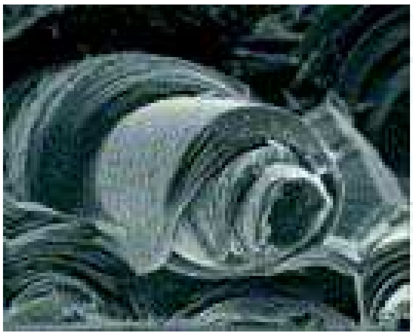
Karlsruhe Institute of Technology
Institute of Engineering Mechanics

University of Paderborn
Chair of Engineering Mechanics

25th International Workshop

Research in Mechanics of Composites



Bad Herrenalb, Germany
Dec. 6-7, 2012

Objective of the Workshop

Modern and classic composites display a macroscopic material behavior depending on their nanostructure, microstructure, and mesostructure in a complex way. The mechanisms and size scales relevant for the macroscopic material behavior depend, among others, on the mechanical or physical sizes considered and on the thermomechanical process conduct. Understanding the correlation of both the microstructure and micromechanical behavior and the macroscopic material behavior of components is of fundamental interest for a number of composite utilization problems such as the selection and the design of materials as well as the dimensioning and optimization of construction parts.

In this workshop, new approaches for the material modeling of composites are introduced and discussed with respect to the multiscale properties of the material type. This workshop serves young researchers and well-established scientists to discuss their research experiences and allows for interdisciplinary discussions covering the fields of applied mathematics, mechanics and materials science.

Prof. Dr.-Ing. habil. Thomas Böhlke

Prof. Dr.-Ing. habil. Rolf Mahnken

Program for Wednesday, 5th December, 2012

Time	
from 18:00 on	Registration and Welcome, Informal Meeting

Program for Thursday, 6th December, 2012

Time	Authors	Title of Lecture
08:30 - 09:00	M. Stommel, J.-M. Kaiser	Modelling of the Deformation and Fracture Behavior of Short Fiber Reinforced Plastics - Potential and Limitations
09:00 - 09:30	M. Kabel, H. Andrä	Fast Numerical Computation of Precise Bounds of Effective Elastic Moduli
09:30 - 10:00	M. Helbig, T. Seelig	Damage in rubber-toughened polymers: modeling and experiments
10:00 - 10:30	Coffee break	
10:30 - 11:00	S. Hoffmann, M. André, R. Müller	Computational Homogenization of Short Fiber Reinforced Thermoplastic Materials
11:00 - 11:30	F. Fritzen	A mixed variational formulation for nonlinear homogenization using reduced basis methods
11:30 - 12:00	H.J. Böhm	Particle Shape Effects in Ductile Matrix Composites
12:00 - 12:30	F. Hankeln, R. Mahnken	Thermodynamic consistent modelling of polymer curing coupled to visco-elasticity at large strains
12:30 - 13:30	Lunch	
13:30 - 14:00	Z. Bare, J. Orlik, V. Shiryaev	Multiscale simulation of textiles based on the asymptotic homogenization and dimension reduction
14:00 - 14:30	A. Rösner, K. Weidenmann, L. Kärger, F. Henning	Modelling the deformation behaviour of a twill-weave-reinforced thermoplast using the angle bisector framework
14:30 - 15:00	K. Schneider, T. Seelig	A cell model study of ternary polymer blends
15:00 - 15:30	B. Brylka, T. Böhlke	Dynamical mechanical analysis on long fibre reinforced thermoplastics (LFT)
15:30 - 16:00	Coffee break	
16:00 - 16:30	M. Marchant, F. Labesse-Jied, N. Gippius, Y. Lapusta	Numerical modeling of a hydrogel diffraction grating on a substrate used for pH sensing
16:30 - 17:00	S. Roy, J. Frohnheiser, K.A. Weidenmann, A. Wanner	In-situ study of compressive damage evolution in metal/ceramic composites based on freeze-cast ceramic preforms
17:00 - 17:30	I. Caylak, R. Mahnken	Modeling of anisotropy at large deformations for polycarbonate
17:30 - 18:00	J. Simon, B. Stier, S. Reese	Numerical Evaluation of Fibre Composites Accounting for Delamination
19:30	Workshop Dinner	

