Annual Report
2014

Chair of Applied Mechanics
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Prof. Dr.-Ing. Kai Willner
Prof. Dr.-Ing. Julia Mergheim
Friedrich-Alexander-Universität Erlangen-Nürnberg

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Editors: D. Süß, F. Wurmer

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1 Preface

This annual report briefly documents the scientific, teaching and social activities at the Chair of Applied Mechanics at the University of Erlangen-Nuremberg during 2014. At the scientific side the never ending enthusiasm of all members of the Chair did indeed result in exciting research and correspondingly in an internationally recognized output in terms of publications and conference contributions. Likewise the demanding teaching load, e.g. some several thousand written exams that require correction, could only be carried due to the amazing level of dedication exhibited by all members of the Chair. Of course all these efforts in turn fully justify team building activities in terms of excursions, summer barbecues and various types of parties that characterize the social life at the Chair. In summary we hope that this report convinces the reader of the level of academic achievements at the Chair of Applied Mechanics during the past year.

Paul Steinmann, Kai Willner, Julia Mergheim

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Professorship for Continuum Mechanics:
Prof. Dr.-Ing. habil. Paul Steinmann (Head of the Chair)

Professorship for Structural Mechanics:
Prof. Dr.-Ing. habil. Kai Willner

Professorship for Computational Mechanics:
Prof. Dr.-Ing. Julia Mergheim

Emeritus:
Prof. Dr.-Ing. habil. Günther Kuhn


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K. Willner


J. Mergheim

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Dipl.-Ing. (FH) Dieter Pausewang
Dipl.-Betriebswirtin (FH) Ingrid Welsing


C. Bänsch


A. Brütting


S. Lässig


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I. Welsing

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Denis Davydov, Ph.D.	
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Dipl.-Math. Jan Friederich	
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Dipl.-Ing. Stefan Käßmair	
Dipl.-Technomath. Philipp Landkammer	
Dipl.-Ing. Vera Luchscheider	
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Dipl.-Math. techn. Gunnar Possart	
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Daniel Riedlbauer, M.Sc.	
Dipl.-Ing. Stefan Riehl	
Saba Saeb, M.Sc.	(since 01.09.14)
Prashant Saxena, Ph.D.	(until 27.06.14)
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Dipl.-Ing. Stefan Schmaltz	
Dipl.-Technomath. Ulrike Schmidt	(until 31.10.14)
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Dipl.-Technomath. Franziska Vogel	(until 15.08.14)
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Jiong Wang, Ph.D.	(until 30.06.14)
Reza Zabihyan, M.Sc.	(since 01.10.14)


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S. Budday


D. Davydov


F. Endres


A. Esmaeili


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A. Javili


M. Jerschl


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P. Landkammer


V. Luchscheider


M. Mehnert


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S. Pfaller


G. Possart

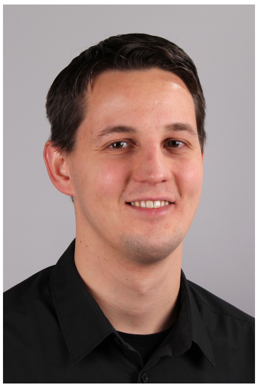

D. Pivovarov


D. Riedlbauer


S. Riehl


S. Saeb


P. Saxena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U. Schmidt


O. Schmitt


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B. Söhngen


F. Vogel


B. Walter


J. Wang


R. Zabihyan

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Dipl.-Ing. Wolfgang Steinbach	(until 15.05.14)


M. Roux


W. Steinbach

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Dipl.-Phys. Patrick Schmitt
Dipl.-Ing. Jürgen Metzger
Dipl.-Ing. (FH) Paul Wilhelm

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Hesam Kandelousi, M.Sc.
Andrew McBride, Ph.D.
Amirtham Rajagopal, Ph.D.
Prof. Dr. Bozidar Sarler
Prof. Dr. Matjaz Hribersek
Prof. Dr. Ghodrat Karami
Prof. Dr. Gennady Mishuris
Prof. Dr. Zoran Ren
Prof. Dr. Leopold Skerget

Assistant lecturer

Dr.-Ing. Karsten Kolk
PD Dr.-Ing. Ralf Meske

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Wurmer, Florens	Zabihyan, Reza	Zilker, Julian
Zint, Daniel		

Student assistants are mainly active as tutors for young students in basic and advanced lectures at the BA- and MA-level. Their indispensable contribution to high quality teaching at the Chair of Applied Mechanics is invaluable, thus financial support from various funding sources is gratefully acknowledged.

3 Scientific Reports

The following pages allow a short overview on the various ongoing research projects pursued at the Chair of Applied Mechanics during 2014. These are mainly financed by third-party funding of various (public and industrial) funding sources and are in addition supported by the core support of the university. Topicwise we have a nice mix of continuations of previous projects with projects that started afresh in 2014. Also the complementing expertise as displayed in the three professorships for continuum mechanics, structural mechanics and computational mechanics established at the Chair of Applied Mechanics is reflected by the variety of research that is performed. This spans from atomistic approaches to material modeling, from experimental investigations to computational challenges and from frictional contact to structural problems. Of course the research on these topics constantly produces new insights, thus the following reports can only shed a spot-light on the current state of affairs.

Constitutive friction law in sheet-bulk metal forming (SBMF)

Florian Beyer, Kai Willner

Friction has a remarkable impact on metal forming both in economic and technical terms. This is particulary true for SBMF which applies bulk forming on semi-finished sheets. The forces acting in such a process can be moderate making Coulomb's friction law applicable, but also very high for which Tresca's law of friction is advisable.

A bypass for this issue is the development of a constitutive friction law (CFL) which is suited both for low and high contact loads. It was derived from several contact configurations of rough surfaces that were simulated in an elastic-plastic half-space model. The CFL consists of the two equations

$$\tau_r = m \cdot k \cdot \alpha_{rc} = m \cdot k \cdot \sqrt[n_1]{\tanh\left(\frac{p \cdot C_1}{H}\right)^{n_1}}$$

and

$$\tau_r = m \cdot k \cdot \sqrt[n_2]{\tanh\left(\frac{p \cdot C_2}{H \cdot \alpha_{rc}\left(p_{his}\right)}\right)^{n_2}} \cdot \alpha_{rc}\left(p_{his}\right).$$

The first equation treats contact at first loading and the second equation is applicable for un- and reloading. The parameters C_1, C_2, n_1 and n_2 are evaluated with the half-space model. As the CFL is based on a local law of Tresca, m is the corresponding friction factor and k the shear strength of the softer material. Similar to Coulomb's law, the resulting shear stress τ_r depends on the local acting normal load p. Furthermore, H is the surface hardness and p_{his} is the maximum historic normal load.

In order to see the differences between the CFL and conventional friction laws, the CFL was implemented with an user-code written in Fortran into the commercial software Simufact.forming 12.0.1. A well-established SBMF process which aims to form cups with integrated external gearing teeth in a single-stroke process through the combination of deep drawing and upsetting was chosen as simulation model. The forming degree φ after the simulation of a segment of the workpiece is shown in Fig. 1 and Fig. 2, whereas Fig. 1 was simulated with the CFL and Fig. 2 with Tresca's law of friction. The differences support the recommendation of the CFL.

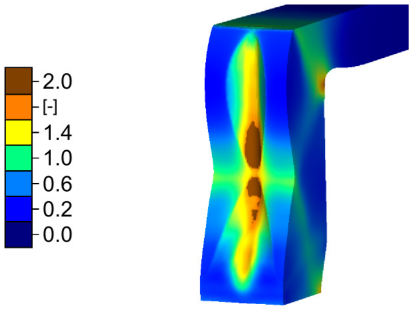


Figure 1: φ with CFL

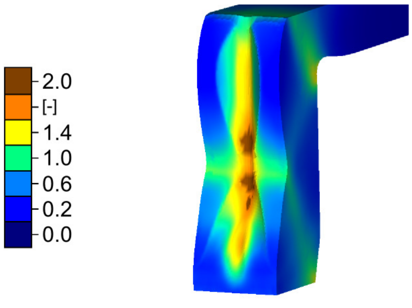


Figure 2: φ with Tresca's law

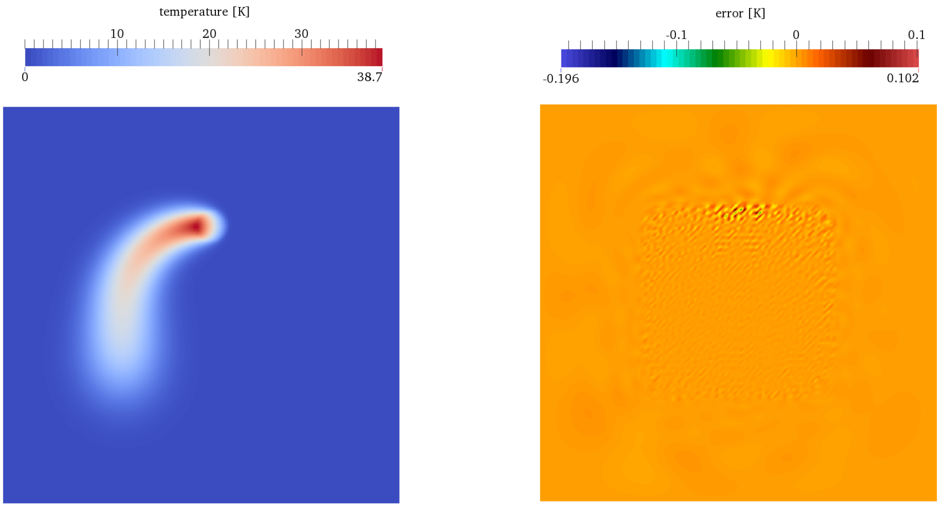
This work is supported by the German Research Foundation (DFG) within subproject C1 of the transregional collaborative research centre (Transregio) 73 "Sheet-bulk-metal-forming".

Reduced-Order Modelling using Proper Orthogonal Decomposition

Benjamin Brands, Paul Steinmann, Julia Mergheim

The purpose of Reduced-Order Modelling (ROM) is to substantially reduce the computational cost of a numerical simulation. In this context the Proper Orthogonal Decomposition (POD) is used to extract linearly independent basis functions from given data, e.g. previously computed simulations. The POD ensures optimality of the approximation in a least square sense [2] and the basis functions are later used for Galerkin projection of the governing equations. The connection between the POD method and singular value decomposition in the Euclidean space $\mathbb{R}^m$ can be found in [1].

The ROM has been applied to the linear heat equation and the equations of linear thermoelasticity. Fig. 1a displays the thermal solution of linear thermoelasticity in 2D for a moving heat source at a certain time step computed with ROM.



(a) (b)

Figure 1: Results of ROM

The temperature field of the reduced model is compared with a conventional FEM simulation which is taken as reference solution. The absolute error $\Delta\theta^{\text{err}} = \theta^{\text{FEM}} - \theta^{\text{ROM}}$ of the temperature field displayed in fig. 1b is acceptable with respect to a reduction of the total number of degrees of freedom from roughly 198000 (FEM) to 6237 (ROM).

It could be observed that the number of basis functions to be taken into account is almost independent of the mesh size. This is an advantage of ROM using POD as the computational costs of the reduced model do not directly increase with the request for higher accuracy.

