MATFEM

4th MATFEM Conference

25 April 2017
Schloss Hohenkammer

Welcome!

Comprehensive material models with reliable material data are a key enabler for predictive finite-element simulation. In 2010, we organised the 1st MATFEM Conference, where material scientists, CAE engineers and users of MF GenYld + CrachFEM met to discuss the many aspects of material testing and material modelling and to share their experience. Meanwhile, the MATFEM Conference is established as a biennial event.

We now welcome you to the 4th MATFEM Conference at Schloss Hohenkammer. We are looking forward to the lectures and hope that they inspire discussion.

Welcome and introduction **8:30**

Crash of Polymers & Composites

Chair: M. Blagdon, Jaguar Land Rover Ltd.

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Advanced crash simulation of continuous-fiber reinforced thermo-plastics with MF GenYld + CrachFEM **8:45**
• M. Franzen[1]*, R. Schwarzer[2], H. Gese[3], G. Oberhofer[3]
• [1]Ford R&A Europe, [2]Kirchhoff Automotive, [3]MATFEM

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A comprehensive concept for modelling polymers and composites in crashworthiness using MF GenYld + CrachFEM **9:10**
• G. Oberhofer*, H. Dell, M. Oehm, M. Vogler
• MATFEM

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Strength fracture criteria for UD materials and isotropic foams **9:35**
• R. Cuntze • Carbon Composites e.V

Coffee break **10:00**

Metal Forming

Chair: I. Heinle, BMW Group

4

A Fourier series based generalized yield surface description and its application to the modeling of yield asymmetry, anisotropy and anisotropic hardening in commercially pure titanium **10:35**
• C. Raemy*, N. Manopulo, P. Hora • ETH Zürich

5

Analysis of the Young's modulus reduction and cyclic hardening of HCT780X **11:00**
• M. Rosenschon*, M. Merklein • LFT Erlangen

6

Advanced features of MF GenYld + CrachFEM for the simulation of metal forming **11:25**
• H. Gese[1]*, H. Dell[1], M. Reissner[1], F. Brenner[1], A.N. Heath[1],V. Yelisseev[2], A. Goltsev[2] • [1]MATFEM, [2]MATTEST Voronezh

11:50 Lunch

Crash of Metallic Components

Chair: A. Bach, Ford R&A Europe

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13:25 **Material model dependency of optimal topologies for crashworthiness** • F. Duddeck[1], D. Zeng[1], M. Richter[2] • [1]TU Munich, [2]MATFEM

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13:50 **Influence of strain rate on the instability in high speed cupping tests – Investigation on dual phase steel and numerical validation by Crach** • N. Weiß-Borkowski[1], A. Camberg[1*] ,T. Marten[1], T. Tröster[1], H. Richter[2], H. Gese[3] • [1]University of Paderborn, [2]thyssenkrupp Steel, [3]MATFEM

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14:15 **Notch stress raiser detection and handling in automotive body structures – an approach at Jaguar Land Rover** • M. Buckley[1], H. Lacy[1*], M. Richter[2], F. Brenner[2], H. Gese[2] • [1]Jaguar Land Rover Ltd., [2]MATFEM

14:40 Coffee break

Material Characterisation

Chair: A.-C. Höppner, ARRK | P+Z Engineering GmbH

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15:15 **Challenges in accurate prediction of the fracture behaviour of 6000 series aluminium sheet in automotive applications** • M. Blagdon • Land Rover Ltd

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15:40 **Developing consistent methods for fracture testing (VDEh Working Group – Fracture Testing)** • C. ten Horn • Tata Steel R&D

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16:05 **Additively manufactured components local properties assessment with the use of mini-specimens** • J. Dzugan*, R. Procházka • COMTES FHT a.s.

