11th World Congress on Computational Mechanics (WCCM XI)
5th European Conference on Computational Mechanics (ECCM V)
6th European Conference on Computational Fluid Dynamics (ECFD VI)
July 20 - 25, 2014, Barcelona, Spain

CRACHFEM – A COMPREHENSIVE APPROACH FOR THE PREDICTION OF FAILURE IN METALLIC MATERIALS

Matthias Reissner[1]*, Harry Dell[1], Helmut Gese[1], Gernot Oberhofer[1]

[1] MATFEM Partnerschaft Dr. Gese & Oberhofer, Nederlinger Strasse 1, 80638 München, Germany
matthias.reissner@matfem.de, www.matfem.de

Key Words: *numerical prediction of localized necking for sheets, criteria for ductile normal and ductile shear fracture of metallic materials, damage accumulation with tensorial description of damage, damage plasticity*

With new and increasing applications of advanced metallic materials, for instance Advanced High Strength Steel (AHSS) and light-metal alloys, there are new and different challenges for numerical procedures. Well known is the classical forming limit diagram, which is mainly used in industrial sheet metal forming simulation to predict a possible sheet failure. This criterion is based on the onset of localized necking. Its validity is limited to linear strain paths. Advanced models should be used to achieve also valid predictions for nonlinear cases. For AHSS, aluminium and magnesium components fracture can also appear without prior necking. Depending on the stress state and on the forming history ductile normal fracture or ductile shear fracture can occur. Also the damage accumulation for fracture should be valid in case of a nonlinear strain path.

The module CrachFEM of the material model MF GenYld+CrachFEM offers a comprehensive approach to meet all of these challenges. MF GenYld+CrachFEM can be used as a user material model for different commercial explicit-dynamic FE codes. For industrial use the material models offers reliable phenomenological models for the failure modes given above. For academic research and a better understanding of the macroscopic failure phenomena the fracture models can be combined with a damage plasticity model to achieve a more detailed prediction.

For a shell discretization it is not possible to resolve the onset of necking directly as the width of the necked region is typically smaller than the edge length of a shell element. Therefore CrachFEM uses the submodule “Crach” to model the onset of necking with a detailed discretization of the neck [1]. The module Crach uses a plastic material model which accounts for orthotropic plasticity, isotropic-kinematic hardening and strain rate sensitivity. The discretization is based on an initial imperfection to allow for a realistic prediction of necking. The strain hardening, strain rate sensitivity and the hardening due to change of stress state inside the necked region (change to plane stress condition in neck; increase of stress component normal to sheet) contribute to the limit strain for instable necking. As the main physical effects are accounted for, Crach can also be used in case of nonlinear strain paths. Besides tensile tests no extra tests are needed to predict the forming limit diagram. For the prediction of fracture (without prior necking) CrachFEM uses phenomenological models for the phenomena of “ductile normal fracture (DNF)” and “ductile shear fracture (DSF)”. DNF accounts for a fracture which is caused by void growth and void coalescence (in case of ductile sheets voids do only appear just before fracture) with a fracture surface normal to the direction of the first principal strain. DSF accounts for a shear band localization in the material which is followed by fracture. The equivalent plastic strain at fracture as a function of a relevant stress state parameter is used as a failure criterion in case of linear strain paths. In case of nonlinear strain paths the initial fracture limit curves are used as a master curve for an integral damage accumulation law. In CrachFEM a tensorial description of damage is used. The limit strains for DNF and DSF cannot be predicted based on elastoplastic properties as the ductility of metals depends on the microstructure of the material and must be measured with different kind of specimens. A model for the post-instability strain (PIS) completes the CrachFEM approach in case of shell discretization [2]. The PIS model accounts for the additional strain in a shell element from the onset of necking until final fracture – by DNF or DSF - inside the neck.

For the forming simulation of thick sheets or bulk forming problems CrachFEM can also be used in combination with solid elements. The algorithm Crach for the prediction of instability is not used in this case. Necking must be directly resolved by the FE mesh. The fracture criteria for DNF and DSF in CrachFEM are based on two different stress state parameters β and θ. Both parameters can be used for a general 3d-stress state as they depend on 2 stress invariants each [1].

As an example for the advantage of the tensorial damage accumulation in fracture models of CrachFEM a cutting process of a sheet edge followed by a forming operation of the sheet is discussed.

On a next and even more detailed level the introduction of a damage plasticity model in MF GenYld+CrachFEM (i.e. accumulated damage of CrachFEM influences elastoplastic model in module GenYld) allows also for a mesoscopic modeling of fracture initiation (i.e. development of shear bands) and fracture propagation. The model for damage plasticity has been introduced in line with the model suggested by [3]. However a damage plasticity model causes a mesh dependent solution. Corrective measures are suggested for this problem. Monotonic crack propagation problems in aluminium sheets have been modelled as an example.

REFERENCES

[1] Dell H., Gese H., Oberhofer G.: CrachFEM - A Comprehensive Approach for the Prediction of Sheet Metal Failure. in: *Numiform '07, Part I, AIP Conference Proceedings*, American Institute of Physics, pp 165–170, 2007

[2] L. Keßler, H. Gese, G. Metzmacher, H. Werner: An approach to model sheet failure after onset of localized necking in industrial high strength steel stamping and crash simulations, *SAE 2008 World Congress*, Michigan, SAE-Paper 2008-01-0503, 2008.

[3] H. Huang, L. Xue: Prediction of slant fracture using damage plasticity theory. In: International Journal of Pressure Vessels and Piping **86**, pp. 319-328, 2009