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The role of mechanics during brain development

Silvia Budday, Paul Steinmann, Ellen Kuhl

Mammalian brains display a wide variety of shapes and surface morphologies which are closely correlated to neuronal activity. The folding pattern serves as clinical indicator for physiological and pathological conditions. Yet, the regulators of pattern formation in evolution and development remain poorly understood. We hypothesize that mechanical instabilities induced by differential growth - with a faster growing outer layer, the cortex, and slower growing inner layers, the subcortex [1] - drive brain folding.
We establish a continuum model of differential growth by multiplicatively decomposing the deformation gradient $\boldsymbol{F} = \boldsymbol{F}^{\mathrm{e}} \cdot \boldsymbol{F}^{\mathrm{g}}$ and the volume change $J = \det(\boldsymbol{F}) = J^{\mathrm{e}}\, J^{\mathrm{g}}$ into a reversible elastic part and an irreversible growth part. For simplicity, we assume that growth is purely isotropic and the growth tensor is parameterized in terms of a single scalar-valued growth multiplier ϑ, $\boldsymbol{F}^{\mathrm{g}} = \vartheta \boldsymbol{I}$. We let the cortex grow morphogenetically at a constant rate $\dot{\vartheta}_{\mathrm{c}} = G_{\mathrm{c}}$. The subcortex only grows when stretched ($J^{\mathrm{e}} > 1$) at a stretch-dependent rate $\dot{\vartheta}_{\mathrm{s}} = G_{\mathrm{s}}(J^{\mathrm{e}} - 1)$ [3], which mimics the chronic elongation of subcortical cells when stretched beyond their physiological limit. By simulating the evolution of complex instability patterns in the post-critical regime, we show that mechanics play a major role in pattern selection. The model further provides mechanistic interpretations of malformations [2]. Understanding the process of cortical folding in the mammalian brain has direct implications on the diagnostics of neurological disorders such as schizophrenia and autism.

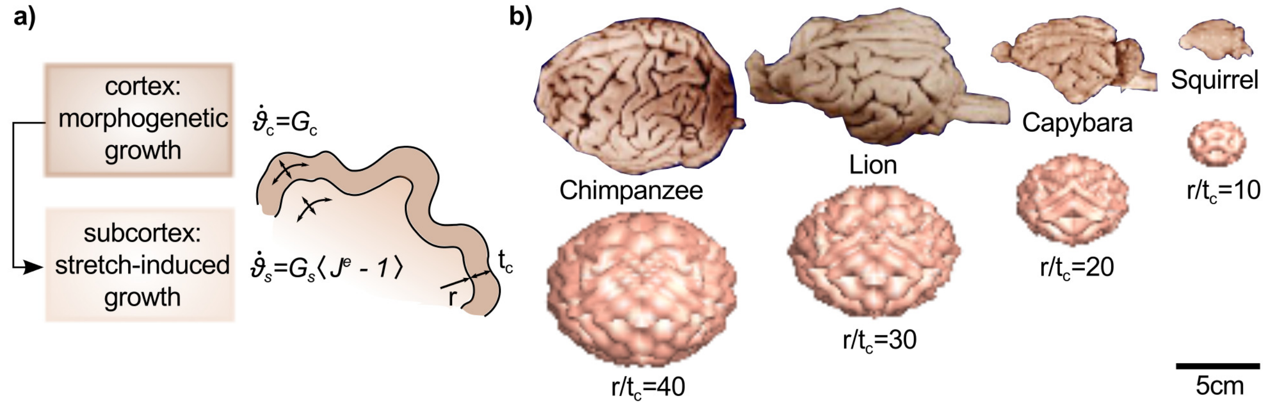

Figure 1: a) Continuum model for brain growth. b) Mammalian brains of different size and corresponding numerical simulations. Cortical complexity increases with brain size.

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[1] P.V. Bayly et al. "A cortical folding model incorporating stress-dependent growth explains gyral wavelengths and stress patterns in the developing brain". *Physical biology* 10.1 (2013), p. 016005.

[2] S. Budday, C. Raybaud, and E. Kuhl. "A mechanical model predicts morphological abnormalities in the developing human brain". *Scientific reports* 4 (2014).

[3] S. Budday, P. Steinmann, and E. Kuhl. "The role of mechanics during brain development". *Journal of the mechanics and physics of solids* 72 (2014), pp. 75–92.

Adaptive Finite Element solution of the Kohn-Sham equations

Denis Davydov, Paul Steinmann

Properties of matter, such as electric conductivity, magnetizm, and mechanical response under applied loads are ultimately determined by its electronic structure. The latter can be obtained by solving the Schrödinger wave equation: $\hat{H}\psi_\alpha = \lambda_\alpha \psi_\alpha$, that represents a quantum mechanical many-body eigenvalue problem. The exact solution to this problem can be obtained for a single hydrogen atom only. Many of the physical properties of condensed matter systems are dictated by its ground state. One of the most successful and widely adopted approaches to obtain the ground state of electronic structure theoretically, is within the context of Density Functional Theory (DFT) of Kohn and Sham [3].

The adaptive Finite Element (FE) analysis of the Kohn-Sham equations was implemented [2] using the open-source Differential Equations Analysis Library (`deal.ii`) [1]. A FE basis set has a number of significant advantages: (i) It can account for arbitrary geometries and arbitrary boundary conditions; and (ii) the strict locality of the FE basis, and the sparse matrices that arise from it, facilitates parallelization of the problem and distributed computing. As an example of calculations using FE, consider a hydrogen molecule ion (Fig. 1). The molecule H2+ is a two H nuclear system with bound one electron.

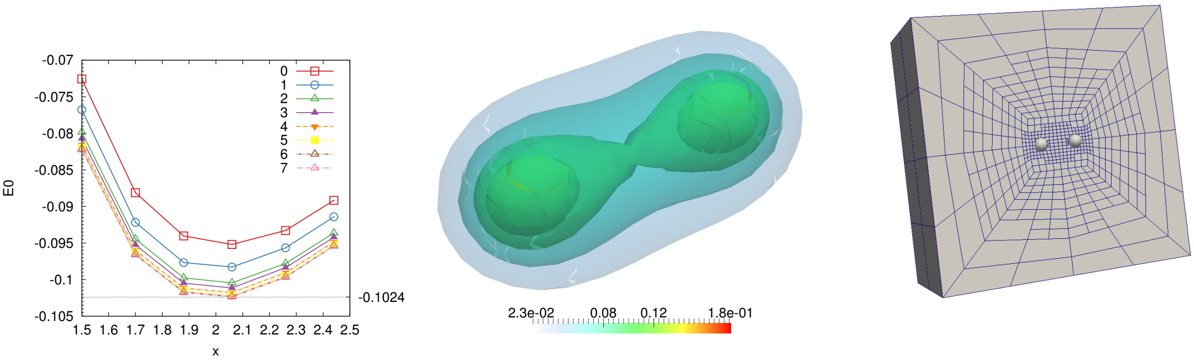

Figure 1: FE calculations of hydrogen molecule ion. (left) change of the bond energy with *a posteriori* refinement; (middle) electron density at the equilibrium configuration; (right) cut of the FE mesh.

The ultimate goal of this project is to develop an adaptive FE solution of the KS equations that not only provides good accuracy at modest numerical cost, but also scales well to large problems, thus making calculations on super computers more efficient.

References

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Extended molecular statics for the simulation of electromechanical continuum response of ferroelectric materials

Florian Endres, Paul Steinmann

Smart materials are of great interest not only for scientific, but also for technological reasons due to miniaturization and rapid developments in manufacturing technologies of nanocomponents. Therefore atomistic simulations will become more important in the future, not only to predict the complex behaviour of smart materials such as ferroelectrics, but also to understand material on the atomistic length scale in general. Since classical atomistic simulations are limited by their computational costs, we developed an efficient molecular statics algorithm including a new methodological ansatz for the calculation of continuum deformations of discrete particle systems in analogy to the Parrinello-Rahman method. Therefore, our extended molecular statics algorithm computes not only the dielectric hysteresis but also the butterfly hysteresis of ferroelectric crystals [1].

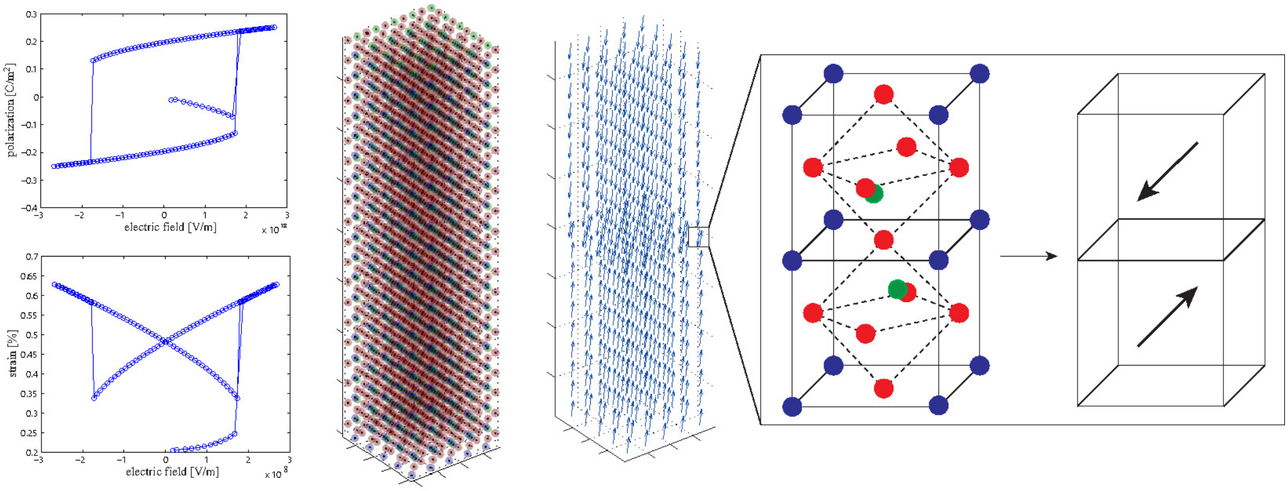

Figure 1: Dielectric hysteresis, butterfly hysteresis and head to head nanodomain of a ferroelectric BTO crystal.

Furthermore, the developed algorithm is an excellent tool to investigate size effects and interfaces of nanodomains as shown in figure 1. Therefore size effects of 180° head-to-head nanodomains have already been investigated [2]. In a next step the developed algorithm will be used to further investigate discrete multidomain particle systems and their macroscopic continuum response under electromechanical loading.

References

[1] F. Endres and P. Steinmann. “An extended molecular statics algorithm simulating the electromechanical continuum response of ferroelectric materials”. *Computational Mechanics* 54.6 (2014), pp. 1515–1527.

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Thermomechanical coupling of geometrically non-coherent interface

Ali Esmaeili[1], **Ali Javili**[2], **Paul Steinmann**[1]

[1]Chair of Applied Mechanics, Friedrich-Alexander University Erlangen-Nuremberg
[2]Department of Civil and Environmental Engineering, Stanford University

An evacuated (vacuum) tube collector is a device in solar panels to collect solar energy and is composed of a vacuum glass tube forged to a metal tube (heat tube) creating an interface to preserve the vacuum. The interface undergoes thermal cyclic and pressure loading. Because of the importance of preserving the vacuum, exploring different design alternatives to perform such a forging has been the starting point to come up with a general finite element framework for the thermomechanical modeling and simulation of non-coherent interfaces.