16:30 Conclusion

Advanced crash simulation of continuous-fiber-reinforced thermoplastics with MF GenYld + CrachFEM

1

M. Franzen[1*]
R. Schwarzer[2]
H. Gese[3]
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[1]Ford Werke GmbH, Research & Innovation Center

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The specific behavior of non-reinforced and short-fiber reinforced polymers in crash or drop test load cases imposes special demands on the material model as well as on the experimental determination of material parameters. If plastic compressible behavior is taken into account the visco-plastic material characterization must also account for compressible behavior for the failure characterization; the relevant material parameters must be adjusted in an appropriate way.

Among other methods, the material model MF GenYld + CrachFEM describes the evolution of the volumetric plastic straining with reference to the equivalent plastic straining, which is based on plastic work, through an equation of state. Parameters for this equation can be determined from uniaxial tensile tests (standard tensile tests), plane strain tensile tests (e.g. tests with waisted tensile specimen) and equibiaxial tensile tests (e.g. Erichsen test). Per definition the fracture strain is defined based on the "geometric" equivalent plastic strain, which includes volumetric straining in its general definition. In order to obtain the fracture strain at different stress states all three principal strains have to be measured. The described simulation method makes it possible to describe the failure behavior of polymers with comparatively high compressibility (low plastic Poisson's ratio of 0.1 and below) correctly even if the material shows very ductile behavior.

In this study, examples for a material characterization in consideration of plastic compressible behavior are shown. Results are compared to standard approaches without consideration of plastic compressible behavior and the additional experimental expenses are opposed to the increase in accuracy.

2 A comprehensive concept for modelling polymers and composites in crashworthiness using MF GenYld + CrachFEM

G. Oberhofer*
H. Dell
M. Vogler
M. Oehm

MATFEM Partnerschaft
Dr. Gese & Oberhofer

Injection molded non-reinforced and fiber reinforced thermoplastics are widely used in the automotive area and show still potential for cost effective weight reduction. Endless fiber reinforced thermoplastics and carbon fiber reinforced composites show a high potential for further weight reduction. In case of crash load cases these materials feature a complex mechanical behavior with respect to elastic, plastic and fracture characteristics.

The modular approach of material model MF GenYld +CrachFEM enables its application to a wide range of different materials including metals, polymers and composites. Key objective of the development is a systematic procedure for the determination of the required material parameters as well as an accurate, effective, and industrially applicable solution method with a solver independent solution.

This presentation provides an overview about characteristics of different polymers and composites and its representation in crashworthiness simulation using one common approach. Apparently, this method is also advantageous for modelling composite structures consisting of different materials e.g. short fiber reinforced polymers and endless fiber reinforced polymers, respectively composites of metals and polymers.

In order to obtain a predictive simulation a correct representation of all characteristic material effects is inevitable. These characteristic effects are typically determined based on a reference quality, which can be an injection-molded plate in case of non-fiber and short-fiber reinforced polymers. It is common to the different groups of materials however that the production process can significantly influence local properties. MF GenYld + CrachFEM is able to account for different types of local properties if the process history is known. Exemplary the orientation tensor is one of the dominating process parameters in case of short fiber reinforced polymers. Based on the orientation tensor MF GenYld + CrachFEM can calculate the principal directions of anisotropy as well as the degree of orientation. During simulation an interpolation between the highly oriented state and the quasi-isotropic state is carried out. At an early design state where no information from the form filling process is available, the material representation can be switched instantaneously to isotropic, still accounting for stress state dependent hardening which can be different for tension, compression and shear.

Current developments are focused on the extension to generally anisotropic behavior as well as the modelling of non-linear out of plane shear behavior.

Mechanical properties and failure behavior of hybrid organic sheets under quasi-static tensile load

3

R. Cuntze

Carbon Composites e.V., Augsburg

Initiated by the increasing use of endless fiber-reinforced polymer composites QinetiQ in the UK organized the World-Wide Failure Exercises (1993-2013) WWFE-I and WWFE-II. Whereas WWFE-I served for the validation of failure theories on the 2D stress state level the WWFE-II should do that on the 3D level. 3D validation is necessary due to the upcoming 3D analysis efforts and the necessary design verification. The WWFEs were subdivided into two parts: Part A was a blind prediction of the failure surface on the basis of provided strengths, only. Part B was the comparison of theoretical results with provided test data sets. WWFE-I provided 14 test cases, WWFE-II 12 test cases.