Program for Friday, 7th December, 2012

Time	Authors	Title of Lecture
08:30 - 09:00	A. Lion, M. Johlitz, C. Mittermeier, C. Liebl	Modelling and simulation of the temperature-dependent behaviour of supported polymer films
09:00 - 09:30	C. Dammann, R. Mahnken	Simulation of strain induced anisotropy for polymers with weighting functions
09:30 - 10:00	V. Müller, T. Böhlke, F. Dillenberger, S. Kolling	Micromechanical modeling of short fiber reinforced composites with orientation data
10:00 - 10:30	R. Al-Kinani, S. Hartmann	Modeling of fiber-reinforced hyperelastic composites using a multiplicative decomposition of the deformation gradient
10:30 - 11:00	Coffee break	
11:00 - 11:30	J. Dieker, K.-H. Sauerland, R. Mahnken	Meso-macro modeling of a coated forming tool including damage
11:30 - 12:00	C. Helfen, S. Diebels	FE^2 modelling of composite plates
12:00 - 12:30	U. Ehlenbröker, A. Schneidt, R. Mahnken	Micromechanical modeling of bainitic phase transformation for multi-variant polycrystalline low alloy steels
12:30 - 13:00	C. Cheng, R. Mahnken, E. Uhlmann, I. M. Ivanov	A Multi-Mechanism Model for Cutting Simulations Combining Visco-plastic Asymmetry and Phase Tranformation
13:00 - 13:30	Final discussion	
13:30	Lunch	

Order of Abstracts

Modeling of fiber-reinforced hyperelastic composites using a multiplicative decomposition of the deformation gradient

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Abstract. Frequently, the case of finite strain anisotropy, particularly, the case of transversal isotropy, is applied to biological applications or to model fiber-reinforced composite materials. In this work the multiplicative decomposition of the deformation gradient into one part constrained in the direction of anisotropy (fiber direction) and one part describing the remaining deformation is proposed. Accordingly, a form of additively decomposed strain-energy function is suggested. This leads to a clear assignment of deformation and stress states in the direction of anisotropy and the remaining part. The decomposition is explained and a constitutive model of hyperelasticity for the case of transversal isotropy is proposed. The behavior of the model is investigated analytically at uniaxial tension along and perpendicular to the axis of anisotropy. In addition, the model is investigated numerically using h-version and p-version finite elements, where two examples are considered, one showing the influence of existence of anisotropy and the other showing the influence of orientation of the axis of anisotropy (fiber direction).

Multiscale simulation of textiles based on the asymptotic homogenization and dimension reduction

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Abstract. Textiles are materials with a periodic microstructure composed by thin and long fibers being in a contact with each other. In different applications, textiles are putting on some surfaces by sliding along them. Our research is devoted to simulate such problems.

Mathematically the problem corresponds to the quasi-static contact problem with multiple contact interfaces. Since the structure of textile is periodic, the homogenization method can be applied to the problem to reduce its dimension. The extension of the two-scale analysis to the contact, corresponding corrector (or RVE) problem and the homogenized elasto-plastic problem are presented in [1], [2]. The main phenomenological result is that, the microscopic contact sliding results into the macroscopic plasticity.

Furthermore, the structure of the textile can be considered as a network of thin contacting beams. Again, some asymptotic analysis was required to obtain the contact conditions for beams and justify them mathematically. In [3], the frictional forces and Moments for beams are obtained in terms of the 3D friction traction and some cross-sectional characteristics. Further, the network was discretized and contact problem solved numerically by augmented Lagrange method [4], and beam finite elements. Although, the theoretical results were justified only for infinitesimal deformations, large tension of streads was implemented on an incremental way using a Newton method with a continuation [5].

Finally, the quasi-static uni-lateral contact sliding of the textile membrane (consisting of 1D-beams) on a smooth surface was simulated using the obtained results [6].

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Particle shape effects in ductile matrix composites

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Abstract. Multi-particle unit cells containing a number of randomly positioned and oriented, identical particles of spherical, octahedral, cubic or tetrahedral shape, respectively, are used in modeling the thermoelastoplastic behavior of a ductile matrix composite. The particles are treated as thermoelastic and the matrix is described by J_2-plasticity with linear isotropic hardening. Using standard Finite-Element-based periodic homogenization techniques, the macroscopic responses as well as the phase averages, standard deviations and distribution functions of microfield variables are evaluated for uniaxial, shear and thermal load cycles. Results are ensemble averaged over 5 different volume elements per particle shape and over different loading directions.

