MATFEM

6th MATFEM Conference

13–14 May 2024
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.

We now welcome you to the 6th MATFEM Conference at Schloss Hohenkammer. We are looking forward to the lectures and hope that they inspire discussion.

Monday 13 May

12:30 Reception and snack

13:30 Welcome address

Keynotes

Chair: G. Oberhofer, MATFEM

1 13:40 **Material modelling – from ductile to brittle** • H. Gese • MATFEM

2 14:10 **Influence of material modelling in crash simulation on discontinuous fiber reinforced thermoplastic parts** • G. Fruhmann[1]* · A. Rager[1]* · P. Maeser[2] · S. Mönnich[3] · M. Richter[4] · G. Oberhofer[4] • [1]BMW AG · [2]ARRK · [3]PEG · [4]MATFEM

3 14:40 **MegaCastings in Crashworthiness CAE** • J. Jergeus[1]* · P.-A. Eggertsen[1] · M. Landervik[2] • [1]Volvo Cars · [2]DYNAmore Nordic/ANSYS

15:10 Coffee break

Passive safety – polymers

Chair: G. Fruhmann, BMW AG

4 15:50 **A comprehensive test program for non-reinforced and short fiber reinforced polymers as input for MF GenYld + CrachFEM** • E. Hontiyuelo* · J. Ferrer · A. Regidor · D. Muñoz • NewGenTechs

5 16:15 **Polymer material test, parameters identification and application with MF GenYld + CrachFEM and MAT187 of LS-Dyna** • S. Wu • ShareFEA

6 16:40 **Upgrade parts' crashworthiness by exploiting injection molding manufacturing effects** • P. Fotopoulos[1]* · M. Richter[2]* • [1]Beta CAE Systems · [2]MATFEM

7 17:05 **Defining and validating a MF GenYld + CrachFEM material model for an SFRP material** • L. Douven[1]* · M. Richter[2] · G. Oberhofer[2] • [1]Envalior · [2]MATFEM

19:00 Dinner

Tuesday 14 May

Crash – cast materials

Chair: A. Bach, Ford Werke GmbH

8	08:30	**General strategy and new features in MF GenYld + CrachFEM 4.4.0** • G. Oberhofer* · A. Heath · M. Oehm • MATFEM
9	08:55	**Experimental characterization and parameter identification for a HPDC aluminium alloy** • P. van der Loos[1]* · S. Wu[2] · L. Peng[3] · P. Konopík[4] · H. Gese[1] • [2]MATFEM · [1]ShareFEA · [3]Shanghai Jiao Tong University · [4]Comtes FHT
10	09:20	**A practical approach to parameter identification for material damage models MF GenYld + CrachFEM and Gissmo and application in alloy wheel crush test** • T. Gakhar* · T. Sharma · K. J. Sijo • SSWL India
11	09:45	**Crash performance of a HPDC sustainable E-Bracket** • M. Rakotomahefa • Nemak Europe GmbH
	10:10	Coffee break

Forming & crash – sheet metals

Chair: K. Wiegand, Mercedes-Benz AG

12	10:50	**MBW1200 – New potentials for increased concept requirements: MFGenYld + CrachFEM is the optimal tool** • J. Quandt · H. Rösen* • thyssenkrupp Steel Europe AG
13	11:15	**How the manufacturing process affects the function of sheet metal safety components** • R. Lingbeek • Autoliv
14	11:40	**Mubea Tailor Hardening – specific material cards for innovative tailored steel** • T. Wilks[1]* · T. Labudde[1] · P. Panchal[2] • [1]Mubea TRB GmbH · [2]Mubea TRB North America
15	12:05	**Impact of optical strain rate controlling on the determination of mechanical sheet metal properties** • D. Naumann* · M. Merklein • LFT FAU Erlangen
	12:30	Lunch

Advanced material modelling

Chair: P. Konopík, Comtes FHT

16	14:00	**Application of MFGenYld + CrachFEM for fiber reinforced polypropylene** • S. Niedrig • Brose Fahrzeugtechnik
17	14:25	**From crack initiation to final collapse – Simulation of the post-critical behavior of composites** • M. Tönjes[1]* · M. Richter[2]* · C. Kartal[2] • [1]LCC TU München · [2]MATFEM
18	14:50	**Modelling additively manufactured metallic structures** • K. Komeilizadeh* · P. van der Loos · H. Gese • MATFEM
19	15:15	**Challenges in testing foams, glass and composites** • D. Muñoz* · A. Regidor · J. Ferrer · A. Tobías • NewGenTechs
	15:40	Closing remarks

Material modelling – from ductile to brittle

1

H. Gese

MATFEM Ingenieur-gesellschaft mbH

The modular material model MF GenYld + CrachFEM started as a material for very ductile steel sheets in forming and crashworthiness simulation. The limits for plastic deformation of sheets are mainly defined by localized necking and not by limited ductility. Therefore the algorithm Crach has been used to predict the onset of necking for linear and nonlinear strain paths. A post-instability model accounts for the regularization of the remaining strain of an element until fracture.