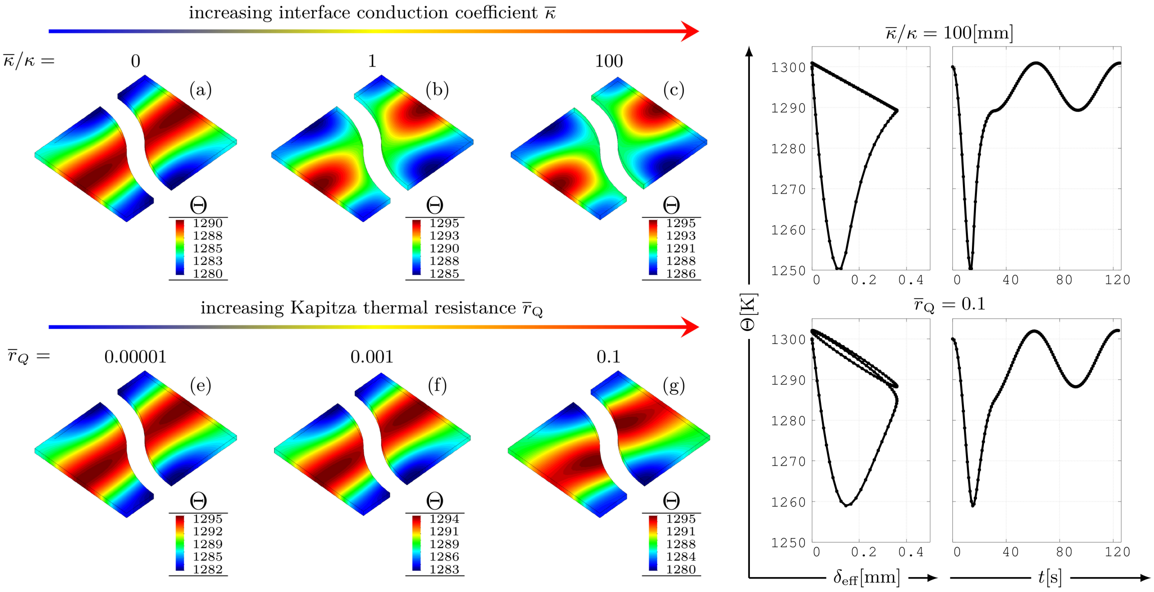

Figure 1: The influence of the interface conduction coefficient and Kapitza resistance on the overall temperature distribution of a *highly-conductive* and *Kapitza* interface.

Two case scenarios are considered here [1, 2] . A highly-conductive interface assumes no jump in temperature. However the jump of the heat flux across the interface exists due to the presence of heat flux along the interface $[\![\boldsymbol{Q}]\!] \cdot \overline{\boldsymbol{N}} = -\overline{\mathrm{Div}}\,\overline{\boldsymbol{Q}}$. A generalized Kapitza interface assumes no heat flux across the interface. However a jump in temperature is allowed. Increasing the Kapitza resistance $\overline{r}_{\mathrm{Q}}$ causes a more pronounced jump in the temperature across the interface. To justify the above observation one should notice the relation between the temperature jump and the average of the heat flux across the interface $[\![\Theta]\!] = -\overline{r}_{\mathrm{Q}}\{\!\{\boldsymbol{Q}\}\!\} \cdot \overline{\boldsymbol{N}}$. In general temperature evolution of a Kapitza interface (see the graphs) shows the same trend as the highly-conductive interface does except for the higher dissipation of the Kapitza interface.

References

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On the homogenization of technical textiles

Sebastian Fillep, Julia Mergheim, Paul Steinmann

Rope-like textiles are applied in architecture and mobility e.g. for bridges or cable cars. For other applications e.g. for climbing ropes, the flexibility plays an important role. Due to the variety of processable materials even bio-compatible structures for medical applications, e.g. surgical material, can be found. Beside the fiber material the arrangement of the fibers play an important role for the effective behavior of the rope.
On the macroscopic level rope-like textiles are characterized by a large length-to-thickness ratio, such that a discretization with beam elements is numerically efficient. For the macroscopic behavior the micro-structural assembly of the fibers plays an important role. To capture the contact behavior the representative volume element is explicitly modeled by means of a volumetric micro sample. On the macro level the rope can be considered to be homogeneous. To connect the heterogeneous micro level with the macro level a specific homogenization scheme is developed. In general, the homogenized macroscopic material behavior is nonlinear depending on the heterogeneous micro structure. By application of suitable homogenization techniques information can be transferred between the scales [1, 2]. The micro and the macro scale are then connected by requiring equality of the internal macro and micro power densities.

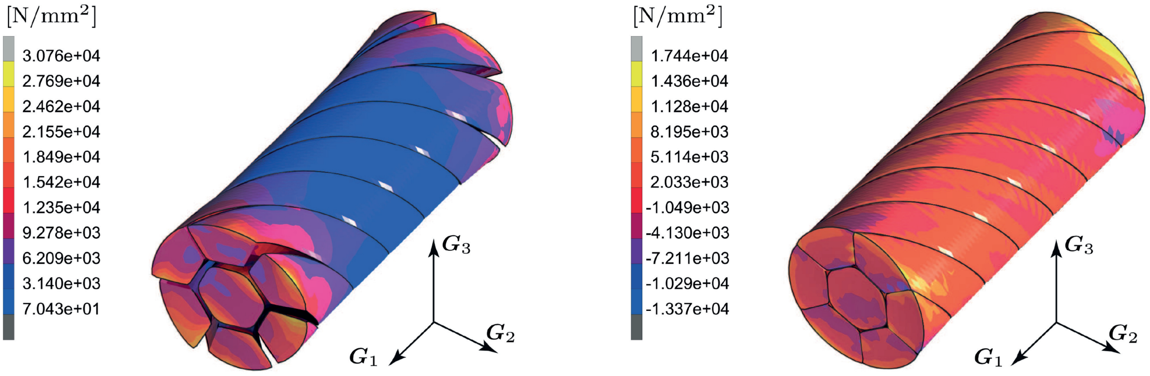

Figure 1: Model of a compacted braid consisting of seven fibers. Von Mises stress plot in the deformed state with a torsional deformation against the drilling direction (left) and with the drilling direction (right).

As depicted in Figure 1a the drilling of the fiber assembly i. e. the drilling direction of the considered braid has a significant influence the stress state and therewith the effective behavior of the rope structure. A torsional loading against the drilling direction results in gaps between the fibers while a torsional deformation in drilling direction results in a compression of the fibers and a more homogeneous stress state. With the data gathered on the micro level the macroscopic boundary value problem can be solved.

References

[1] S. Fillep, J. Mergheim, and P. Steinmann. “Computational homogenization of rope-like technical textiles” (2014), submitted.

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Sensitivities for topological changes in finite element meshes and application to anisotropic adaptive refinement

Jan Friederich, Günter Leugering[1]**, Paul Steinmann**

[1]Chair of Applied Mathematics 2, Friedrich-Alexander-Universität Erlangen-Nürnberg

We consider adaptive h–refinement as the result of a continuous operation on the edge graph of the finite element discretization, for instance by splitting nodes along edges and expanding edges to elements. This allows for the derivation of sensitivies of a given objective function, which may in turn be used for the definition of refinement indicators [1]. In this context, a particular objective function of interest is the total potential energy, minimization of which is related to the reduction of the energy error.

In particular, this concept leads to new approaches in anisotropic refinement: Considering refinement of an edge $E = (\boldsymbol{x}_i, \boldsymbol{x}_j)$ by splitting either one of the two adjacent nodes $\boldsymbol{x}_i$ or $\boldsymbol{x}_j$, we obtain two sensitivies for the insertion of a new node on edge E. Based on this, we define an anisotropic refinement indicator which approximates the reduction of the energy error depending on the position of the new node [2]. This enables optimal positioning of new nodes during refinement, see Fig. 1 for a numerical example. However, in an iterative adaptive algorithm the regularity of the mesh has to be maintained by using for instance edge swapping, edge collapsing or r–adaptive methods in addition. In this context, a further extension of our approach will investigate sensitivies for coupled rh–refinement.

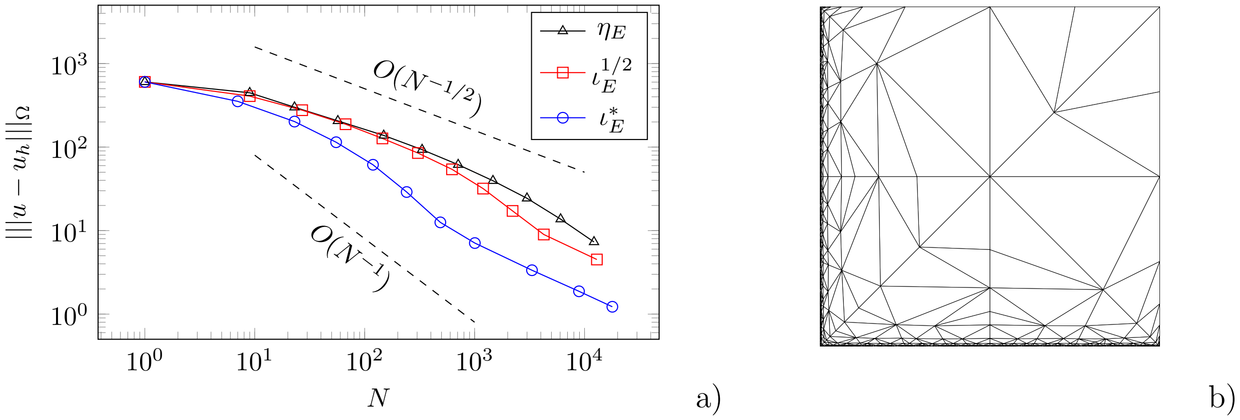

Figure 1: Adaptive algorithm for the reaction-diffusion equation $-\Delta u + \kappa^2 u = 0$ on $\Omega = (0,1)^2$ with Dirichlet boundary data determined from the exact solution $u(x,y) = e^{-\kappa x} + e^{-\kappa y}$ for $\kappa = 1000$. a) Energy error $|||u_h - u|||_\Omega$ vs. number of degrees of freedom N on meshes generated by adaptive algorithms based on ι_E^* (optimal node placement on edge E), $\iota_E^{1/2}$ (bisection of edge E), and the explicit residual-based error estimator η_E (using newest vertex bisection for refinement). b) Mesh generated by ι_E^* with $N = 368$.

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Modeling and simulation of the mechanical behaviors of gels

Sandrine Germain, Paul Steinmann

The aim of the project is to define a material model in order to describe the mechanical behaviors of swollen, superabsorbent polymers. When a solvent enters in contact with a superabsorbent polymer, a material with similar properties as a swollen gel is created. In order to model the mechanical behaviors of a swollen gel, it is usual to decompose the deformation gradient into a mechanical and a swollen part (see for example [1, 3])

$$\boldsymbol{F} = \boldsymbol{F}_m \cdot \boldsymbol{F}_s.$$

The swollen part can be modeled by exploring the volume fraction of the swollen gel over the dry polymer. Furthermore, in order to take into account volume changing and volume preserving deformations, as usual for highly compressible, hyperelastic materials (see for example [2]), the mechanical deformation gradient is defined as

$$\boldsymbol{F}_m = \boldsymbol{F}_m^{vol} \cdot \boldsymbol{F}_m^{iso}.$$

Within a hyperelastic formulation, the free energy density function is outlined by a fully decoupled, additive, volumetric-isochoric decomposition

$$\Psi_m(J_m, \boldsymbol{F}_m^{iso}) = \Psi_m^{vol}(J_m) + \Psi_m^{iso}(\boldsymbol{F}_m^{iso}),$$

where J_m is the Jacobian determinant of the mechanical deformation gradient $\boldsymbol{F}_m$. With the presented kinematics, free energy density function and the use of the first and second laws of thermodynamics, a dissipation inequality is obtained and a constitutive equation for the first Piola–Kirchhoff stress tensor $\boldsymbol{P}$ is achieved

$$\boldsymbol{P} = -pJ\boldsymbol{F}^{-T} + \frac{\partial \Psi_m^{iso}(\boldsymbol{F}_m^{iso})}{\partial \boldsymbol{F}}.$$

It can be seen, that the first Piola–Kirchhoff stress tensor $\boldsymbol{P}$ is also fully decomposed into a volumetric part and an isochoric part. The volumetric part depends on the hydrostatic pressure $p = f(J_m)$, which is a function of J_m. J is defined as the Jacobian determinant of the deformation gradient $\boldsymbol{F}$. The isochoric part can be completed by taking free energy density functions from the literature. From the definition of the first Piola–Kirchhoff stress tensor, the second Piola–Kirchhoff stress tensor and the corresponding tangent stiffness matrix can be established for the use in finite element analysis. The above, hyperelastic model for swollen gels will be extended to viscoelastic and visco-elasto-plastic behaviors.