The author successfully contributed with his so-called Failure-Mode-Concept (FMC). This is an invariant-based concept that relies on Beltrami, Mises and Mohr-Coulomb and uses the UD-lamina as building block in a ply-by-ply laminate analysis. The formulation of the strength failure conditions of the homogenized lamina material follows the material symmetry requirements of a transversely-isotropic UD material. This means that five UD strengths and two friction values must be considered. Observed fracture morphology outlines that each single strength reigns one associated failure mode of the five independent modes: 3 for Inter Fiber Failure (IFF) and 2 for Fiber Failure (FF). The FMC-based fracture criteria (conditions) could be validated as far as reliable data sets were provided.

Nowadays, for structural sandwiches of high stiffness, honeycombs are often used as core materials. With the new Rohacell Hero, a Poly-Methacryl-Imide (PMI) closed-cell, structural foam with an increased tensile fracture strain is available which may replace the more expensive honeycombs.

Structural integrity requires reliable multi-axial fracture stress (strength) test data as well as reliable strength criteria for supporting an optimal design development process. The author applied his FMC to this isotropic material. The validation could not yet performed for Hero however, by still available 2D-test data of a similar behaving low dense foam material, termed Rohacell 71 G (courtesy LBF, Dr. Kolupaev). If the strength behavior of a similar behaving material is still known the shape of the fracture body is known. Then, pretty simple, the size of the envisaged fracture body of Rohacell Hero can be determined by measurement of its uni-axial strengths, i.e. tensile strength R_t and compressive strength R_c.

4

A Fourier series based generalized yield surface

description and its application to the modeling of yield asymmetry, anisotropy and anisotropic hardening in commercially pure titanium

The excellent strength to weight ratio, as well as their biocompatibility characteristics make hcp metals the materials of choice in many industries such as aerospace and medical implants. Increasing demands for energy efficiency and the corresponding policy decisions furthermore improve the feasibility of these expensive materials in automotive applications. State of the art plasticity models, however, fall short from delivering the required prediction accuracy. This in turn limits their application in mass manufacturing, where simulation is nowadays a fundamental constituent of the design process. A completely new approach in constructing yield surfaces with arbitrary complexity will be discussed in the talk, by using a Fourier series representation of the yield condition. It will be demonstrated that both symmetric and non-symmetric yield loci can be accurately modelled using this approach and this with at most comparable computational cost as with state of the art models. Furthermore, a physically motivated anisotropic hardening approach is proposed to model the effect of twinning induced plasticity under compressive loading.

C. Raemy*
N. Manopulo
P. Hora

Institute of Virtual Manufacturing,
ETH Zurich

Analysis of the Young's modulus reduction and cyclic hardening of HCT780X

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M. Rosenschon*
M. Merklein

Institute of Manufacturing Technology, Friedrich-Alexander-Universität

At the present time, the numerical pre-design of sheet metal forming processes plays a decisive role in the economic manufacturing of components. Besides the process limits, the final shape of the component can be calculated at an early stage of the design process, which enables a virtual adaption of the tools geometry and thus a reduction of subsequent optimization cycles on the physical tool. However, especially for lightweight materials, like high strength steels or aluminium alloys, the springback calculation is still limited and does not reach the required prediction accuracy. Since springback is the elastic release of internal stresses, its realistic prediction is influenced by two major aspects: on the one hand the correct calculation of the internal stresses occurring after the forming operation and on the other hand the precise description of the Young's modulus.

Dual phase steels tend to feature a significant Bauschinger effect that means a reduction of flow stress after a load reversal and a strong dependence of their Young's modulus with respect to the level of plastic strain. Within this research, both material characteristics are analysed for a HCT780X and reviewed with respect to their influence on a bending as well as a deep drawing operation. The behaviour of the Young's modulus is observed via tension tests with cyclic loading and unloading. To evaluate the Bauschinger effect, the kinematic hardening model according to Chaboche and Rousselier is calibrated on basis of compression-tension tests and compared to a conventional isotropic hardening model.