Less ductile AHSS and UHSS sheets can also fail in ductile normal fracture (DNF) and ductile shear fracture (DSF) besides localized necking. In most of the commercially available material models an integral damage accumulation with a scalar description of damage is used to describe the risk for fracture. However after any pre-deformation the residual ductility depends on the loading direction. A scalar description of the residual ductility is not sufficient. The residual ductility of these materials are described with a tensor in CrachFEM. Examples will be given, how CrachFEM can predict ductile fracture in case of nonlinear strain path.

But even ductile sheet metals can fail by brittle intergranular fracture, if the material suffers from high strain hardening, high strain rates and low temperature. The brittle stress-based fracture criteria in CrachFEM also allows to account for this case. The stress-based failure can be combined with strain-based failure in one material card.

Also in an early phase of the development of MF GenYld+CrachFEM models for non-reinforced and short-fiber-reinforced polymers had been included. Non-reinforced polymers exhibit a very high ductility. Due to J-type of strain hardening necking is not an issue at high strains. But for very high strain rates some ductile polymers show a transition from ductile to brittle. This problem is highlighted for a polycarbonate (PC). The combination of ductile strain-based fracture and brittle stress-based fracture allows to predict the fracture behaviour with all its facets.

In the last years MF GenYld + CrachFEM has been extended by features to model UD fiber reinforced polymers and fiber fabric reinforced polymers (e.g. organic sheets). For loading in the fiber direction a brittle, stress-based failure is used, whereas a ductile fracture model is used for the thermoplastic matrix. In the frame of a research project new testing and simulation methods have been developed to describe the behaviour of free edges and the post-fracture behaviour of glass-fiber reinforced polymer structures.

One of the newest developments of MF GenYld + CrachFEM is a model for windshield glass. This glass shows a pure brittle behaviour. The rules of linear fracture mechanics (LEFM) apply to the failure behaviour. However as the windshield glass layers are modelled with shell elements the impact of LEFM has to be accounted for in the right way. The fracture is typically caused by existing small microcracks in the glass. However the impact of such a microcrack is different in the glass surface and at the outer edge of the windshield glass. The new glass model initiates a lower fracture strength at free edges and automatically for elements in the vicinity of deleted elements during crack propagation.

Influence of material modelling in crash simulation on discontinuous fiber reinforced thermoplastic parts

2

G. Fruhmann[1*]
A. Rager[1*]
P. Mäser[2]
S. Mönnich[3]
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Injection molded parts with discontinuous fiber reinforcement usually show local and anisotropic behavior. Without any process simulation information only an isotropic material model with homogenized information of all directions can be used. As soon as valid results of injection molding simulations are available, a mapping of the local fiber orientations and the weld lines can be introduced. It should be possible to integrate this additional information without a change of the material model in the crash simulation model. Therefore, it is assumed that the used material model can represent the material in an early stage of development as a homogenized isotropic material and later in a more detailed stage of development in using the process information as an anisotropic material with the corresponding local properties in the part.

In this contribution, it will be shown that this is possible with the MF GenYld + CrachFEM model in combination with preprocessing in ANSA. It is assumed that the injection molding results will be available from a 3D Moldflow simulation. This information will be mapped with the ANSA mapping tool onto the corresponding mesh for the crash simulation in LS-DYNA. Because of the different meshes in Moldflow and LS-DYNA, settings for the mapping are of high relevance. Also, the weld lines generated in Moldflow need some care before the mapping can be performed successfully.

Regarding the material modelling, the standard modelling with an isotropic material model MAT024 with von Mises flow potential and load-independent behavior supplemented with the load-dependent DIEM damage model will be compared with a) the isotropic MF GenYld + CrachFEM material model and b) the anisotropic MF GenYld + CrachFEM material model using the fiber orientation mapping with/without weld line mapping.

The comparison will be shown on coupon level and part level.

3 MegaCastings in crashworthiness CAE

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1 | Volvo Cars

2 | DYNAmore Nordic AB

New advanced materials are necessary for reduced weight and improved attributes, but they also present a lot of challenges for the CAE community. Traditionally, cars were made of mild steel with very ductile behaviour and material failure was normally not an issue. As higher strength steel was introduced, this problem increased and so the need for failure prediction tools in crash CAE. When Volvo introduced a high amount of ultra-high strength hotformed boron steel (UHSS), the challenge became imminent and we introduced CrachFEM as a tool for advanced material behaviour prediction, including failure.

For further lightweighting, needed for our fully electric strategy, UHSS is not enough, but we need to introduce aluminium, magnesium and composite materials. Casted aluminium has interesting, but challenging, properties and will be the topic of this presentation.