Considerable particle shape effects on the macroscopic responses are predicted for the mechanical load cases, tetrahedral particles leading to considerably stronger strain hardening of the composite than do spherical ones. No comparable behavior is found, however, for thermal cycling. The particle shapes are predicted to influence the microscopic volumetric stresses mainly in terms of the standard deviations in the particle phase. Pronounced differences are obtained between the deviatoric (von Mises) stress fields of composites reinforced by spherical and tetrahedral particles, respectively, both the phase averages and the standard deviations showing markedly higher values for the latter. For thermal load case clear particle shape effects are present for both deviatoric and volumetric microstress fields. The responses obtained for cube-shaped and octahedral particles generally lie between the ones predicted for spheres and tetrahedra. The tendency of the polyhedral particles towards showing high average and local stresses in the particles indicates that such shapes may induce an increased susceptibility to damage due to particle failure.

Dynamical mechanical analysis on long fibre reinforced thermoplasstics (LFT)

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Abstract. Discontineous glass fibre reinforced thermoplastics are commonly used for nonstructural parts in automotive applications. Due the versatile possibilities of manufacturing, forming, joining and recycling, thermoplastic matrix based composites are increasingly used also for semistructural parts. Thermoplastics like, e.g., polypropylene show a high temperature and strain-rate dependence. Therefore, for the automotive application sector, material models for a wide range of strain rates and temperatures are needed. Additionally, the influence of the viscoelastic behaviour of the matrix material on the effective material behaviour of the composite is of high interest. The DMA technique is an effective method to investigate the elastic and viscoelastic stiffness response of materials under cyclic loading. After a short introduction into the DMA technique, results for polypropylene and polypropylene based composite material will be presented. The composite under consideration is a long glass fibre reinforced thermoplastic manufactured in compression moulding. This manufacturing process induces an anisotropic fibre distribution and for that reason, the effective properties as well as the temperature and strain rate dependency has been investigated in different material directions. The comparison of the elastic and visocelastic material response of the matrix and the composite will be discussed in detail.

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Modeling of anisotropy at large deformations for polycarbonate

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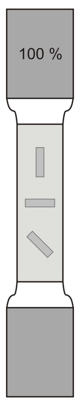
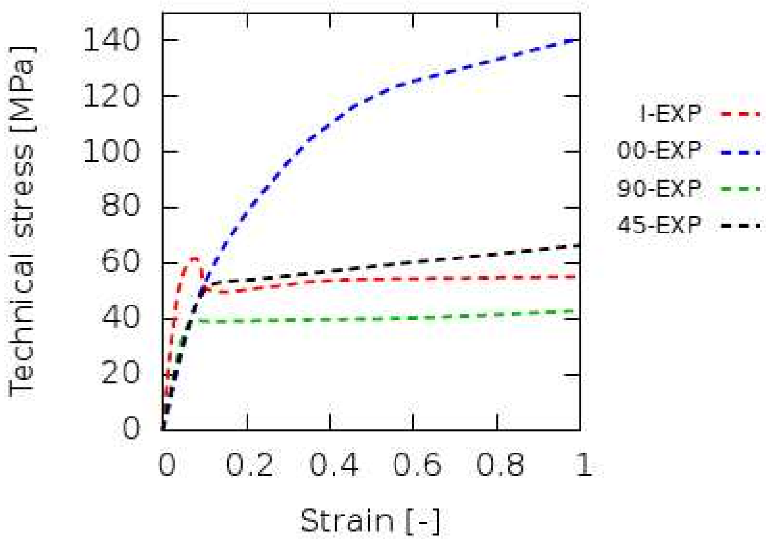
Abstract. In this presentation we develop a model to describe the induced plasticity of polymers at large deformations. Polymers such as stretch films exhibit a pronounced strength in the loading direction. The undeformed state of the films is isotropic, whereas after the uni-axial loading the material becomes anisotropic. In order to consider this induced ansiotropy as an initial anisotropy the yield function can be formulated as a function of the anisotropic tensor, where again the anisotropic tensor is a function of the direction of the stretched polymer chains. A backward EULER scheme is used for updating the evolution equations, and the algorithmic tangent operator is derived. The numerical implementation of the resulting set of constitutive equations is used in a finite element program and for parameter identification.





A Multi-Mechanism Model for Cutting Simulations Combining Visco-plastic Asymmetry and Phase Tranformation

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Abstract. We develop a multi-mechanism model for strainrate- and temperature-dependent asymmetric plastic material behavior accompanied by phase transformations, which are important phenomena in steel production processes. To this end the well-known Johnson-Cook model is extended by the concept of weighting functions [1], and it is combined with a model of transformation-induced plasticity (TRIP) based on the Leblond approach [2]. The bulk model is formulated within a thermodynamic framework at large strains, and it will be specialized and applied to cutting processes in steel production. In this prototype situation we have: Transformation of the martensitic initial state into austenite, then retransformation of martensite. For incorporation of visco-plastic asymmetry we present a model, which consists of a rate dependent flow factor with a rate independent yield function. In the examples parameters are identified for the material DIN 100Cr6, and we illustrate the characteristic effects of our multi-mechanism model, such as strain softening due to temperature, rate dependence and temperature dependence as well as the SD-effect. A finite-element simulation illustrates the different mechanisms for a cutting process.