6 Advanced features of MF GenYld + CrachFEM for the simulation of metal forming

H. Gese[1*]
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The presentation summarizes recent developments of the material model MF GenYld + CrachFEM and highlights advanced features in the field of forming simulation.

The government-funded project UltraCaulk investigates ultrasonically assisted forming and caulking. Superimposed ultrasonic pulses decrease the necessary tool force during caulking and increase the formability of metals, although not all mechanisms are yet fully understood. MATFEM has implemented new elastoplastic models of the early replastification of metals during pulsating or cycling loads with an associated temperature rise.

The current computer power and multiscale techniques such as adaptive meshing allow to resolve very sharp radii in forming simulations accurately with shell elements. However, large ratios of sheet thickness to curvature radius violate the basic kinematic assumptions of shell theory. Further, conventional thin shells do not account for pressure in thickness direction, which can lead to problems at sharp tool radii. The use of hybrid meshes with shells and solids or of pure solid meshes may be a solution. CrachFEM can predict localized necking with a solid mesh. The partner lab MATTEST has performed experiments on the influ-ence of the punch radius on the necking strain in equibiaxial tension. This is part of a wider experimental study to use selected specimens for the evaluation of both limit strain for necking and fracture limit curves. These experiments can also be performed at high temperature and at high strain rates. The width of the neck was predicted with Crach.

Simulations of manufacturing processes such as cutting, hole punching or joining with self-piercing rivets also require solid meshes. For such problems LS-Dyna offers r-adaptivity for 2D axisymmetric solids and 2D plane-strain solids. MF GenYld + CrachFEM can be used in combination with r-adaptivity.

The tensorial description of damage ensures a physical prediction of fracture for strongly nonlinear strain paths. Such strain paths can occur in apparently simple cases, for example bending and subsequent flattening of a thick metal sheet. Simulations of this problem with MF GenYld + CrachFEM with a scalar and the recommended tensorial description of damage yield different results.

Material model dependency of optimal topologies for crashworthiness

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The need for lightweight and therefore optimized structures fulfilling or even exceeding stipulated requirements is omnipresent in various industries. To enable this in early phase design, the hybrid cellular automata (HCA) method is presented here to conduct a topology optimization of structural components with respect to crashworthiness load cases addressing in particular the influence of simple and more advanced material models on the topologies.

Due to its high energy absorption ability and low weight, thin-walled structures are widely used in automotive crashworthiness design. In this paper, crashworthiness topology optimization is conducted for the 3-point bending of an extrusion profile. In contrast to classical topology optimization, which is limited to static load cases and linear-elastic material behavior, the approach presented here couples the effective HCA method – using explicit-dynamic FE methods – with elastoplastic material behavior. The HCA method has been developed for 3D voxel structures and then been transferred more recently to thin-walled structures using a modified version, the hybrid cellular automata method for thin-walled structures (HCATWS). In the outer loop of this HCATWS, a bi-section search within limited length is used to identify a proper target mass according to the global response and predefined constraints. In the inner loop, proportional updating and mass correction techniques are utilized to redistribute the mass.

This optimization study is conducted for a magnesium extrusion profile. Mg alloys offer a high potential for lightweight design on the one hand but exhibit a complex elastoplastic behavior on the other hand. Typically CAE engineers in industry are using simple material models for a first optimization (e.g. Mises yield locus and strain hardening based solely on tensile tests). However, extruded Mg alloys typically show a pronounced asymmetry in the yield limits and strain hardening behavior for tension and compression. Hence, the question arises whether a simple material model might provide misleading optimization results. Therefore, more appropriate material models for Mg alloys are used here within the crashworthiness topology optimization. This comparative study should help to understand the influence of the underlying material model on the final structural topology.