These challenges include brittleness, scatter in properties over both geometry and time and complex geometries. The availability of large casting equipment has provided the possibility to cast very large parts, replacing many welded sheet metal parts by one single casted part. The term MegaCasting is commonly used for casted parts of a certain size, and the integrated rear floor is the most common application so far.

Since the properties of a casting will vary over the geometry due to the casting process, this must be reflected in a crash CAE model. Since it is not obvious how output from a casting simulation should be translated into input for a crash simulation, a simplified approach, based on a random distribution of properties calibrated from mechanical testing of specimens taken from different positions in a production part, has been applied for some time.

As a next step, we are now working on a method to map properties like flow length and solidification time from a casting simulation into scale factors on strength and ductility in a crash model. This is ongoing work, but we see promising progress. We see a great need for further research to refine these methods.

Thin-walled structures have traditionally been modelled with shell elements in crash simulation. However, the casted structures are complex and very difficult to mesh with shell elements. In order to improve efficiency and also quality of results, we see a tendency towards solid elements and hence a need for full 3D material models in the future. This will also generate very large models and put high requirements on both hardware and software.

4 A comprehensive test program for non-reinforced and short fiber reinforced polymers as input for MF GenYld + CrachFEM

E. Hontiyuelo*
J. Ferrer
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Knowing and understanding the behavior of a material, subjected to different types of stresses and conditions, is an important prerequisite for its modelling and further simulation. This needed foundation of knowledge and understanding is provided by a series of experimental characterization tests. Therefore, due to the need for the simulation to represent the real behavior of the material as reliably as possible, it is necessary to ensure that the data obtained from the experimental characterization phase are sufficient, representative of the material and of a high quality.

Being aware of the importance of the experimental data in all the process, it is necessary to consider the complexities of characterization testing and the huge number of variables which could affect the results of the tests. Because of this, the test program should be designed specifically for each material considering, among other factors, its properties, the possible changes of these properties due to different factors such as temperature, strain rate, fiber orientation or ageing, or the law of material that is intended to use in simulation, without forgetting the specific requirements of each project. This means that, apart from applying standardized methods, in many cases, it seems inevitable to develop specific tooling, samples manufacturing, testing or analysis methods in order to be able to obtain the desired quality in the measures for each kind of material.

A very important group of materials for many industries, such as the automotive industry, is the non-reinforced and short fiber reinforced polymers. This is a broad range of materials that varies widely in properties and raises a number of challenges for material characterization. Strain rate dependency, temperature dependency, different Young's modulus, hardness, strain at break and chemical properties, temperature dependency, ductile to brittle transition, triaxiality, anisotropy and local effects are some of the characteristics of these polymeric materials that increase the difficulty to have a standardized method for all of them.

MATFEM's MF GenYld + CrachFEM aims to address most of these characteristics and therefore requires a full experimental description of the materials. This means that an extremely wide range of tests can be considered as candidates for a characterization program. The challenge is to obtain all the necessary information from a limited number of tests and to optimize the test matrixes to obtain a complete characterization at affordable costs.

This talk describes the different types of tests considered to generate this data and gives an overview of the options performed at Newgentechs for the characterization programs of polymers for MATFEM's software, explaining the reasons for the selection and the experimental and analytical methods used.

5 Polymer material test, parameters identification and application with MF GenYld + CrachFEM and MAT187

S. Wu

ShareFEA,
Shanghai

Reliable prediction of polymer components plays an important role in restraint systems and pedestrian safety simulation. Mat187 and MF GenYld are two widely used material models for polymer. They can describe the asymmetric-hardening, plastic-compressible, strain-rate-depended fracture, etc. A reverse-engineering method using LS-OPT is introduced to generate material parameters from specimen test data for both Mat187 and MF GenYld + CrachFEM. Materials are validated in a dynamic B-pillar inner plastic pad test case with the same modelling methodology. Accuracy and calculational efficiency between two material models are reviewed.

6 Upgrade parts' crashworthiness by exploiting injection molding manufacturing effects

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In the recent years, the pursuit of lightweight products is an important objective. Specifically in the automotive industry an increasing number of parts is replaced by non- as well as fiber reinforced plastic materials to meet the demands with respect to lightweight and safety. This poses further challenges for the industrial crashworthiness as well as pedestrian safety simulations of larger components with locally varying mechanical properties caused by the injection molding process.

The above ignites the following process loop: (i) run injection molding simulation, (ii) transfer and map the results onto the structural mesh, (iii) run the structural simulation with the modular material model MF GenYld + CrachFEM for a high-quality material and (iv) post-process the results. The aforementioned loop is fully covered by the harmonic connection of ANSA – CrachFEM – META software products.