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Simulation of strain induced anisotropy for polymers with weighting functions

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Abstract. The alignment of polymer chains is a well known microstructural evolution effect due to straining of polymers [1]. This has a drastic influence on the macroscopic properties of the initially isotropic material, such as a pronounced strength in the loading direction of stretch films [2]. For modelling of this effect of strain induced anisotropy, a macroscopic constitutive model is developed in this presentation. Within this framework, an additive decomposition of the logarithmic Hencky strain tensor into elastic and inelastic parts is used to formulate the constitutive equations. In order to handle the induced anisotropy, weighting functions are introduced to represent a strain-softening-effect for different loading directions. The weighting functions depend on the direction of the stretched polymer chains. Under these circumstances they are applied to additively decompose direction-dependent material parameters into a sum of weighted direction related quantities. The resulting evolution equations are updated using a backward Euler scheme and the algorithmic tangent operator is derived for the finite element equilibrium iteration. The numerical implementation of the resulting set of constitutive equations is employed into a finite Element programm to identify the unknown parameters.

References

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Meso-macro modeling of a coated forming tool including damage

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Abstract. A hybrid forming process is considered where the forming tool is subjected to cyclic thermal shock loading [1]. The thermal shock results from the contact of the forming tool with the heated workpiece. In order to reduce fatigue phenomena and to improve the tool service life, a multilayer coating system is applied on the tool. In particular, a thermal barrier layer (TBL) is used to reduce the impact of the heating.
In this contribution, an existing two-scale model for the simulation of the coated forming tool [2] is extended. On the mesoscale, the different constituents of the coating system are dissolved within a representative volume element (RVE). The homogenized properties are then used to simulate the coating system on the macroscale. Furthermore, a damage model is used on the mesoscale to account for delamination effects.

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Micromechanical modeling of bainitic phase transformation for multi-variant polycrystalline low alloy steels

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Abstract. Metal forming processes are important technologies for the production of engineering structures. In order to optimize the resulting material properties, it becomes necessary to simulate the entire forming process by taking into account physical effects such as phase transformations.

In our work, we develop a micromechanical material model for phase transformation from austenite to bainite for a polycrystalline low alloys steel. In this material (e.g., 51CrV4), the phase changes from austenite to perlite-ferrite, bainite or martensite, respectively. The presentation is concerned with phase transformation between austenite and n-bainite variants in N differently orientated grains. The characteristic features of bainite formation are the combination of time-dependent transformation kinetics and lattice shearing in the microstructure. These effects are considered on the microscale and transferred to the polycrystalline macroscale by means of homogenisation of stochastically orientated grains.

Furthermore, the numerical implementation of our model with a two-step algorithm is presented. In the first step, we use a projected Newton algorithm, based on the algorithm in [2], for the calculation of phase transformation. Then, in a second step, a Newton algorithm is used for the calculation of visco-plasticity.

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A mixed variational formulation for nonlinear homogenization using reduced basis methods

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Abstract. The homogenization of nonlinear micro-heterogeneous materials is a computationally challenging procedure. While FEM simulations on representative volume elements can capture the effect of the heterogeneities and the nonlinearities to a good extent, the associated computational cost is prohibitively large. In order to satisfy the demands from industry, it is required to accelerate the simulations by a factor of 10^4 or more in order to be competitive with heuristic models, which cannot consider all microstructural effects.

A recent proposition that can lead to such gains is the Nonuniform Transformation Field Analysis (NTFA) [1, 2]. The method belongs to the class of reduced basis model order reduction techniques. Its main feature is a low-dimensional parametrization of the plastic strain fields using global ansatz functions referred to as inelastic modes. Unfortunately, the method has some short-comings since the evolution of the internal variables of the model is derived from a heuristic macroscopic yield criterion.

Recently, the author has extended the method for linear visco-elastic materials [4]. In the new model the evolution of the internal variables is mircomechanically derived from the dissipative effects on the microscale. In the current contribution the method is extended to allow for rate-dependent Generalized Standard Materials. The evolution of the internal variables of the model is based on a mixed incremental variation formulation. Numerical examples for isotropic and anisotropic visco-plasticity models are presented.