8 Influence of strain rate on the instability in high speed cupping tests

– Investigation on dual phase steel and numerical validation by Crach

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Material characteristics such as yield strength and failure strain are affected by loading speed. Furthermore, the start of instability and necking before fracture depends on strain rate. Therefore, the strain rate dependency of materials has to be taken into account in crash simulations. The current standard experiment for investigation of strain rate dependency is the high speed tensile test as described in a FAT guideline. Moreover, the need for material characterization at multi-axial loadings and high strain rates is pointed out there. Forming limit curves (FLC) can be used for the description of the material's instability behavior at multi-axial loading. Usually, the FLC are determined quasi-statically at a punch velocity of 1.5 mm/s. The usage of experimentally determined, quasi-static FLC also at high strain rates leads to great uncertainties and thus can be used in crash simulations only with restrictions. A possibility for predicting FLC at high strain rates offers the numerical algorithm Crach as part of the modular material and failure model MF GenYld + CrachFEM 4.2. The numerical algorithm Crach uses Lankford parameters and the strain rate dependent hardening as an input. All input data can be derived from static and dynamic uniaxial tensile tests. The strain hardening exponent n and the strain rate sensitivity m may change for a given material as a function of strain rate. Therefore an FLC for dynamic strain rates can differ from the quasi-static one. As localized necking in a component initiates a dramatic increase of strain up to fracture, a correct predicting of necking is crucial for crashworthiness simulation. In the present work, the dual phase steel DP600 is tested in quasi-static and high speed cupping tests, which were done at a loading speed of 10 m/s. The evaluation of forming limits is measured by 3D high-speed camera system at a frequency of 10,000 Hz and evaluated with the software Aramis. The test setup is presented and the differences of forming behavior at quasi-static and high strain rates are pointed out. The prediction of the static and dynamic FLC with the algorithm Crach is based on tensile tests at nominal strain rates of 0.004 s^{-1}, 1 s^{-1}, 10 s^{-1}, 100 s^{-1} and 250 s^{-1}. Finally, the measured and predicted FLC at dynamic strain rates are compared and still existing deficits of the experimental setup and the numerical method are discussed.

Notch Stress Raiser Detection and Handling in Automotive Body Structures

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It has long been known that local stress raisers can lead to premature failure of sheet metals in automotive applications. This loss of strength is undesirable and a means of detecting and managing such issues in a structure undergoing crash loads is an important enabler for high performance, light weight structures.

Typical notch stress raisers may be rivets, spot welds or apertures, where the size, shape and manufacturing process used (e.g. laser cut, machined or pierced) will all have an effect on the ultimate load carrying capacity of a structure. The impairment of the base material by a given notch is the sum of the metallurgical detriments and the geometrical notch effect. For industrial crashworthiness simulations based on shell discretization the geometrical notch cannot be modelled in detail (e.g. stress concentration at sharp corners in a quadratic aperture).

MF GenYld + CrachFEM can be used to simulate the behaviour of notches by using appropriate scale factors for strain hardening, ductile normal fracture, ductile shear fracture and forming limit curve . These scale factors are applied to the elements at the rim of the hole or in the vicinity of the joint. In general for a given notch type and manufacturing technique the parameters which are to be scaled are identified based on a physical motivation. The quantitative evaluation of the scaling factors has to be done for each different material and manufacturing technology. The scale factors have to be identified for a given mesh size.

Jaguar Land Rover have partnered with MATFEM to create a process whereby notch types are detected and appropriate scale factors assigned in an automated fashion requiring minimal input from the user. This paper will describe this process and discuss some of the results found during this project.

10 Challenges in accurate prediction of the fracture behaviour of 6000 series aluminium sheet in automotive applications

M. Blagdon

Jaguar Land Rover Limited

Aluminium is increasingly being used in automotive applications as a lightweight solution for body panels. 6000 series aluminium sheets are used for more structural panels due to their higher strength in the "in-service" condition. This has led to the requirement for accurate prediction of the materials strength and fracture behaviour under dynamic crash loading.