It is remarkable that the above solution also suits the early design stages of product development where the design is rough and full injection molding analyses with the standard solvers are costly in time and money. So, here comes the ANSA one-step molding solution to cover this efficiently and facilitating further solutions via multiple "what-if" studies or optimization loops.

The material model CrachFEM is then used in the structural simulation accounting for the fiber orientation, strain-rate dependency, load-dependent plastic strain hardening and orthotropy of fracture among others. For its capabilities this material model has comparatively low computational cost, rendering it suitable for industrial crashworthiness analysis.

The postprocessing of the simulation results such as visualizing fiber orientation and weld lines as well as identifying critical regions of plastic parts are covered by META. Furthermore, META provides plenty of tools and capabilities, among others the full automation of processes and report generation.

7 Defining and validating an MF GenYld + CrachFEM material model for an SFRP material

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Short glass fiber reinforced thermoplastics (SFRP), are a class of composite materials which are processed by injection moulding. These materials consist of a polymer matrix filled with short glass fibers. During the injection moulding process, on a local scale, the glass fibers orient according to the local flow field. The stiffness and strength are highly dependent on the orientation of the glass fibers. The injection moulded parts have an inhomogeneous fiber orientation, which entails anisotropic mechanical properties that vary throughout the part. These materials are light and strong and are used more and more for load bearing automotive applications.

However, when using CAE to ensure an optimal design of the component, a proper anisotropic material model is highly recommended. It is a “must” when it comes to simulating thermal expansion or material failure, e.g. crush, crash, post failure behavior.

From a modelling point of view we need to include anisotropy, and non-linear behaviour, on a local scale. In addition the failure of the material is dependent on the stress state, fiber orientation and strain-rate. For accurate results of FEA simulations, at an early stage of development, we need a versatile and robust modelling approach.

In this study we report the steps needed to build a material modelling approach using MF GenYld + CrachFEM for a PA6 material with a high degree of glass fibers (50% weight).

We have executed an elaborate testing campaign on coupon level, to quantify the effects of anisotropy, stress state, temperature, and weldlines, among others.

The local microstructure of the test specimens has been measured using microCT and compared to the prediction from a mold injection simulation

The team of MATFEM has calibrated the MF GenYld + CrachFEM material cards by modelling the coupon experiments.

At Envalior we have tested injection moulded applications at different load cases and impact speeds. These are used to validate the derived material cards, as well as to demonstrate the complete integrative simulation workflow on coupon and component level

8 General strategy and new features in MF GenYld + CrachFEM 4.4.0

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A. Heath
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The material model MF GenYld + CrachFEM has been developed to describe a wide variety of different materials with a single material model approach. The accuracy of the material description is targeted to provide a predictive numerical simulation of industrial components with focus on load cases with highly nonlinear material behavior, as relevant e.g. in misuse, forming and crash load cases in automotive and aircraft components, consumer electronics, as well as medical devices.

The single material model approach facilitates a high level of material representation including the consideration of individual process chains for different materials in a comparable way. It significantly supports the integration of new features to accompany the effective use of existing materials and enables a fast integration of new materials and processing techniques in industrial components. The modularity of the model leads to synergy effects. For instance the recent extension to describe brittle failure behavior can be used for the modelling of glass and ceramic materials, but offers the possibility to describe ductile to brittle transitions of generally ductile material behavior as it can be seen in polycarbonates, for example.

The single material model approach is used on different levels of material modelling, namely the determination of material parameters, as numerical model in the solver and for the visualization of material behavior with MF View. This enables a straightforward material characterization process minimizing the need of reverse engineering which substantially supports the quality management process. Applications of MF GenYld + CrachFEM cover the modelling of micro and mesoscopic structures, industrial components as well as the derivation of parameters for simpler material models.

Recently integrated new features allow to consider anisotropic characteristics of hardening behavior for failure prediction based on forming limit curves. Another extension affects the description of compressible material behavior. Furthermore the modelling of glass including failure behavior is now supported. The possibility to interpolate between different material states is an effective and generally applicable way to account for local effects. The superpositioning method can be used if general anisotropy is relevant. For license customers a database with a growing number of high-level material cards is provided.

Experimental characterization and parameter identification for a HPDC aluminium alloy

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As high-pressure die casting (HPDC) materials continue to gain more significance in the automotive industry, larger casting tools enable the production of larger components, often referred to as megacastings. With the increase in component size comes an increase in requirements for the material models utilized in the FEA design process as it typically entails a greater variation of casting properties such as cast length, solidification time and porosity.

Meeting these heightened requirements necessitates the accurate representation of material properties, accounting for both unsystematic scattering due to the casting nature and systematic scattering influenced by varying process parameters. The latter is primarily determined by cast length and local solidification time. The material model MF GenYld + CrachFEM, developed by MATFEM, addresses these challenges by enabling the characterization of material properties as functions of their casting properties while also incorporating normally distributed material properties to account for unsystematic scattering in cast components.