References

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Thermodynamic consistent modelling of polymer curing coupled to visco-elasticity at large strains

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Abstract. We develop a macroscopic constitutive model for temperature-dependent visco-elastic effects accompanied by curing of polymeric matrix material, which are important phenomena in production processes. Within a thermodynamic framework we use an additive ternary decomposition of the logarithmic Hencky strain tensor into mechanical, thermal and chemical parts. Based on the concept of stoichiometric mass fractions for resin, curing agent and solidified material the bulk compression modulus as well as the bulk heat- and shrinking dilatation coeffcients are derived and compared with ad hoc assumptions from the literature [1, 2]. Moreover, we use the amount of heat generated during dynamic scanning until completion of the chemical reactions, to define the chemical energy. As a major result, the resulting latent heat of curing occurring in the heat-conduction equation derived in our approach reveals an ad hoc approach from the literature as a special case. In addition, thermodynamic consistency of the model will be proved, and the numerical implementation of the constitutive equations into a finite-element program is described. In the examples we illustrate the characteristic behaviour of the model, such as shrinking due to curing and temperature dependence [3] and simulate the deep drawing of a spherical part with the finite-element-method.

References

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Damage in rubber-toughened polymers: modeling and experiments

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Abstract. Distributed Crazing seems to be the most important mechanism underlying the inelastic behaviour of rubber toughened polymers such as acrylonitrile-butadiene-styrene (ABS). A micromechanics based constitutive model focussing on this mechanism is developed and presented here. It is based on the idea that the formation of distributed crazes (i.e. cohesive crack-like surfaces) give rise to an overall inelastic strain in the direction of maximum principal stress. This concept is used in a homogenized model for ABS which explicitely accounts for microstructural parameters such as the rubber content and the rubber particle size. Tensile tests under different loading conditions are used to determined the material parameters of the constitutive model.

Numerical simulations as well as experiments are conducted on a Single Edge Notched Tensile (SENT) specimen in order to validate the model and analyze the fracture behaviour of ABS. The distributed crazing model proves successful in reproducing the characteristic elongated shape of the plastic zone in front of a notch in ABS.

FE^2 modelling of composite plates

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Abstract. Nowadays, composite plates, such as hybrid laminates and sandwich plates, present an interesting issue for the transport industry, because of their good mechanical properties at relatively limited weight. In the present communication, a multi-scale modelling of the mechanical behaviour of composite plates is proposed. The principle of the FE^2 method [1-4] is to consider two scales: on the macroscale, a FE computation of a homogeneous plate is performed. But instead of using the constitutive law of the plate, the deformations are projected in an accurate way from each integration point of the macroscale to the boudaries of an RVE on the mesocale. In the mesoscale, another FE computation of the resulting Dirichlet boundary value problem for a Representative Volume Element (RVE) is defined. Finally, a modified Hill-Mandel condition enables the compution of the macroscopic stress resultants. In this work, special attention is paid to the definition of an analytical tangent and to the consideration of non-linear material behaviour.

Further improvements concerning the modeling of complicated structures, as for instance of the interface between metallic and polymeric layers, will be handled in a forthcoming work.

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Computational Homogenization of Short Fiber Reinforced Thermoplastic Materials

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Abstract. In this work an anisotropic failure criterion for short fiber reinforced thermoplastic materials is developed. The basis for the computational homogenization of the material is the representative volume element (RVE) method, see [1]. In order to increase the accuracy of the computational homogenization process, an exact generation of fibre orientation in the RVE is desired. Therefore, an iterative algorithm for fiber orientation generation is presented. The algorithm allows the generation of a set of fibers that exactly satisfy a given target orientation tensor within the RVE. The development of a failure criterion starts with the identification of the dominating damage mechanisms. FESEM analyses of fracture surfaces suggest that the fiber matrix coupling is strong and interface damage (delamination) does not occur. Fiber fracture and matrix damage are the dominating failure mechanisms. After introduction of suitable material and damage models for the fiber and matrix material, the experimental results from tension tests could be successfully simulated by RVE computations, see [2]. On this basis a failure criterion for the composite is developed. Computational examples are given for a composite material with two different fiber orientation distributions.

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Fast Numerical Computation of Precise Bounds of Effective Elastic Moduli

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Abstract. A fast numerical solver to compute precise bounds of effective properties of multi-phase elastic composites is presented in contrast to analytical estimates like Hashin-Shtrikman bounds.

