finite-element simulation of the rolling process.

1 INTRODUCTION

Micromechanical material models describing failure mechanisms in structural steels have been successfully applied for the safety assessment of nuclear power plants. Especially the Gurson model for ductile failure caused by void initiation, extension and coalescence has been widely used not only to determine the stability of postulated flaws but also to acquire material parameters and curves from very small specimens. Consequently, the local concepts of fracture have also been used for the assessment of spacecraft structures and automotive components during crash. The following examples demonstrate that local concepts may open new opportunities towards the optimisation of products and processes.

2 THERMOMECHANICAL FATIGUE (TMF)

A metallic material exposed to high stresses/stress variations and temperatures/temperature variations experiences damage due to both elastic and plastic parts of the deformation as well as due to high temperatures over a certain

period of time. Several developments in theories to describe the damage appropriately have been done in the past, starting out with the simple K-Factor for elastic deformation, leading to the Z_D-Parameter able to describe the plastic part of the damage, over to the D_{CF} Parameter describing elastic and plastic damage for higher, but constant temperatures. The drawback, however, was the inability of these theories to deal with the effect of damage due to the exposition of the material to high temperatures over a certain period of time (e.g., holding times). This is where the newly developed parameter D_{TMF} comes into play. This parameter quantifies damage in terms of an elastic and a plastic part of the deformation as well as a thermal part which depends (besides constant material parameters) only on the temperature regime and the main principal stress the material is exposed to.
In order to calculate the deformation parameter D_{TMF} we need to reveal the stress and strain history throughout the lifetime of a sample. For this purpose we employ a Chaboche type model which describes the cyclic stress strain curve by means of strain rate dependent back stresses.

The fatigue of exhaust components under operation is one important example in which the damage mechanisms addressed by the D_{TMF} scheme do contribute to the lifetime of the sample. The load during operation does include fluctuations of temperature of up to 900°C as well as mechanical constraints. Because of these excessive thermo-mechanical loading conditions crack initiation in the component leading to the replacement of the component might occur well before the nominal lifetime in case of an unfavorable design. Once the model parameters are adjusted one is able to analyze the damage in the sample by evaluating the D_{TMF} parameter. One can then relate D_{TMF} to the lifetime of the sample and find an easy potential law to describe this relation. A typical distribution of lifetimes in a manifold is given in figure 1.

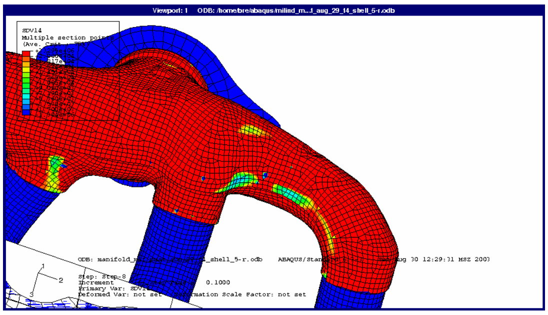

Figure 1: Lifetime prediction for a manifold, rear view, the regions green and blue denoting the lowest value of lifetime.

3 FORMABILITY OF A SHEET MAGNESIUM ALLOY

Stimulated by the need for light-weight construction in the automotive industry sheet magnesium alloys have attracted growing attention in the recent years. Poor formability of magnesium due to only a few active slip systems in its hexagonal close-packed lattice at ambient conditions necessitates the processing at temperatures above 150°C, where the thermal activation of additional slip systems is achieved. The use of sheet magnesium alloys for deep drawn components like motor hoods requires numerical simulations of the drawing process not only to control the elastic spring back but also to ensure that the forming limits of this material are not exceeded. Therefore, the deformation and damage properties of a MgAZ31 sheet were investigated, appropriate material models were selected, and the model parameters were determined. The models were validated by testing and simulation of hat profiles.

Tensile tests were performed on sheet magnesium alloy MgAZ31 at elevated temperatures and different strain rates. For 200°C the results are shown in Figure 2.