In an ongoing project together with ShareFEA and Shanghai University, a reference material card was derived from a flat zone of a cast component near the ingate in a first step. In this location, the highest ductility can be found. The experimental program and the derivation of material parameters for the reference location are discussed. In a subsequent step, the systematic variation of mechanical properties as a function of process parameters were quantified. To achieve this, colleagues from Shanghai University developed a compact quadratic spiral casting tool with a different cross-sectional area in three spiral arms. This innovative tool allows to reach high and clearly defined casting lengths with a nearly constant local solidification time in each arm of the spiral.

Based on the reference characterization and the output derived from the novel spiral casting component MATFEM derived a material characterization for an Al-HPDC alloy with the mentioned modules for systematic and unsystematic scattering of properties. The promising approach, demonstrated here for a current research project, bears the potential to define a standard component in further casting characterization projects.

10 A practical approach to parameter identification for material damage models MF GenYld + CrachFEM and GISSMO and application in alloy wheel crush test

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SSWL India

This paper is related to development of Finite Element Material Damage Models (i.e. MF GenYld + CrachFEM Damage Model and GISSMO Generalized Incremental Stress State dependent Damage Model) that can be further implemented in various FEA codes (i.e. LS-Dyna, Abaqus) and will aid in fracture behavior prediction in alloy wheel strength analysis.

In the automotive industry there is huge surge in use of CAE methodology to reduce physical testing and validation time and also increased safety requirements for passenger car vehicles. But most of the current CAE methods are based on stress analysis without fracture or damage prediction and this approach may be less effective during vehicle crash scenarios. Considering vehicle crash condition, crack prediction approach in FEA is vital as it helps OEMs to understand rupture path and crack location in component. Fracture behavior prediction requires development of material damage model that helps to identify all possible failure modes and hence require extensive testing on test coupons extracted directly from the component (alloy wheel).

The material model MF GenYld + CrachFEM and GISSMO Models have been developed at MATFEM Labs. Material Model MF GenYld describes material behavior under elasto-plastic deformations. CrachFEM is used to model material failure and allows to model failure due to localized necking, ductile normal fracture (DNF, caused by void nucleation, void growth), ductile shear fracture (DSF, caused by shear band localization). Second material damage model GISSMO is an LS-Dyna inbuilt damage model requires extensive testing to identify various damage parameters, stress triaxiality versus plastic strain to failure. GISSMO damage model allows for an incremental description of damage accumulation (D) including softening and failure.

Alloy wheels may be subjected to severe loading during vehicle crash and play a significant role in vehicle and occupant safety specifically in frontal load cases such as small overlap crash. Considering severe impact condition, the only official test alloy wheels are predominantly subjected to is Impact Test as per SAE J175, this test also may not provide detail regarding wheel fracture pattern during crush forces similar to frontal small overlap and crashworthiness scenarios. Wheel crush test FEA methodology was developed using Material Damage Models (MF GenYld + CrachFEM and GISSMO) and helps to predict fracture zone of wheel accurately under crush loads. With implementation material damage models in FEA significant improvement can be done to wheel design prior to physical test to improve wheel performance during wheel crush test.

11 Crash performance of a HPDC sustainable E-Bracket

M. Rakotomahefa

Nemak Europe GmbH

A multifunctional E-Bracket has been developed and produced in series by Nemak in HPDC. Nemak's aggressive lightweighting allowed to design a component with up to 30% weight saving for less development time and less validation loops. In that quest, a material card for cast material incorporating an extensive description of behaviour and specificity of HPDC materials was specially developed in cooperation with MATFEM. Among its structural functions, the E-bracket serves as an energy absorber in crash case. During the development phase, crash load cases were considered and simulated in Altair Radioss using the aforementioned material card. The results showed very good correlation with real component testing.

MBW1200 – New potentials for increased concept requirements: MF GenYld + CrachFEM is the optimal tool

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J. Quandt
H. Rösen*

thyssenkrupp
Steel Europe AG

The material grade MBW1200 is characterized by excellent performance in terms of dynamic crash loads (axial and lateral), combined with the necessary ductility and manufacturability of the components. This material rounds off the portfolio of tkSE-MBW steels and forms the bridge between the highest-strength cold-forming steels and the classic hot-forming steels. This opens new possibilities for designs that meet the requirements (system and package solutions). The AS-coating also makes it possible to use it in wet areas.

As part of this contribution at the MATFEM user conference, the good performance of this type of material will be presented, starting from laboratory and component tests through to concepts in the vehicle. The MBW1200 achieves a bending angle of up to 20° higher in the VDA plate bending test than the next strength class of the MBW grades. The resulting new concept possibilities are also reflected in the fact that the material is also very well suited to axial stress. Components such as side members and crash boxes are now of new importance alongside typical applications such as sills, side frames and pillars. New requirements-based solutions or system solutions are eventually feasible.