Analytical homogenization methods fulfil the requirements (with respect to accuracy, computational effort and generality of the microstructures) for predicting effective properties of multi-phase elastic composites only for simple shaped inclusions. Curved fibers and even more complex non-convex inclusions cannot be considered or lead to bad approximations at least for higher stiffness ratios. Furthermore, the usage of analytical homogenization on base of micro-tomographies often requires additional image processing and image analysis steps. Since micro-tomographies become more and more mainstream in material science, numerical homogenization as additional tool for image processing software is qualified for highly precise predictions directly from three-dimensional segmented images.

For numerical homogenization the equations of elasticity are formulated as integral equations of Lippmann-Schwinger type [6, 4], which can be efficiently solved by using Fast Fourier Transformations (FFT). This approach is particularly suited for digital images (CT images) of complex microstructures and needs much less computational effort than finite element schemes to predict the effective properties [1, 2]. Although this method is well-known [5, 3], the usage of this method to compute lower and upper bounds is new.

A first numerical test for a simple microstructure demonstrates the numerical convergence with respect to the resolution of the microstructure. The quality of the new bounds is compared with analytical bounds. The second numerical example examines the linear visco-elastic behaviour of laminates as used by the automotive industry.

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Modelling and simulation of the temperature-dependent behaviour of supported polymer films

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Abstract. In order to comprehend the thermomechanical behaviour of glass-forming polymer films which are deposited on thermally deformable substrates it is indispensable to take the lateral geometric constraints into account. They are caused by differences in the thermal expansion behaviour between the substrate and the film and provoke the evolution of stresses. Since these stresses depend on the temperature process, they influence the specific heat of the film and change during physical ageing.

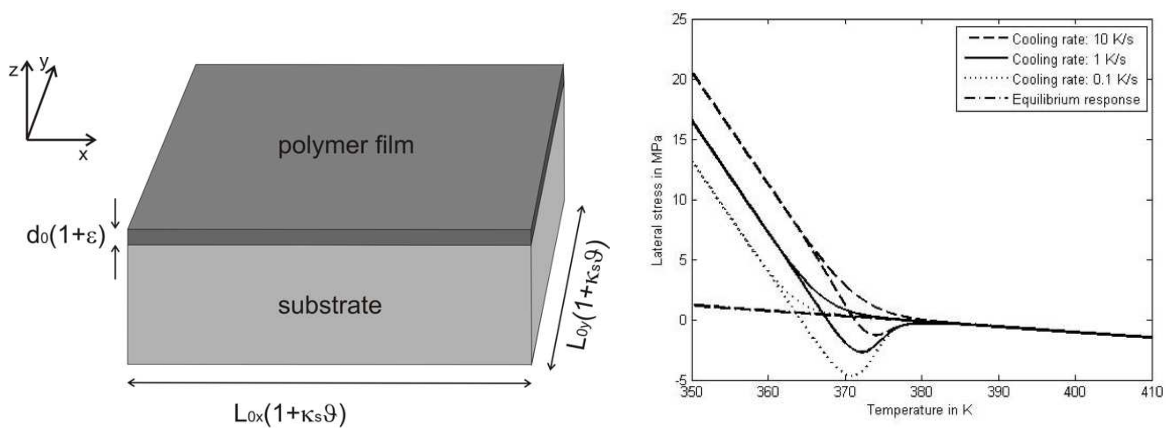

Fig. 1. Sketch of the geometry and cooling rate-dependent lateral stresses in the film

In the presentation, a novel constitutive approach is applied and adapted to simulate and to analyse the temperature rate-dependent response behaviour of constrained thermoviscoelastic films. The focus of the presentation is the physical understanding of the film behaviour and the interpretation of the simulated results. The theory is just shortly discussed. The highlights of this study can be summarized as follows:

- Explicit relations are obtained for the specific heat of the supported film, the normal strain and the lateral stress.
- The magnitude of the lateral stress at temperatures below the glass transition depends strongly on the cooling rate (see Fig. 1).
- The specific heat of the supported film is principally different from the isobaric specific heat of the stress-free bulk material.

- The glass transition temperatures of the constrained film and the stress-free bulk material are nearly equal.

If the model is reduced to the special case of linear thermoelastic films, then simple relations for the specific heat of the film (is the isobaric specific heat of the free polymer film), the lateral stress and the normal strain can be derived:

$$\begin{aligned} \sigma &= \frac{-E_0\,(\kappa_0-\kappa_s)}{1-\nu_0}\,\vartheta,\; \epsilon = \left(\kappa_0 + \frac{2\,\nu_0}{1-\nu_0}\,(\kappa_0-\kappa_s)\right)\vartheta \\ c_{\mathrm{F}} &= \left(1+\frac{\vartheta}{\theta_{\mathrm{ref}}}\right)\left(c_{\mathrm{p0}} - \frac{2\,E_0\,\kappa_0\,\theta_{\mathrm{ref}}}{\rho(1-\nu_0)}(\kappa_0-\kappa_s)\right) \end{aligned} \tag{1}$$

As it can be seen, all these quantities depend on the difference between the thermal expansion coefficients of the substrate and the film.