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A multi-scale approach to model the curing process in magneto-sensitive polymeric materials

Mokarram Hossain, George Chatzigeorgiou, Fodil Meraghni, Paul Steinmann

A magneto-mechanically coupled multi-scale model for simulating the curing process of polymers has been proposed. In the case of magneto-sensitive polymers, micron-size ferromagnetic particles are mixed with a liquid polymeric matrix in the uncured stage. The polymer curing process is a complex process that transforms a fluid to a solid with time. To transfer the constituent parameter information from the micro-scale to the macro-scale for a composite magneto-mechanically coupled polymeric material, an extended Mori-Tanaka semi-analytic homogenization procedure is utilized [1]. The stiffness gaining phenomenon as in the case of a curing process is realized by time-dependent material parameters appearing within the composite piezomagnetic material tensors. To compute the volume reduction during curing, a magnetic induction dependent shrinkage model is proposed. Several numerical examples show that the homogenized parameters of the composite can be obtained using the model, cf. Fig (1). Moreover, the proposed model can capture major observable phenomena in the curing process of polymers under magneto-mechanically coupled infinitesimal deformations [3, 2].

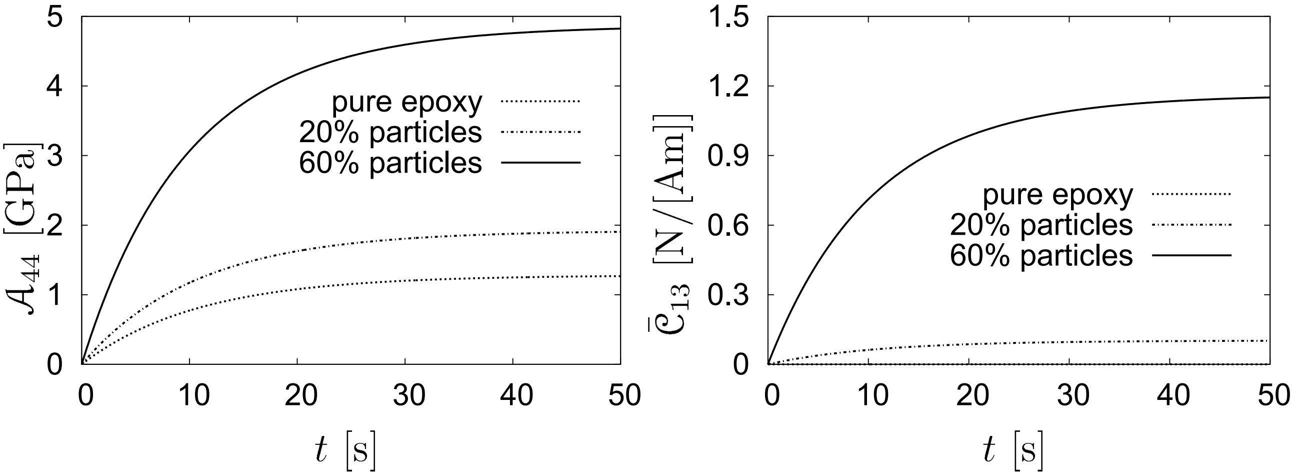

Figure 1: Evolution with time of macroscopic a) shear modulus in the 2-3 direction, b) magnetic permeability in the 1 direction and c) coupled term $\bar{\mathcal{C}}_{13}$.

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Towards modelling the curing process in particle-filled electro-active polymers

Mokarram Hossain, Paul Steinmann

In dielectric elastomers, a large actuation voltage is required to produce a desired mechanical deformation. To reduce the amount of the actuation voltage, several mechanisms can be applied and the inclusion of high dielectric permittivity fillers in the matrix material in the uncured stage is one of them. Moreover, to obtain a maximum advantage from the high dielectric permittivity fillers, an electric field is applied during the curing process which helps the particles to align in a preferred direction. The polymer curing process is a complex viscoelastic phenomenon where a liquid polymer gradually transforms into a solid due to cross-linking of the initially short polymer chains. This phase transition comes along with an increase in material stiffness and a volume shrinkage. Such stiffness gaining is modelled by an appropriate constitutive relation where the temporal evolution of the material parameters is considered. We present a phenomenologically-inspired large strain framework for simulating the curing process of polymers that can work under the use of an electro-mechanically coupled load. The application of the proposed approach is demonstrated via some numerical examples, cf. Fig (1). These illustrate that the model can predict common features in particle-filled electro-active polymers undergoing curing processes in the presence of an electro-mechanically coupled load. [1, 2].

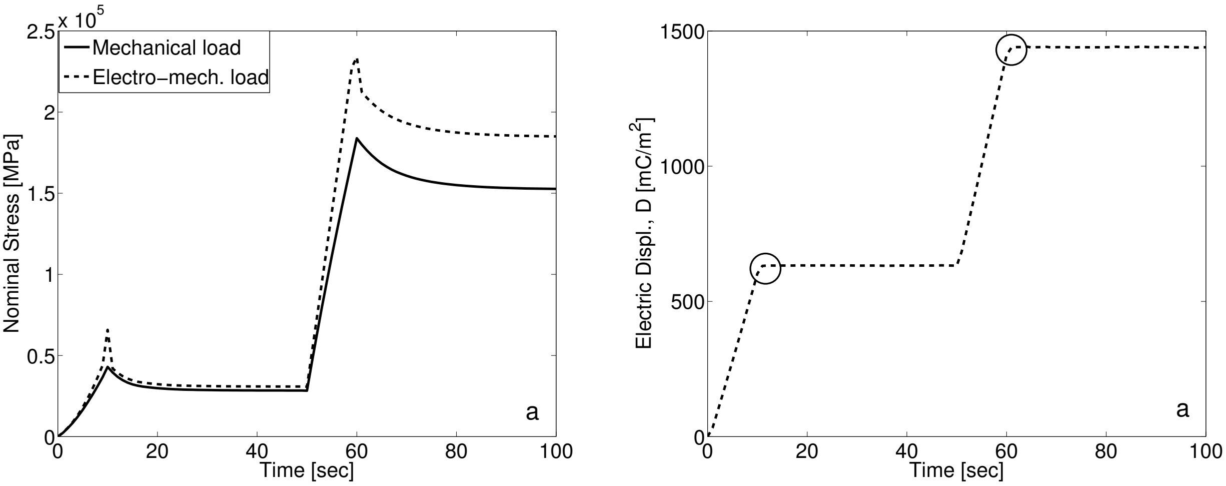

Figure 1: The response of the electro-viscoelastic model with a four-phase pure mechanical and an electro-mechanical coupled loading, i.e. *pull-hold-pull-hold* : (a) The total stress evolution over curing time (b) The electric displacement over curing time. The mechanical relaxation process takes longer time while the amount of electric relaxation is unaffected by the curing time

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Interaction of particles in viscous flows

Simone Hürner, Paul Steinmann

Numerical simulations are used in several fields of science to predict interactions of particles in viscous flows under various conditions. In biomedicine they are used, for example, for magnetic separation of labelled cells and for therapeutic drug delivery[2].

The motion of a single particle in a Lagrangian reference frame can be written as:

$$m_p \frac{d\overrightarrow{u}_{pi}}{dt} = \overrightarrow{F}_D + \overrightarrow{F}_g + \overrightarrow{F}$$

where m_p is the particle mass, $\overrightarrow{u}_{pi}$ is the particle velocity, $\overrightarrow{F}_p$ is the drag force acting on the particle, $\overrightarrow{F}_g$ is the gravity and $\overrightarrow{F}$ are additional forces like the paramgnetic force $\overrightarrow{F}_p$, the Magnus force $\overrightarrow{F}_M$ due to particle rotation and the Saffman lift force $\overrightarrow{F}_{Saff}$ due to the pressure distribution developed on a particle in a velocity gradient[1].
For the simulations the particles were assumed to be spherical with a diameter of $d_p = 1.7nm$ and a density of $\rho_p = 1521\frac{kg}{m^3}$. Thus the Stokes number is very small, which means that the particles follow the flow almost exactly. As fluid, water is used with the density of $\rho_f = 998.2\frac{kg}{m^3}$ and an initial velocity of $u_0 = 0.05\frac{m}{s}$. On the upper and the lower wall of the channel acts a magnetic flux density of $\overrightarrow{B} = 0.3T$.
Because of the very small diameter, the particle can be treated as paramagnets and the magnetic force acting on a single particle reads as:

$$\overrightarrow{F}_p = \frac{1}{2}\mu_0[X_p - X_f]V_p\overrightarrow{\nabla}(\overrightarrow{H} \cdot \overrightarrow{H})$$

where $[X_p - X_f]$ is the magnetic susceptibility difference between the particle and the fluid, and V_p is the particle volume.

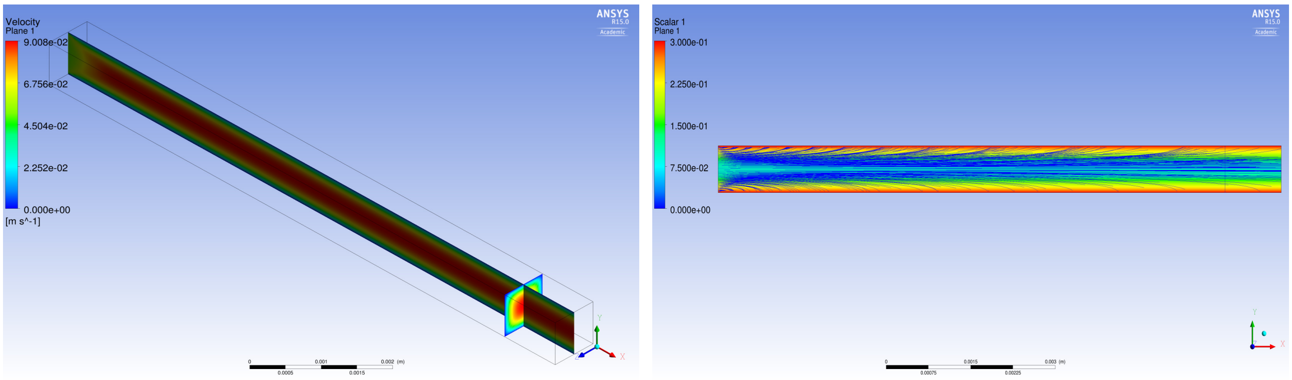

Figure 1: velocity contours and particle tracks for $u_0 = 0.05\frac{m}{s}$ and $B = 0.3T$

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Modelling large deformations with nonlinear beams

Martin Jerschl, Kai Willner

The nonlinear dynamic effects (described in [1]) of a one sided clamped beam supported with a small metal sheet at its tip are investigated. This support, shown in figure 1, can be modeled as a cubic spring element [1]. However other nonlinear effects like friction in the clamping joints cannot be coupled to the nonlinear spring element. In order to get a formulation able to account for such effects the metal sheet is modeled with nonlinear Euler-Bernoulli-beam elements. The nonlinear governing equations are derived by starting with the nonlinear Green-Lagrangian strain measure and assuming that the difference between the axial deformations and the curvature is much smaller than the bending rotation. So one ends up with the quadratic strain equation:

$$\varepsilon_{11} = \frac{du}{dX_1} - X_3\frac{d^2w}{dX_1^2} + \frac{1}{2}\left[\frac{du}{dX_1} - X_3\frac{d^2w}{dX_1^2}\right]^2 + \frac{1}{2}\left[\frac{dw}{dX_1}\right]^2 \quad \Rightarrow \quad \varepsilon_{11} = \frac{du}{dX_1} - X_3\frac{d^2w}{dX_1^2} + \frac{1}{2}\left[\frac{dw}{dX_1}\right]^2 .$$