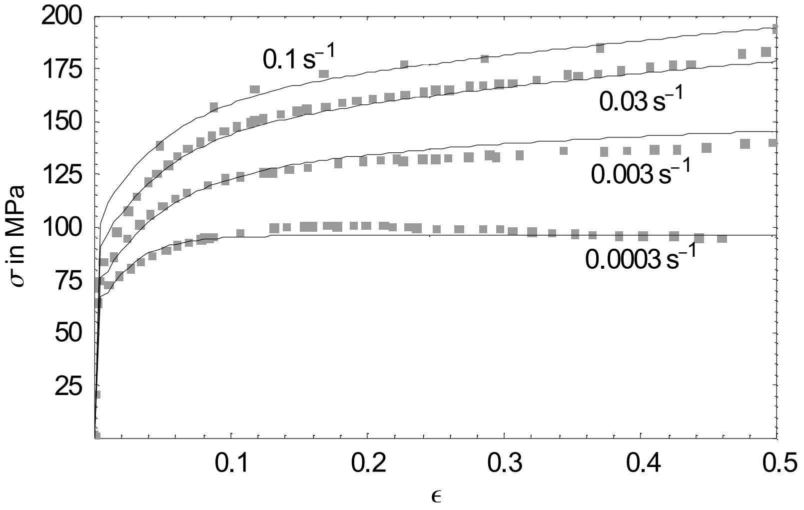

Figure 2. True stress - true strain curves of sheet magnesium alloy AZ31 in tension at 200°C for different strain rates (symbols), and fit with Chaboche-Jiang model (lines).

As can be seen from the diagram magnesium shows strong strain rate effects. There are two main mechanisms acting in the visco-plastic regime. Plastic overstress due to higher viscous resistance at fast deformations, and some time dependent recovery processes (i.e. reduction of hardening or even softening) at lower strain rates. The experiments were fitted with a Chaboche-Jiang model with several kinematic hardening components and one recovery term.

The damage behaviour was modelled with a Gurson model. An example of parameter fitting for an uniaxial tensile test is shown in Figure 3.

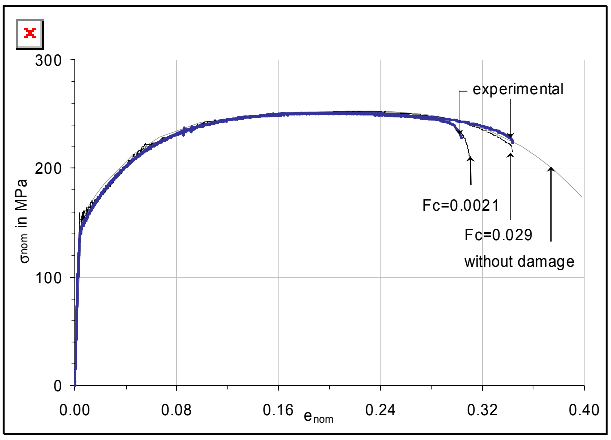

Figure 3. Parameter fitting (Gurson model) for tensile test at room temperature.

An example of the sheet metal forming simulation is shown in Figure 4 where the distribution of the sheet thickness is plotted.

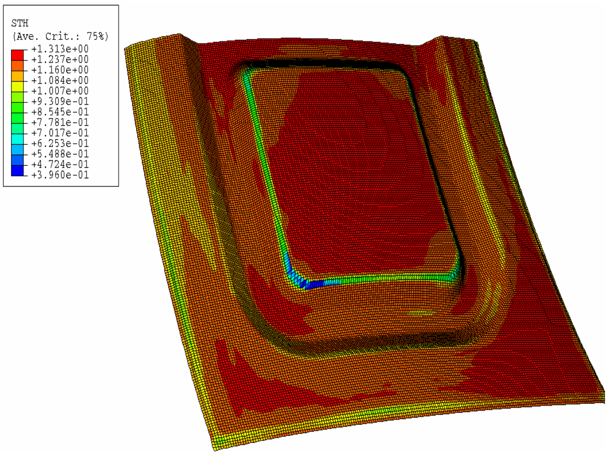

Figure 4. Forming simulation: distribution of sheet thickness in mm.