There are three hardening mechanisms seen in the production of body panels made from 6000 series aluminium. Initially there is "age hardening" which starts as soon as the material is heat treated at the end of the production line. Further work hardening occurs when the panel is formed in the stamping process, and a final precipitation hardening effect occurs when the vehicle goes through the paint cure ovens. All these manufacturing processes affect the strength and fracture behaviour of the final "in service" properties.

This presentation will cover material characterisation and simulation work carried out by Jaguar Land Rover and the material supplier Novelis in three areas.

The first will cover a suite of coupon level tests that seek to understand how the strength and ductility of the material varies with both pre-strain and paint bake. The conclusion of this show that there is a non-commutative relationship between the pre-strain effect and the paint bake effect on the final strength and ductility.

Developing consistent methods for fracture testing (VDEh Working Group – Fracture Testing)

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C.ten Horn

Tata Steel
Research & Development

The need for improved crash performance combined with improved fuel efficiency has led to the increased use of Advanced High Strength Steels (AHSS) in the automotive industry. For these materials, the start of necking (FLC forming limit) is no longer the only failure mechanism that needs to be taken into account when evaluating the forming and crash performance. The fracture limit is needed as well.

In literature and in commercial FE codes, a large number of damage and fracture models are available. Choosing a suitable model is a challenge but the biggest challenge is to obtain parameters for the models. The tests that are being recommended are not standardised; neither the specimen geometry nor the strain measurement technique. This has resulted in that almost every lab has their own way of measuring fracture properties. Therefore, the results obtained by different labs may be not be consistent and will probably not be comparable.

That was the starting point for the VDEh (Association of German Steel Manufacturers) to start a working group with the ultimate goal is to align and standardise the fracture testing procedures. The challenges to reach this are: finding the best fracture test specimens for a wide range of stress states and finding the best fracture strain measurement methods. The difficulty with the fracture strain measurement is that the results are sensitive to both the time resolution and the spatial resolution of the technique used.

The working group started with compiling a list of all specimen geometries used for fracture testing and organising them with respect to stress state. From this list the most promising specimens were chosen using the collective experience in the group. Simulations of these specimens were performed in order to see to what extent they comply with the list of requirements that we set up.

Currently, the specimens are being tested at the different partners of the working group. The next steps will be to compare the results from the different labs and investigate the influence of the fracture strain measurement technique that was used.

This presentation gives an overview of the fracture testing problem, the plan of the working group and the results that have been obtained so far.

12 Additively manufactured components local properties assessment with the use of mini-specimens

J. Dzugan*
R. Procházka

COMTES FHT a.s.

Characterization of engineering materials and components is a crucial part for design and save service life utilization. Due to components processing technologies and exploitation conditions local properties can significantly vary from location to location over larger components as well as over small material volumes with gradual material changes such as welds, coatings or additively manufactured parts. The current paper is dealing with local properties characterization for additively manufacture (AM) components by micro tensile test (M-TT). Components produced by additive manufacturing techniques yield properties variation in dependence of the considered location within the component regarding to direction in relation to deposition process. Properties vary over the thickness, length, angle or contacts with the supporting structures necessary for a successful components production by additive manufacturing techniques. The properties differences are mainly related to varying heating / reheating and cooling conditions at various locations of usually very complex parts produced mainly by these technologies. The standard testing procedures fail to characterize such local properties of complex shaped objects due to large size requirements on specimens. Therefore, new techniques have to be established for such detailed local characterizations.

At first, experiences with miniaturized tensile tests specimens are going to be presented. Subsequently, results of miniaturized tensile tests application for local properties and orientations characterization are shown here for some AM produced components made of Ti and Ni-alloys. Quasi-static room temperature tests as well as high temperature and high rate tests are shown here. Components thickness dependence of the properties is demonstrated on several examples. Brief summary of the miniaturized test techniques for further mechanical properties investigations is going to be demonstrated finally.

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