Since this material is a high-strength material, it is particularly important to be able to numerically evaluate its performance in the component. Here, MF GenYld + CrachFEM is of great importance with its diverse possibilities, especially with regard to the assessment of the fracture and the associated intrusion and energy absorption. The modular structure of the material cards makes it possible to set different degrees of complexity of the material cards. Starting with hardening, plasticity, instability and fracture, MF GenYld + CrachFEM offers the possibility to adjust the material description according to the requirements of the customer and the material to be considered. This was also used extensively with regard to the MBW1200. The material card is created based on the material characterizations. In addition to the numerical comparison of the fracture samples, extensive investigations are also carried out on the hat profile with a locking plate for the lateral loads and on the L-compression test with regard to the axial loads to secure the material map. By mapping the sheet thickness, the quality of the forecast for the final numerical design of the components under crash stress can be further increased. With this validated material card, concepts can then be designed, evaluated and optimized.

13 How the manufacturing process affects the function of sheet metal safety components

R. Lingbeek

Autoliv

Autoliv is a supplier of automotive safety equipment, such as airbags and seat belts. The company has set itself the target to become carbon neutral across the supply chain by 2040. Many components of a restraint system are made from steel. Now, steel is a big contributor to greenhouse gas emissions, hence, a target is to develop lightweight components. From the material perspective, 50% less steel implies 50% less greenhouse gas emissions. To retain performance in a thin component, stronger steel grades must be used. FEM simulation is a key technology to develop such components.

Components of restraint systems must function in a highly dynamic crash situation; there can be no compromise in quality. For this reason, components are tested up-to-and-including breakage. Some examples: a seatbelt bracket is tested in various static and dynamic overload conditions. A passenger airbag is deployed at very low temperatures. It’s challenging to reproduce such tests in an FEM simulation. Zooming in on the sheet metal components, the material modeling must cover plastic deformation and ductile failure at high strain rates and low temperatures. Now, the manufacturing process starts to play a key role: after forming the part from a flat blank, the component will show work hardening, the sheet thickness may have changed, and damage is accumulated. It is beneficial to make a simulation chain and map the material properties from the manufacturing simulation into the functional simulation. This leads to interesting situations, where a mild forming steel develops such a high yield stress, that brittle failure mechanisms may become relevant. Another challenge is, that in a chained forming and function simulation, the strain path may be highly nonlinear, even load-reversals are common. For these challenges, MATFEM software provides unique modelling capabilities. Such capabilities are a great help in making restraint products more sustainable – and safer at the same time.

Mubea Tailor Hardening – specific material cards for innovative tailored steel

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1 | Mubea
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Mubea has been delivering Tailor Rolled applications for cold formed and hot formed automotive structural parts for more than 20 years. Started as an idea in the early 1990s, the TRB process is currently being produced locally in Europe, NA and China on 6 rolling devices including post operation processes to deliver cold and hotformed finished parts as well as assemblies. This success story was only possible by increasing the know-how and capabilities continuously according to the market requirements.

On cold formed applications Mubea is currently using micro-alloyed AHSS to produce blanks and formed parts with variable gauges.

In the last few years, Mubea TRB developed new material families called MTS (Mubea Tailor Softened) and MTH (Mubea Tailor Hardened), which offer, in addition to variable thickness, also tailored mechanical properties in cold formed structural parts to efficiently meet local performance requirements of structural BiW and frame vehicle components.

In case of the Tailor Hardening material the higher strength is being achieved by lifting up the mechanical properties to the higher strength level (Yield and Tensile strength) by cold rolling using the mechanism of dislocation hardening in defined borders. Different to the already established TRB process for cold formed material we are starting with a much lower (and therefore cheaper) material grade compared to the benchmark solution and we are waiving the annealing process. These two aspects are the main driver to achieve a cost reduction compared to the baseline material.

In order to be able to predict the material behavior in forming and the performance of the part in the vehicle, we choose MATFEM as the adequate partner to perform an intensive investigation on different material grades and rolling degrees. All with the final target to create Material Cards for Forming and Crash simulations.

Starting with DD13 and S700MC raw material (followed by S420MC and CP800) MATFEM performed a quasistatic material characterization for different degrees of rolling (DoR). The material characterization includes tests for strain hardening, yield locus and fracture limit curves or each DoR. In addition dynamic tensile tests have been used to describe the strain rate sensitivity. The static and dynamic forming limit diagram has been predicted with algorithm Crach. The derived materials cards have also been successfully correlated against dynamic drop tower testing (at flb Siegen). Profile deformation and crack initiation in timing and location as well as the further progress has been well predicted by simulation. With that, we can now officially release the cards for the first 4 materials (DD13, S420MC and S700MC) to start design and performance validation of MTH parts together with the OEM.