Numerical modeling of a hydrogel diffraction grating on a substrate used for pH sensing

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Abstract. Many engineering applications involve stimuli-responsive hydrogels that swell under the constraint of hard materials or substrates. The hydrogels are networks of polymers that can imbibe a solution and swell under the action of different stimuli such as light, temperature, magnetic field or pH. One of numerous applications of a pH-sensitive hydrogel is a diffractometric biochemical sensor reported in [1]. It is composed of a hydrogel diffraction grating situated on a hard substrate. The aim of the present study is to develop a numerical model of such a bi-material device. A diffraction grating on a substrate is analysed. The grating is made of a pH-sensitive hydrogel that is capable of swelling or shrinking with pH changes. The system is modeled using the approach proposed in [2]. Note that measurement of pH of a solution is possible by comparing the photonic properties of smart hydrogel gratings before and after swelling due to the pH changes. In other words, it is possible to link the reflected beam measurement with the pH value. First, the hydrogel grating deformation is calculated as a function of the pH. Further, the diffraction intensities are analysed for different hydrogel grating deformations. A comparison between the numerical results and experimental measurements from the literature [1] is carried out to validate the developed model. The proposed model allows studying and predicting the mechanical and photonics behavior of the smart hydrogel gratings connected to substrates for pH-detection.

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Micromechanical modeling of short fiber reinforced composites with orientation data

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Abstract. Nowadays, short fiber reinforced plastics play a crucial role in the construction process. By using this class of material, the design engineer can not only benefit from the advantageous ratio of stiffness to weight in comparison to the pure materials like polypropylene or glass but also from the possibility of a low-cost manufacturing. Components made of short fiber reinforced plastics are usually fabricated by an injection or compression molding process.

Apart from the orientation distribution of the reinforcing fibers, the particular manufacturing process influences as well the geometry and spatial distribution of the fibers. With respect to the microstructural properties, short-fiber reinforced polymers show, therefore, heterogeneities on different length scales which results in a topological dependence of the mechanical properties [1].

The variation of the microstructural parameters like orientation and aspect ratio of a single fiber requires a consideration of these characteristics in the context of a micromechanical approach. Hence, besides a two step approach, the self-consistent method is utilized to get the elastic properties of several microstructures. For that reason, specific artificial microstructures are considered which statistically represent different positions of a part fabricated by injection molding [2].

Furthermore, for an experimentally determined orientation distribution, the effective elastic properties are calculated and the local fiber stresses are discussed.

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Modelling the deformation behaviour of a twill-weave-reinforced thermoplast using the angle bisector framework

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Abstract. Twill-weave-reinforcements offer a good compromise regarding structural performance, handling and draping behaviour. Therefore, they are well suited for load carrying structures based on fiber-reinforced polymers with complex 3D geometries. Being formed into 3D geometries the twill weave deforms permanently by local changes in fiber angle. This manufacturing effect has a significant impact on the local, as well as overall mechanical behaviour of the resulting composite structure and has, therefore, to be considered within finite element simulation. Aiming at describing the deformation behaviour efficiently while taking into account local changes in fiber angle, the angle bisector framework has been identified as a suitable basis for the material formulation. Regardless of the local fiber angle, it offers the possibility to describe each layer of the woven composite as a homogenized orthotropic continuum. However, material properties such as stiffness and strength vary with the change in angle and have, therefore, to be formulated in relation to the fiber angle. Within this work the deformation behaviour of a carbon fiber twill-weave-reinforced polyamide 6 has been characterized in order to evaluate the ability of the angle bisector framework to model this behaviour accurately and efficiently. Therefore, quasi-static tension and compression tests have been carried out in different material directions and at different loading speeds to investigate the visco-elastic-plastic behaviour and to determine the elastic constants of the orthotropic material system. Furthermore, tensile tests featuring loading-unloading cycles have been carried out in the angle bisector directions in order to determine the influence of fiber rotation effects under loading.