Inserting this strain measure into a linear constitutive law, applying the principle of virtual displacements to the strong formulas of the differential equations for an infinitesimal 2-D beam element and inserting linear interpolation functions P_I, $I = 1, 2$, for the rod part and cubic interpolation functions Ω_i, $i = 1..4$, for the bending part [2] leads to additional terms compared to the linear rod and Euler-Bernoulli beam

$$0 = \delta u_I^e \left\{ \text{"linear rod"} + \int_0^{l_e} \frac{1}{2} EAP_I'\Omega_j'\Omega_k' dx \; w_j^e w_k^e \right\}$$

$$0 = \delta w_i^e \left\{ \text{"linear beam"} + \int_0^{l_e} EA\Omega_i' P_J' \Omega_k' dx \; u_J^e w_k^e + \int_0^{l_e} \frac{1}{2} EA\Omega_i'\Omega_j'\Omega_k'\Omega_l' dx dx \; w_j^e w_k^e w_l^e \right\}$$

which describe the coupling between the bending and the stretching of the beam. The coupling produces the cubic stiffening effect of the geometric nonlinearity. This is shown in figure 2, where a clamped-clamped metal sheet, meshed with seven nonlinear beam elements, is loaded with different constant line loads and a comparable cubic stiffness is identified.

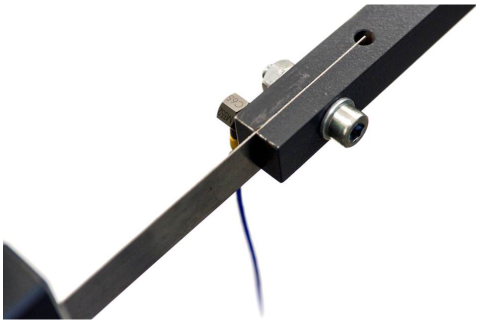

Figure 1: Clamped beam tip with metal sheet, behaving like a cubic spring.

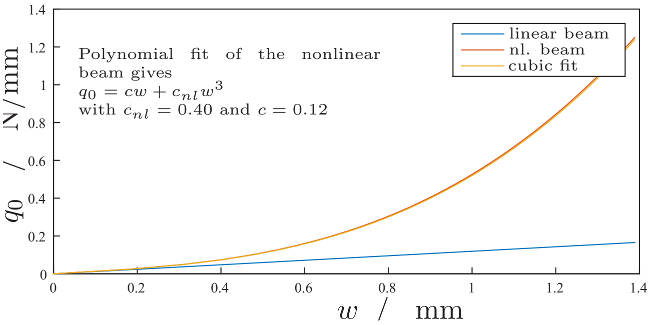

Figure 2: Displacement of a clamped-clamped metal sheet under constant line load.

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Mixed and Second Gradient Approaches to the Cahn-Hilliard Diffusion Equation

Stefan Kaessmair, Paul Steinmann

In order to describe diffusive phase separation in binary mixtures, Cahn and Hilliard [1] propose a free energy composed of a non-convex configurational part ψ_c and an interface contribution $\lambda|\nabla c|^2$. The chemical potential μ, given by the variational derivative of the free energy with respect to the concentration c, characterizes the tendency of the species of the mixture to redistribute in space. Thus, the evolution of the concentration is described by the conservation law

$$\dot{c} = \operatorname{div}\left[\boldsymbol{M} \cdot \nabla \mu\right] \qquad \text{with} \qquad \mu = \partial_c \psi_c - \lambda \Delta c,$$

with the mobility tensor denoted as $\boldsymbol{M}$ and the gradient energy coefficient denoted as λ. The resulting fourth-order partial differential equation can be solved pursuing two different approaches. First, the equation is replaced by a coupled system of two second order equations. This is achieved by the introduction of a micromorphic variable or by a second order splitting scheme where the chemical potential is considered being an independent variable. Second, the weak formulation of the fourth order equation is solved directly. Classical C^0 continuous mixed finite element formulations can be used to solve the system of equations obtained from the micromorphic and the second order splitting schemes whereas the direct method requires C^1 continuous element basis functions. Therefore, the natural element method is employed using a transformation of the Farin interpolant to obtain the element shape functions [2, 3].

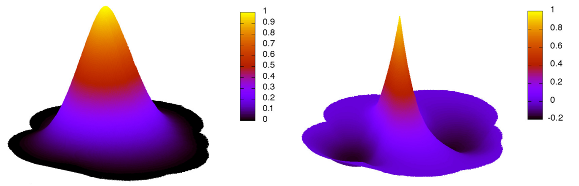

Figure 1: NEM shape functions N^1 and $\partial_x N^2$. N^1 is related to the the function value and N^2 to the x-component of the function gradient.

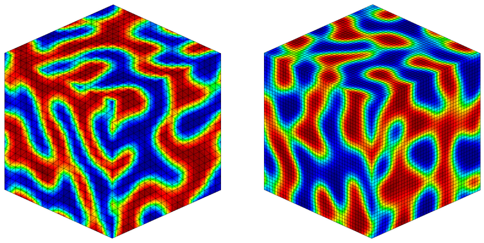

Figure 2: Solution of the Cahn–Hilliard equation with perturbed initial concentration $c = 0.5 + \delta$; left: NEM, right: FEM.

It is emphasized that the perturbations in Fig. 2 are generated randomly and thus are not equal for both examples but still, qualitative similarities can be observed. The computational costs of the NEM are higher compared to the FEM but allows to solve the equation directly.

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Inverse form finding with application to sheet-bulk metal forming

Philipp Landkammer, Paul Steinmann

Inverse form finding aims in determining the optimal blank design (material configuration) of a workpiece to a specific forming process whereby the desired target geometry (spatial configuration) is known. This is a great challenge, especially within forming near-net-shaped functional components as in the context of sheet-bulk metal forming.

An iterative algorithm is developed [1] to solve inverse form finding problems for orthotropic elasto-plasticity with large deformations. The problem of path-dependency within plasticity is herein circumvented by alternating between a mechanical formulation with direct and inverse kinematics while transferring the plastic variables. The approach will be extended with respect to kinematic hardening, contact, friction and different element-types (e.g. Solid-Shells) to solve form finding problems also for complex real-life forming processes.

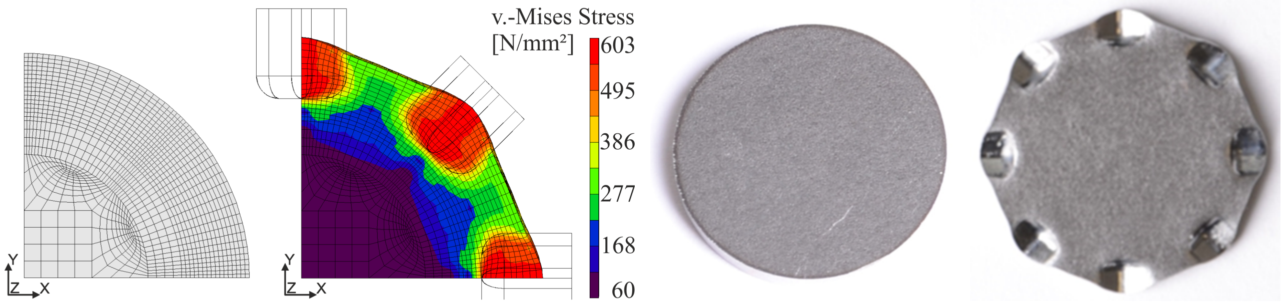

Figure 1: Simulation and experiment of a benchmark forming process as proposed in [2]. Pressing eight punches into circular blank workpiece results in an angular deformed workpiece.

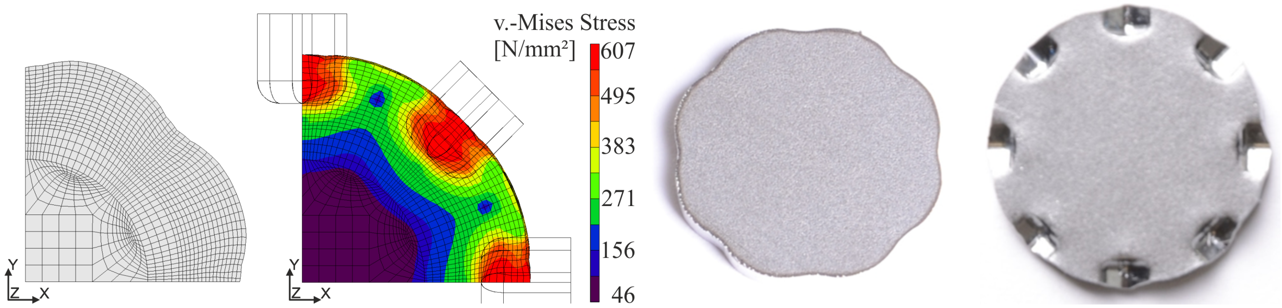

Figure 2: In contrast the forming process with the optimal blank design of the workpiece, determined by the inverse mechanical formulation, results in the desired circular geometry.

This work is part of the collaborative research project *Manufacturing of complex functional components with variants by using a new metal forming process - Sheet-Bulk metal forming* (SFB/TR73 - online: www.tr-73.de).

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Analysis of the lamination stack influence onto the damping and stiffness of armature and stator active components

Vera Luchscheider, Kai Willner

The lamination stack is part of every electric motor. With the trend to reduce the machine frame, the mechanical behavior of the lamination stack becomes more important for the motors behavior. The aim of this project is to identify a representative material model for the whole stack, because a calculation with the single sheets is not feasible.

The stacks behavior is mainly dependent on the behavior of the sheets interactions. The surfaces roughness and the coreplate varnish are responsible for the nonlinear visco-elasto-plastic behavior. To simulate the behavior of two sheets in contact, models based on surface parameters and the Hertzian contact description are available. In our case the model of Bush, Gibson and Thomas brings good results for the elastic normal behavior. The model of Bowden and Tabor is used for the plastic normal behavior and the model of Rust represents the viscous part. For the tangential direction the model of Olofsson is implemented, which is also based on the Hertzian theory.

With these interaction models the simulation of a whole lamination stack would be possible, but numerically very expensive. For that a material model based on the theory of homogenization is developed. The representative volume element (rve) for the homogenization consists of two steel sheets and the interaction zone, which contains the interaction models. Numerical experiments with different deformations are performed with the rve (see Figure 1).