For higher degrees of rolling the forming limit curves start to deviate in their limit strain level depending on orientation to rolling direction caused by a different strain hardening exponent n. MATFEM is currently developing an extended version of Crach to account for this effect.

In the design phase though, we and MATFEM tried to make working with these cards as easy as possible. Therefore a single material card has been derived for each material where the DoR is a field parameter. These cards are able to interpolate the mechanical properties depending on the degree of rolling degree in every element of the part – based on the thickness of the element relative to the thickness of the raw material (which is the only number we will have to add into the card in advance) and the calculation can start.

The first projects have already been successfully evaluated by the first OEMs – launching of the initial projects will start later this year.

Impact of optical strain rate controlling on the determination of mechanical sheet metal properties

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A key aspect of state of the art part, tool and process development is the prediction quality of numerical simulations. Costs and time in the design process can be reduced only with sufficiently reliable results. To obtain meaningful results, precise material data is an important input variable. In the state of the art material characterization with universal testing machines, material behavior is either determined at constant crosshead speed or at constant strain rates, only in the elastic region, according to ISO 6892-1 for tensile tests. Due to the fact, that commercial simulation software expects strain hardening data at constant strain rates, an error is made with current characterization tests at non-constant strain rates, due to the strain rate sensitivity that most metals exhibit. To obtain constant strain rate material data, optical controlled characterization tests can be conducted.

In the scope of this research, an optical strain rate controlled tensile testing method was developed for and applied to uniaxial tensile tests to investigate its influence on the measurement of mechanical properties of typical drawing grade steels. Therefore, displacement strain rate controlled (DSRC) and optical strain rate controlled (OSRC) tensile tests at room temperature with a nominal strain rate of 0.004 1/s were conducted and evaluated. Flat specimens according to ISO 6892-1 with a gauge length of 80 mm were used. The tests were performed with a universal testing machine (ZwickRoell GmbH & Co. KG.) and the strain was measured and controlled with a 3D DIC System (GOM ARAMIS 12M SRX). The both commercial common steels DP600 (CR330Y590T-DH) and DC05 (CR4) at a nominal thickness of 1.2 mm were analyzed regarding strain rate evolution during tensile testing and how OSRC influences the strain rate development.

The OSRC-method shows the potential to obtain material data in material testing at constant strain rates over the complete tensile testing trial from the elastic area to the failure of the specimen. For both investigated steels DP600 and DC05, the influence of the testing method is negligibly small. The root mean squared error of the averaged strain rates for DP600 and DC05 was decreased from 0.011 respectively 0.012 to $2.4 \cdot 10^{-5}$ respectively $5.6 \cdot 10^{-5}$ with the OSRC-method. In future work, an adaptive strain rate controlling will be developed, to obtain material data to higher strains in the area of diffuse necking. This can be applied to testing at elevated temperatures with e.g. electrically conductive specimen heating, where necking starts at an early stage due to inhomogeneous specimen temperatures.

Application of MF GenYld + CrachFEM for a glass fiber reinforced polypropylene

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Fiber filled thermoplastic materials are widely used for automotive applications. The advantages in high specific strength, due to the need of lightweight design, combined with reasonable material costs still lead to a growing amount of usage in interior and exterior vehicle components. Likewise, the demand of virtual validation increases as well, which requires sophisticated material models to account for local anisotropy of fiber orientation and distribution as well as weld lines inside the components and to increase the accuracy of simulation results.

In this presentation, the MF GenYld + CrachFEM material was utilized to evaluate the deformation and failure prediction of a PP-LGF40 material under quasi-static and dynamic loadings inside a benchmark part. Therefore, also the injection molding simulation is relevant, as it defines the input for an appropriate prognosis with the MATFEM material model. Especially at the area of weld lines, the injection molding analysis was improved in the sense of detecting the location but also the orientation of fibers. Inside the structural simulations, different element types were tested to evaluate the influence of the discretization on the results.

Finally, the CPU costs and the possibility of reducing the calculation time by using multicore processing were evaluated and compared with an isotropic MAT024 material model.

17 From crack initiation to final collapse – Simulation of the post-critical behavior of composites

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When designing against crash and abuse load cases, the post-critical behavior of continuous fibre-reinforced composites is often modelled in a highly simplified manner, where the fibre orientation is not considered. However, when designing damage-tolerant composite parts, this behavior can make an important contribution to the overall energy absorption capacity. In addition to the material orientation, this behavior of composites is also influenced by a pronounced strain rate dependency.