In-situ study of compressive damage evolution in metal/ceramic composites based on freeze-cast ceramic preforms

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Abstract. Metal/ceramic composites fabricated by infiltrating freeze-cast ceramic preforms have a random domain structure in the plane orthogonal to the preform freezing direction. Within each domain the alternating metallic and ceramic lamellae lie almost parallel to each other. The aim of this study is to investigate the effect of orientation of the domains with respect to the direction of compressive stress application on the mechanism of damage evolution. Compression tests were carried out on samples having one, two and multiple domains in-situ inside a scanning electron microscope. The extent of damage was measured by counting the number of cracks at specific locations on the sample surface at various applied stresses. Results show that the orientation of the lamellae with respect to the loading direction strongly influences the composite behavior. When loaded parallel to the lamellae the composite is strong and brittle; however, when the lamellae orientation is more than 30 ° the composite is soft and ductile and shows a metallic alloy controlled behavior. In samples having two and multiple domains the damage predominantly occurs in regions with softer orientations. The following primary damage modes have been identified: longitudinal cracking of the ceramic lamellae at 0-10 °, interfacial shear failure at 10-30 ° and transverse cracking of the ceramic lamellae and shear cracks within the metallic lamellae joining two transverse ceramic cracks at lamellae orientations 30-90.

A cell model study of ternary polymer blends

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Abstract. Like many engineering materials, polymer blends have a heterogenous microstructure that affects the macroscopic behaviour. The polymer blend under consideration here is PC/ABS (polycarbonate/acrylonitrile-butadiene-styrene), a widley used industrial thermoplastic. A remarkable benefit of PC/ABS blends is their enhanced fracture toughness which accrues from complex micromechanical deformation processes. To gain a better understanding of these processes in perspective of predicting macroscopic effects like fracture and failure, a cell model study of the fully resolved three-phase microstructure is conducted. While the two thermoplastic constituents, polycarbonate and styrene-acrylonitrile, are individually described utilizing the visco-plastic Boyce model, the soft rubber particles (butadiene) are treated as voids. From the cell model subjected to uniform macroscopic loading, the effect of the composition on microscale deformation processes is analyzed numerically. Furthermore, results in terms of local as well as macroscopic quantities are qualitatively interpreted with respect to the macroscopic failure behaviour.

Numerical Evaluation of Fiber Composites Accounting for Delamination

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Abstract. In this paper, we consider fiber composites consisting of several layers, each of which is composed of a woven fabric embedded in a matrix material. The according constitutive behavior is anisotropic and typically highly nonlinear. Furthermore, the material's response in tension and compression can differ significantly. In order to capture this rather complex behavior, we use a micromechanically motivated model developed by Reese [1]. In this model, the directions of the fibers are represented using the concept of structural tensors, making it particularly suitable for fiber reinforced composites.

The use of a fully three-dimensional material model strongly suggests using solid elements. On the other hand, fiber composites are mostly applied in thin shell-like structures, where shell elements should usually be preferred. Therefore, we use the solid-shell element proposed by Schwarze et al. in [2], which combines the advantages of both solid elements and shell elements at the same time.

In addition, a reduced integration scheme is used within the shell plane, whereas a full integration is used in thickness direction. Thus, an arbitrary number of integration points can be chosen over the shell thickness. This is advantageous, because it allows an accurate prediction of the stress distribution in thickness direction, which is important if delamination of different layers of the composite shall be considered. Therefore, the proposed element is especially suitable, since the through-the-thickness stress distribution can be computed accurately even in thin shell-like structures.

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Modeling of the Deformation and Fracture Behavior of Short Fiber Reinforced Plastics - Potential and Limitations

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Abstract. In the last decade, several authors have successfully predicted damage and strength of composite materials with mean-field homogenization models (e.g., [1, 2, 3]). These micromechanical models are based on the Eshelby solution for spherical inclusions embedded in a matrix and they allow the calculation of the mean stresses and strains in the constituents. These mean values are commonly the starting point for progressive damage and failure modeling. In the authors´ contribution an incremental mean-field approach is chosen to calculate the elasto-plastic behavior of composites with arbitrarily dimensioned inclusions. Furthermore, the implemented model offers the possibility to consider a non-unidirectional composite as a composition of weighted unidirectional sub-domains. The authors show, that the mean values for stresses and strains of the constituents of a representative volume element are in good accordance with the results achieved by the chosen mean-field homogenization model. As a new feature, the implementation is extended to be able to consider the existing strain and stress distribution based on the calculated mean values, the inclusions dimension and orientation as previously shown in [4]. Since it is well known, that this distribution and especially the local maximums are dominant for failure and the plastic composite behavior, they are of special interest in engineering applications like strength prediction. Hence, the developed model is applied to a short-fiber reinforced polymer composite in combination with known failure models.

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