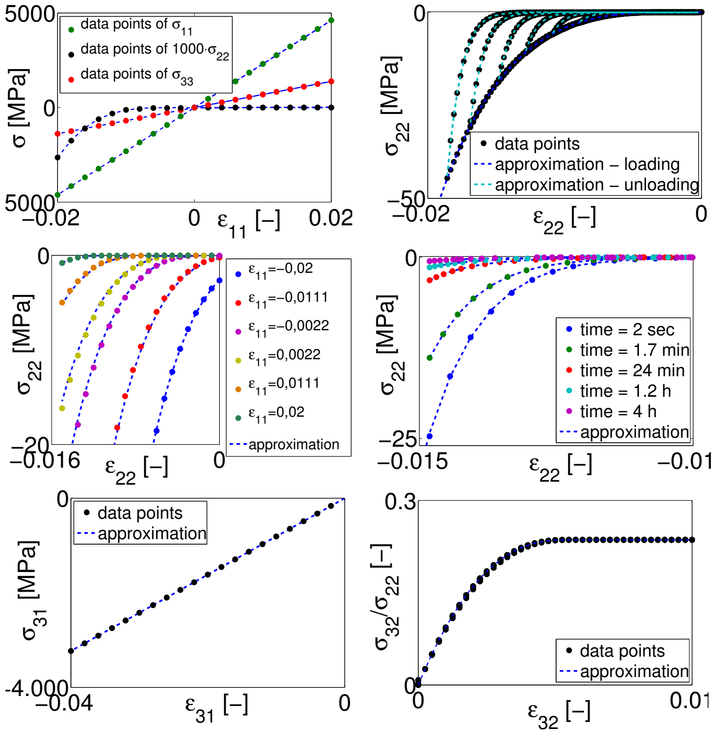

Figure 1: stress-strain curves of numerical experiments at the rve

It was possible to identify connections between some parameters and approximations were found. Consequently a representative material model can be written as

$$\begin{bmatrix}\sigma_{11}\\ \sigma_{22}\\ \sigma_{33}\\ \sigma_{21}\\ \sigma_{31}\\ \sigma_{32}\end{bmatrix} = \underbrace{\begin{bmatrix}\frac{E}{1-\nu^2} & 0 & \frac{E\cdot\nu}{1-\nu^2} & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0\\ \frac{E\cdot\nu}{1-\nu^2} & 0 & \frac{E}{1-\nu^2} & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & \frac{E}{2\cdot(1+\nu)} & 0\\ 0 & 0 & 0 & 0 & 0 & 0\end{bmatrix} \cdot \begin{bmatrix}\varepsilon_{11}\\ \varepsilon_{22}\\ \varepsilon_{33}\\ \varepsilon_{21}\\ \varepsilon_{31}\\ \varepsilon_{32}\end{bmatrix}}_{\text{sheet material}} + \underbrace{\mathcal{F}\cdot\begin{bmatrix}0 & 0\\ 0 & 0\\ 0 & 0\\ \mathcal{G} & \mathcal{G}\\ 0 & 0\\ \mathcal{G} & \mathcal{G}\end{bmatrix}\cdot\begin{bmatrix}\varepsilon_{21}\\ \varepsilon_{32}\end{bmatrix}}_{\text{tangential contact}} + \underbrace{\begin{bmatrix}0\\ \mathcal{F}\\ 0\\ 0\\ 0\\ 0\end{bmatrix}}_{\text{normal contact}} .$$

$\mathcal{F}$ and $\mathcal{G}$ are fourth order functions of strains to fit the nonlinear behavior [1].

This project is a cooperation with Siemens AG.

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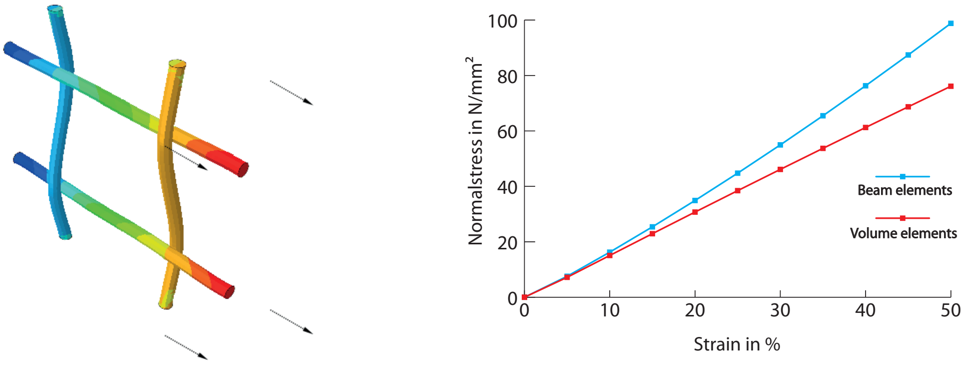
Micromechanical modeling of textile materials by means of 1-D structural elements

Markus Mehnert, Paul Steinmann

Technical textiles exhibit an inhomogneious material behaviour that strongly depends on the characteristics of the underlying fibers. As the experimental investigation is both expensive and time consuming, computational methods for the investigation of the macroscopic material properties are utilized.

Because of their large area-to-thickness ratio a shell specific formulation for the description of technical textiles on the macroscale is used [1]. On the microscale the fibers that compose the representative volume element are discretized by one dimensional beam elements. Therefor the geometry on the microscale is described by a beam specific formulation. Hence a suitable multiscale method using a specific form of the Hill-Mandel condition that links the shell specific formulation on the macroscale and the beam specific formulation on the microscale is developed.



a) b)

Figure 1: Displacement plot of the representative volume element under tensile loading (a) and diagramm of the computed stress resultants using beam or volume elements (b)

After modelling a woven representative volume element (Figure 1a) stess resultants from tensile loading, in plane shear and bending tests are computed. The stresses are compared to results obtained from computations of an RVE discretized with volume elements. Figure 1b shows the resulting stresses of tensile loading. The model discretized with beam elements exhibits a stiffer material response compared to the one with volume elements which can be explained by the higher bending stiffness of the beam elements.

Additionally, tests with varying boundary conditions, fiber sizes, filling grades and sizes of the representative volume element are carried out.

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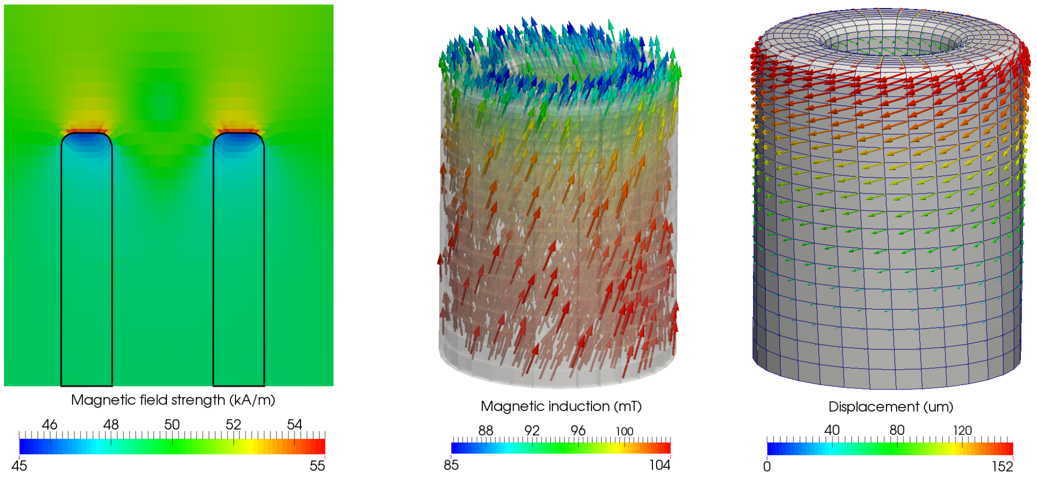
A framework for computational modelling of magneto-sensitive polymers

Jean-Paul Pelteret, Paul Steinmann

The ERC advanced grant MOCOPOLY (multi-scale, multi-physics modelling and computation of magneto-sensitive polymers) project consists of numerous individual components of research working towards the characterisation of the multi-scale behaviour of magneto-sensitive polymers. Within each field of research exist numerous challenges with respect to the simulation of these materials as their behaviour is highly non-linear and the description of the multi-physics problem is challenging. The polymeric matrix is an soft, viscous, incompressible media. Its response is affected by the alignment of embedded particles and the magnetic field that permeates the material.



Magnetic field strength Magnetic induction Displacement

Media with embedded particles forming chain-like structures deforming under an applied magnetic load

To this end, a computational framework aimed at connecting the various components of research is under development. Significant progress has been made in the coupled multi-physics FEM framework that incorporates incompressible finite-strain elasticity together with magnetic fields. The free-space surrounding the magneto-sensitive media can be directly represented in the simulations. This framework has been used to successfully validate a preliminary model characterising isotropic MSE behaviour against our experimental findings [3]. Numerous other coupled material models, including one that directly accounts for the formation of dispersed chain-like particle structures [1], have been implemented. The computation of magnetic forces and torques acting on different materials has also been achieved [2].

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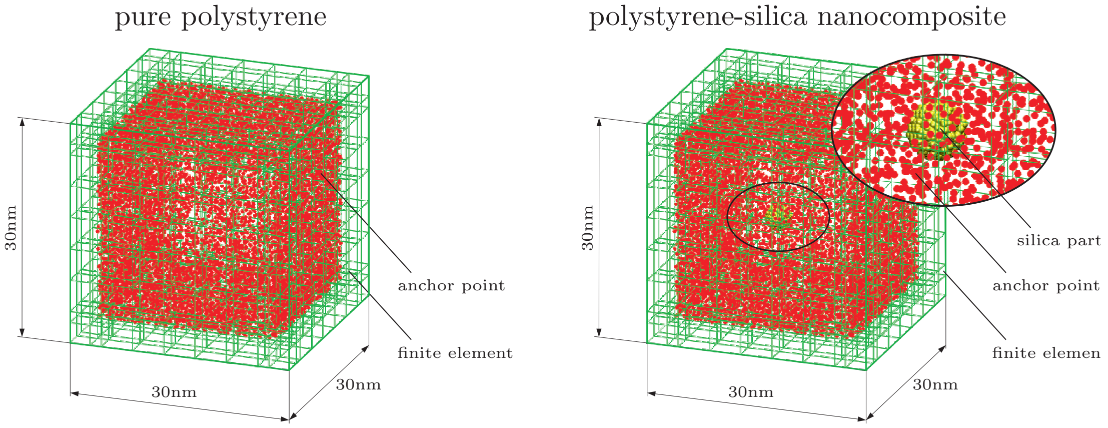
The Capriccio method: coupled particle- and continuum-based simulations

Sebastian Pfaller, Paul Steinmann

Plastics are important elements of many modern engineering applications, for instance in the field of lightweight constructions. Quite frequently, they contain filler particles to adjust their properties, whereby so-called “nanofillers“ have attracted increasing interest in recent years. These very small particles with typical dimensions in the range of some nanometres have significant influence on plastics. For example, such ”nanocomposites“ may not only exhibit improved toughness and prolonged fatigue lifetime, but can be employed even as in situ sensors to measure for instance moisture or damage. In future, numerical investigations will play an important role to enhance the development of these materials and to reduce the associated cost. To this end, simulation tools are required that are able to capture the relevant processes taking place at very small length and time scales. Within our field of research, the Capriccio method has been developed in a close cooperation between the Theoretical Physical Chemistry Group at the Technische Universität Darmstadt and the Chair of Applied Mechanics at the Friedrich-Alexander-Universität Erlangen-Nürnberg [1, 2, 3]. It links molecular dynamics techniques with the finite element method and is designed to model amorphous structures. Numerical studies show the suitability of the novel approach, which is subject of intense research activities.


pure polystyrene

polystyrene-silica nanocomposite

Figure 1: The Capriccio method is applied to coupled molecular dynamics and finite element systems modelling pure polystyrene (left) and a polystyrene-silica nanocomposite (right)

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SFEM application to computational homogenization

Dmytro Pivovarov, Paul Steinmann

In this work we study the stochastic Representative Volume Element (RVE) of a magneto-active composite. The RVE includes a set of random parameters like particle size, shape and position. To solve the problem including uncertainties we use the Stochastic Finite Element Method (SFEM) developed initialy in [1]. In recent years this method was applied to a wide range of problems, including stochastic plasticity [2].

In the current application we involve a formulation for the random field describing the elastic properties quite different from the standard formulation. This in turn necessitates to increase the number of basis functions, which results however in some convergence problems. Options to improve the tolerance and to stabilize the method are currently under investigation.