The Chair of Carbon Composites (LCC) of TU Munich collaborated with MATFEM in a research project to investigate the post-critical material behavior under several loading directions. A thermoplastic tape (UDmax by FRT Tapes) consisting of endless glass-fibers embedded in a PP-matrix with 45% fiber volume content is chosen deliberately for this study due to the strain-rate dependent behavior of both constituents. LCC enhanced existing testing methods using a split-Hopkinson bar to run a comprehensive testing campaign to characterize both the base material behaviour and the post-critical region ranging from quasi-static to dynamic strain-rates. Double-edge notched (DENT) specimens are tested for the first time in different orientations

Based on the experimental data, an elaborate material card for MF GenYld + CrachFEM is derived covering both stress- and strain-based failure criteria for its constituents fiber and matrix failure respectively. Further, a new module for MF GenYld + CrachFEM is developed which accounts for the softening of the material from crack initiation until the final structural collapse including fiber-orientation and strain-rate dependency. To demonstrate its capabilities correlations between experiments and simulation will be shown.

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18 Advanced material modelling of bulk material and lattice structures produced by laser powder bed fusion from alloy AlSi10MnMg

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Additive manufacturing still holds one of the biggest lightweight potentials in mechanical engineering and finds already key use cases in prototyping and the early stages of development cycles in automotive and aerospace industries. Parts can be printed within shortest response time at a low cost. Due to its flexibility in geometry and characteristics, additively manufactured components offer a high potential for weight optimization. Laser powder bed fusion (LPBF) of aluminum alloys was the focus in this project. LPBF was used both for production of bulk structures and open lattice structures. Bulk structures exhibit orthotropic properties due to the layerwise production process. Lattice structures promise significant weight reduction with respect to their stiffness. However, this potential also poses a significant challenge to simulation engineers: Finding an apt material representation in Finite Elements for additively manufactured components in general and lattice structures specifically can be problematic with respect to the process induced anisotropy of material, material scatter, computational expense, and numerical instabilities.

In the current research project addLight, which was thanksfully funded by the Federal Ministry of Economic Affairs and Climate Action, MATFEM shows how to derive material characterizations for additively manufactured bulk components of alloy AlSi10MnMg in different tempers as well as finely printed lattice structures from the same alloy together with partners from TU Darmstadt (MPA-IfW, LSM, PTW, PMD), BMW, EOS and AM Metals. The researched bulk material is modelled with MF GenYld + CrachFEM after its pronounced orthotropy in plasticity and fracture, resulting from the additively manufactured microstructure and subsequent heat treatment. In a second step, MATFEM introduces a newly developed module for its material model MF GenYld +

CrachFEM to overcome the limitations of finely modelled lattice structures in a larger FE model. This novel approach allows for a valid description of the lattice structure, while using homogenized solid elements at an affordable computational cost. It is a further development of material models for crushable foams. The developed module describes the lattice in terms of its compressibility and orthotropy, depending on geometry and process parameters. Physical tests on lattice structures and virtual tests with a detailed FEM model of the lattice structure are used as an input for the parameter identification of the homogenized material model. The resulting functionality is demonstrated showcasing a promising use case with an automotive component.

Challenges in testing glass, foams and thermoplastic composites

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Having good experimental data is essential for a good characterization of materials. This not only implies applying a series of conditions (mechanical, thermal, etc.) to a specimen or component, but also being able to adequately measure a series of magnitudes to extract the desired information. Going one step further, when characterizing a material with the aim of simulating it, we must take into account which law of material we are going to use to define both the tests and the measurement and analysis methods to be applied. This means that many of the tests and methods to be applied go beyond standardized procedures.

While characterization methodologies are relatively well established for many structural materials such as metals and many types of plastics, when it comes to more special cases, specific problems arise that force to develop new experimental methods. This is the case for materials such as glass, foams and thermoplastic composites.

Today, glass characterization is a hot topic for the automotive industry due to pedestrian impact. Glass was traditionally modelled with simple elastic models, but current developments focus on more advanced aspects such as statistical failure distribution or strain rate dependencies. Since glass failure is intrinsically related to the presence of micro-cracks, often generated during the manufacturing process, the tested specimens must be obtained from real windscreens, which implies curved geometries that would otherwise be considered unsuitable for a proper characterization.

Compression tests on foams are widespread and well known, but the characterization of materials for CAE requires other types of loading such as tensile, shear, etc., which are not so easy to reproduce in a laboratory with these variable volume, soft and sometimes crushable materials.

Thermoplastic composites are somewhat intermediate between common thermoplastics (both unloaded and loaded with chopped fiber) and thermoset composites. Experimental methods in both extremes differ due to the characteristics of each material. Specimen geometries, clamping systems, force measurement, etc. are completely different, as they are adapted to the stiffness and brittleness of each material, as well as the possibility of using adhesives to add tabs. Dealing with thermoplastic composites means approaching to the most unfavorable conditions of both types of materials, since we have brittle and rigid materials, but the chemical characteristic of the thermoplastic matrix makes it difficult to use methods used with thermoset materials involving adhesives and tabs.

In this talk we will review the problems associated to these materials and the methodologies defined at Newgentechs to overcome them in order to provide the best possible experimental data to the simulation engineers.

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