In order to better understand and quantify the complex anisotropy behaviour of this material the rolling process of the magnesium alloy AZ31 has been simulated applying a visco-plastic self-consistent texture model (after Lebensohn and Tomé) with material parameters taken from literature. The deformed mesh after rolling (thickness reduction of 30% in one pass) is shown in figure 5. At room temperature the stress-strain curves of the rolled material are shown in figures 6 and 7. The corresponding relative activities of the three deformation modes (basal slip, prismatic slip and twinning) during tension and compression in rolling direction are shown in figures 8 and 9, respectively. The curve for tension looks quite usual while the compression curve starts with a stress value which is only about a third of the value in tension but the compression curve shows a strong hardening when the relative activity of the twinning deformation mode drops.

These results demonstrate that the unusual plastic behaviour of magnesium sheets is a result of the combination of texture and twinning and that interactive texture and finite-element simulations can be powerful tools for modelling the deformation and failure behaviour of materials with twinning induced plasticity like magnesium alloys or TWIP-steels.

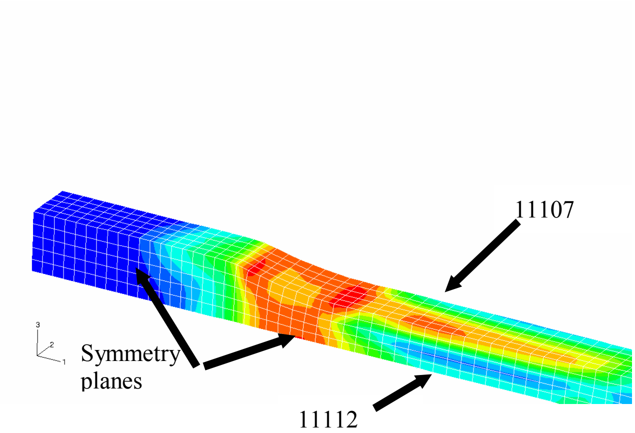

Fig. 5:
Specimen after 30% thickness reduction.

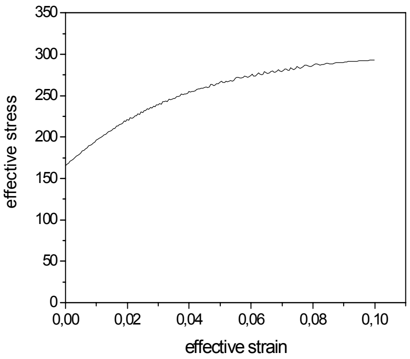

Fig. 6: Stress-strain curve for tension.

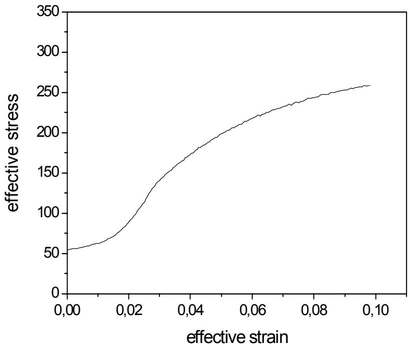

Fig. 7: Stress-strain curve for compression.

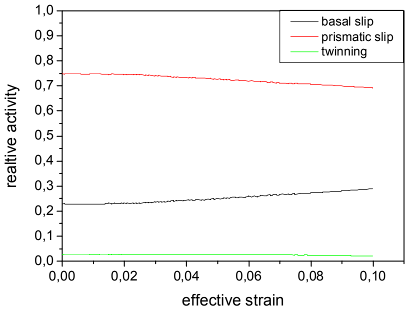

Fig. 8: Relative activity of the three different deformation modes for tension.

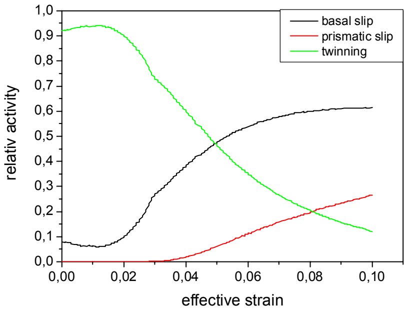

Fig. 9: Relative activity of the three different deformation modes for compression.