Another important task is to obtain the second order statistics for the stress distributed over the volume and the homogenized stress as well. The results obtained are verified by comparing to Monte-Carlo simulations.

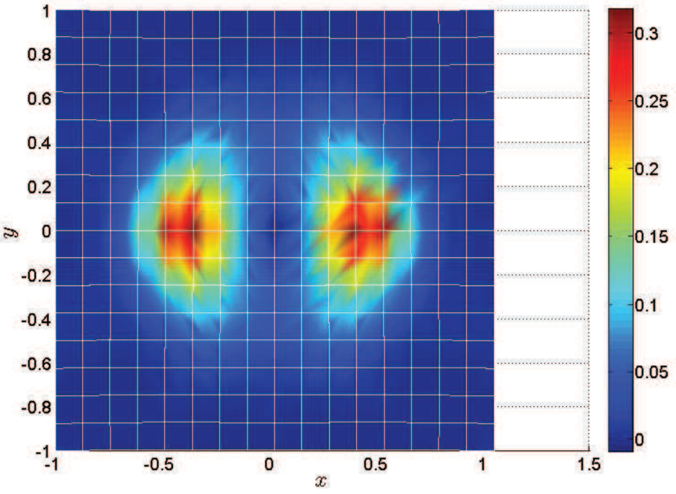

Figure 1: Relative error for stress standard deviation of SFEM in comparison to results from Monte-Carlo simulations

References

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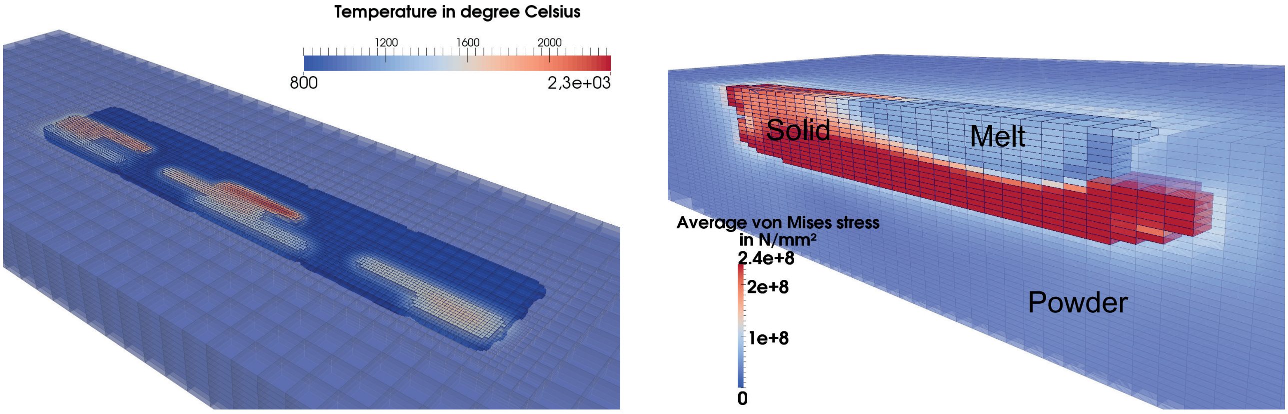
Thermomechanical modelling and simulation of selective beam melting processes

Daniel Riedlbauer, Paul Steinmann, Julia Mergheim

In selective beam melting processes the energy of laser or electron beams is used to build geometrically complex parts from thin layers of powder material. The energy of the beam fuses the powder in defined points of the current powder layer into the already fused and recongealed material of the previous treated layers. As the thickness of one powder layer is in the range from $50\mu m$ to $100\mu m$, hundreds or even thousands of layers have to be processed by the beam to built up the part layer-by-layer. Therefore selective beam melting processes belong to the class of additive manufacturing processes. The intense energy input of the beam causes the particles to undergo an irreversible phase change from powder to melt and then to solid material. In the processes high temperatures up to 3000°C (selective electron beam melting of Ti-6Al-4V) and very inhomogeneous temperatue distributions occur, which might lead to residual stresses and warpage of the produced part and degradation of its mechanical properties.

In order to improve the mechanical properties of the produced parts these quantities and the temperature are simulated by using a nonlinear thermomechanical model [1]. The powder particles are assumed to be a continuum and the strong nonlinear temperature dependency of the material parameters is included [2]. For the discretization in time a very stable and computationally efficient implicit Runge-Kutta method is used. The implementation of the model is done by using the finite element library deal.ii. For describing the temperature-dependent mechanical behaviour of the powder material, a thermo-elasto-plastic material model is developed. In order to capture the extreme temperature gradients in the vicinity of the beam and to obtain more precise results from the simulation, an adaptive refinement strategy for the finite element mesh is adopted.



(a) Temperature distribution

(b) Stresses in the different material phases

Figure 1: Selective electron beam melting of Ti-6Al-4V

References

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A staggered approach to shape and topology optimization

Stefan Riehl, Paul Steinmann

In the field of structural optimization, the greatest domain variability is attributed to methods of topology optimization. As opposed to the sole variation of the domain boundary in classical shape optimization [2], methods of topology optimization do also take into account the possible creation of new holes within the domain. As a consequence, a greater design space is established in which it is possible to seek for optimal design trials that do not only meet the requirements of local but rather global optimality criteria since the limitation to a certain topological space of solutions is overcome.

In this work [1], we consider a staggered optimization routine that brings together a node-based approach to shape optimization and an evolutionary-type element removal procedure that relies on the topological sensitivity as a rejection criterion. As opposed to classical evolutionary-type algorithms in which elements may be removed from the domain boundary as well as from the interior of the domain at the same time, we specify an advancing front algorithm that is only allowed to remove elements from the existing design boundary of the domain. The limitation to a certain topological space of solutions is overcome through consideration of a hole creation phase that is invoked once the minimum topological sensitivity is no longer encountered at the design boundary. The overall shape optimization method is then obtained as a sequence of the advancing front algorithm, a boundary smoothing technique, and a subsequent shape variation phase via the traction method.

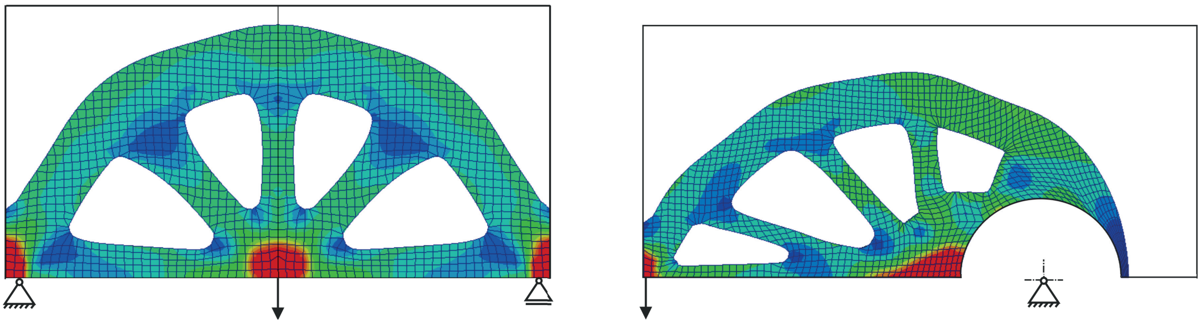

Figure 1: Optimal design trials arrived at for two different case studies using the staggered optimization routine. The contour plot shows the distribution of the topological sensitivity.

References

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Shape optimization using a fictitious domain approach

Stefan Riehl, Paul Steinmann

A critical aspect in numerical algorithms for shape optimization is to compensate for large design changes using an interior mesh update procedure such as to avoid a highly non-uniform interior mesh distribution and the occurrence of severely distorted finite elements. A well-established approach is to accompany the iterative design update procedure by adaptive mesh refinement techniques throughout the course of optimization, cf. [2] and references therein. Another idea is to separate the description of design changes and the finite element analysis mesh from each other by way of adopting so-called embedded or fictitious domain techniques [1]. Therein, one does not establish a conforming analysis mesh but rather provides a higher-level structured mesh that embeds the current shape design. The embedding mesh is then locally refined in order to allow for a tracking mechanism to capture the evolving design boundary. In addition, nodal re-arrangement and adaptive integration schemes are taken into account to compensate for possible non-conformities between the structured analysis mesh and the evolving design boundary.

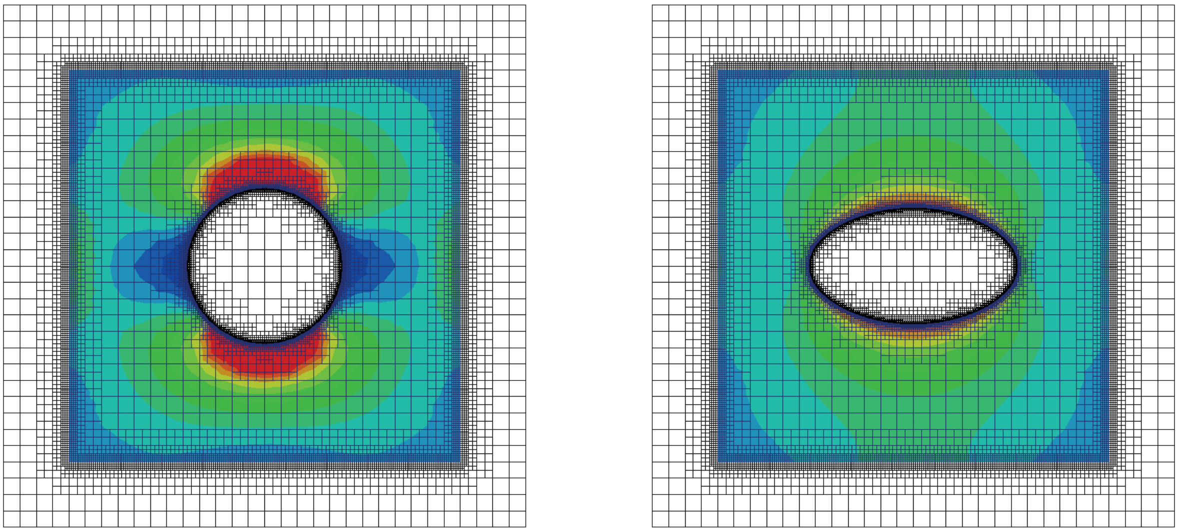

Figure 1: Shape optimization of a quadratic plate with a circular cut-out that is subject to a biaxial loading. The contour plot shows the distribution of the strain energy density for the initial (left) and optimal (right) shape arrived at.

References

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Multi-scale modeling of heterogeneous materials

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Most of materials posses heterogeneous structures at a certain level of observation. In order to model such materials for which an explicit constitutive law is missing, the method of computational homogenization is utilized. The unknown macroscopic response of heterogeneous materials is evaluated from the behavior of their underlying microstructures. In doing so, one needs to define the proper representative volume element (RVE) of the micro-level.

Strain-driven homogenization requires a method to apply the macroscopic deformation gradient on the RVE and calculate the macroscopic Piola stress such that Hill-Mandel condition is fulfilled. Hill-Mandel condition is satisfied for variety of conditions among which linear displacement boundary condition(DBC), periodic displacements and anti-periodic tractions boundary condition(PBC) and constant traction boundary condition(TBC) are more recognized. Moreover, it is well known that Taylor assumption leads to the stiffest material response, referred to as Voigt bound, and that the Sachs assumption leads to the softest material response, referred to as Reuss bound. Obviously, DBC, PBC and TBC lie between the two bounds where DBC is overestimating and TBC is underestimating the PBC. These facts are shown in Fig 1.

A common assumption in the homogenization is that the inclusions are periodically distributed in the material which is often a simplification of real composites. The influence of different morphologies of the microstructure, is explored. As depicted in Fig 1, regardless of the distribution pattern, the results from different boundary conditions converge to each other as the size of the RVE increases. In addition, the random microstructure underestimates the periodically one.

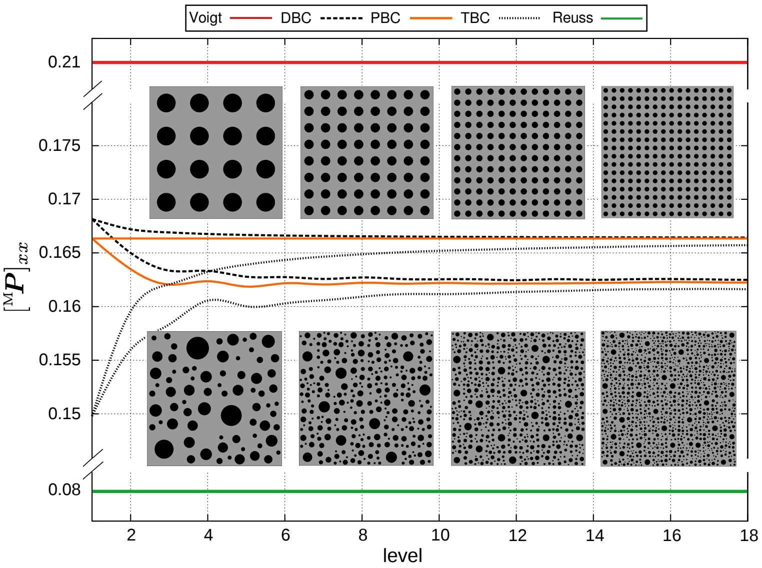

Figure 1: Choice of boundary condition becomes less significant as number of inclusion increases.

References

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Scale effects in homogenization of metal matrix composites

Stefan Schindler, Paul Steinmann

At present composite materials gain in importance due to their tailored properties. One common representative is metal matrix composite (MMC), where a metal for example lightweight aluminum is reinforced by a stiff and wear resistant ceramic for example silicon carbide (SiC), see Fig. 1. In order to determine the material properties of such composites a multi-scale finite element model is developed.

In a first step macroscopic thermal and elastic properties of a MMC are determined from a micro-scale model by homogenization. Therefore a representative volume element (RVE) is designed for a homogeneous distribution of SiC particles inside an aluminium matrix (Fig. 2). For both phases of the composite temperature dependent material properties are available from the literature. For the composite material properties are only available at room temperature. After a verification of the numerically determined elastic and thermal properties at room temperature, these can also be numerically determined for a large temperature range. The elastic and thermal behaviour is only dependent on the volume fraction of both components and not on the size of a single particle.

In a second step also the plasticity of the MMC is investigated. In contrast to the elastic and thermal behaviour, the plasticity depends not only on the volume fraction of the particles but also on their size. The conventional homogenization approach cannot consider those size effects. One approach to account for size effects on the microscopic scale has been presented in [1] for nonlinear elasticity. This approach is transferred to plasticity. The surfaces of the microscopic features, in this case the SiC particles, are endowed with their own (energetic) structure (Fig. 2). The thereby defined surface energy causes a scale effect when homogenizing the microscopic stress response (Fig. 3) in order to determine the macroscopic stress response with a Hill-type averaging condition. The surface energy provides the possibility to adjust the numerically calculated yield stress to experimentally determined yield stresses of MMCs with various particle sizes.

In a third step the plasticity properties could be numerically extrapolated to high temperatures and high strain rates. At high strain rates almost adiabatic heating through dissipation takes place and consequently temperature dependent thermal properties are required.

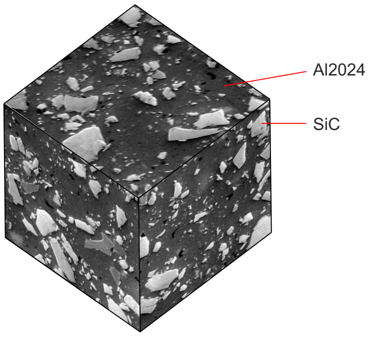

Figure 1: MMC microscale

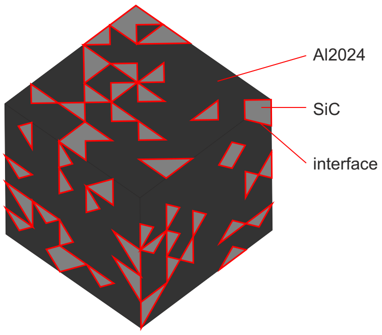

Figure 2: interfaces on RVE

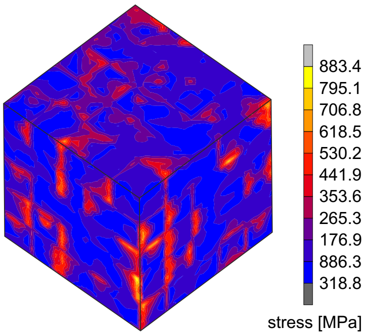

Figure 3: stress response

References

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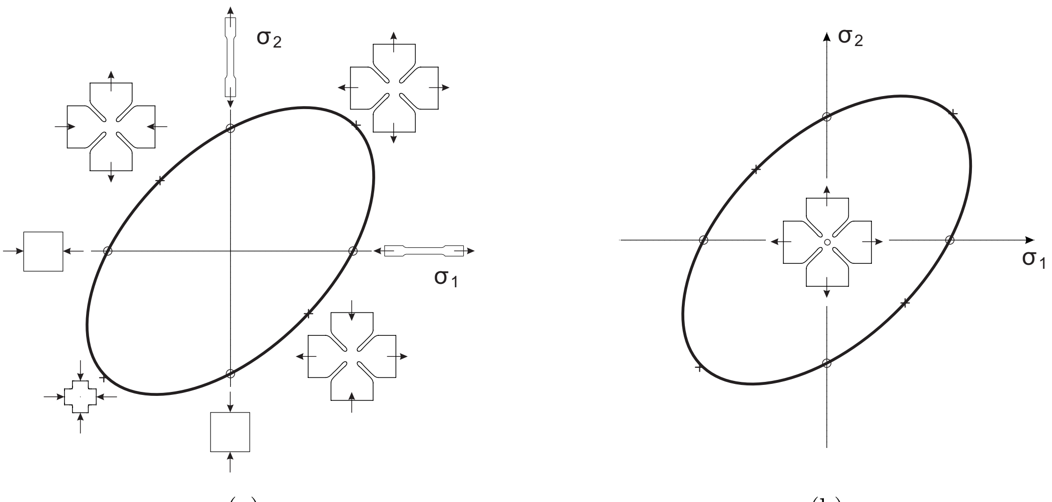
Inverse sheet steel material parameter identification from full-field biaxial tensile test data

Stefan Schmaltz, Kai Willner

Sheet steel is an intensively used raw material in the production industries for the generation of large and thin parts through forming operations. To expand its usage new production techniques like sheet bulk metal forming are defined [1]. There sheet steel is utilized for the generation of small parts with local form elements. The process takes advantage of the more efficient economical performance of forming methods in comparison to shape cutting methods and the resulting higher mechanical strength of the produced parts.

For robust FEM simulations and the competitiveness of the underlying manufacturing processes an accurate knowledge of the material behavior is needed. As sheet steel is produced in rolling processes it shows anisotropic material characteristics. For the direct experimental identification of the anisotropic material behavior, especially in the biaxial regime, several different tests have to be performed. With the utilization of an inverse Finite-Element-Model-Updating method the large experimental effort can be reduced to one single biaxial test with a more complex specimen geometry. In combination with a Finite-Element-Simulation of the test and an iterative optimization procedure the optimal material parameters fitting the sheet steel and the numerical material model are identified taking the full-field displacement measurement on the surface of the specimen into account [2]. In Fig. 1 diagrams for the identification of the initial yield surface of the sheet steel via experimental methods (a) and via an inverse procedure (b) are depicted schematically.



(a) (b)

Figure 1: Schematic yield surface stress-stress diagrams. (a): Sheet steel yield surface identified via several different experimental tests; (b): Inversely identified sheet steel yield surface from one single biaxial test using the FEMU-Method.

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On implicit constraints in parameter–free shape optimization

Oliver Schmitt, Jan Friederich, Paul Steinmann

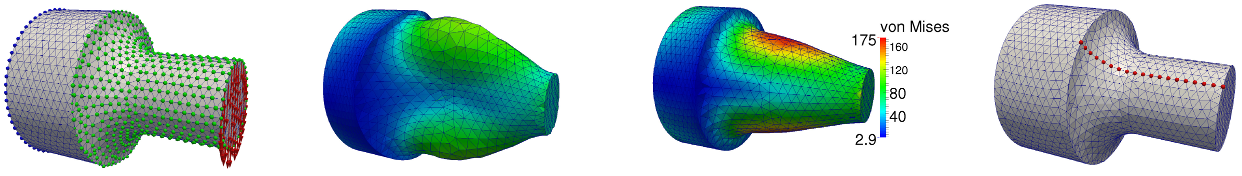
In a general optimization problem constraints are usually formulated as equality or inequality equations in terms of the design variables.When handling optimization constraints implicitly, no additional equations are appended to the optimization problem. The design variables $\mathbf{x}_d$ are split whereas one part of the design variables $\mathbf{x}^{opt}$ is still handled as design variables and the other part $\mathbf{x}^{dep}$ is coupled to the new design variables by an implicit function $\mathcal{F}$ in a way that the constraint is fulfilled:

$$\begin{array}{rlcrl} & \underline{\text{explicit}} & \qquad & & \underline{\text{implicit}} \\ \min & f(\mathbf{x}_d) & & \min & f(\mathbf{x}^{opt}) \\ \text{subject to} & g_i(\mathbf{x}_d) \leq 0, \quad i = 1, \ldots, n_{ieq} & & \text{with} & \mathbf{x}^{dep} = \mathcal{F}(\mathbf{x}^{opt}) \\ & h_j(\mathbf{x}_d) = 0, \quad j = 1, \ldots, n_{eq} & & & \end{array}$$

Through this implicit dependency a further step in the sensitivity analysis [2],[1] is required when computing the gradients of goal function and other explicit constraints. Using the chain rule of differentiation the gradient of the goal function may be stated as:

$$\frac{\partial \tilde{f}(\mathbf{x}^{opt})}{\partial \mathbf{x}^{opt}} = \frac{\partial f(\mathbf{x}^{opt}, \mathbf{x}^{dep})}{\partial \mathbf{x}^{opt}} + \left[\frac{\partial \mathcal{F}(\mathbf{x}^{opt})}{\partial \mathbf{x}^{opt}} \right]^t \cdot \frac{\partial f(\mathbf{x}^{opt}, \mathbf{x}^{dep})}{\partial \mathbf{x}^{dep}}$$

The advantages of an implicitly formulated constraint are that no additional constraint equation has to be considered while finding an optimal solution and the number of design variables which is generally very high in parameter–free shape optimization can be reduced. Figure a) shows the loadcase for a numerical example where the blue nodes are fixed, the design area is marked in green and the load is shown by red arrows. The goal is to minimize the maximal von–Mises stress. The optimization result with only one explicit volume constraint and with additional implicit rotational symmetry constraint can be observed in b) and c). Colors from blue to red show the von-Mises stress distribution. The optimizations nodes which have been used as new design variables with implicit rotational symmetry constraint are shown in d).



a) b) c) d)

References

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Material modelling and parameter identification for sheet-bulk metal forming

Benjamin Söhngen, Kai Willner

The manufacturing of near-net-shape sheet metal components is part of current research. As part of the Collaborative Research Centre (Transregio) 73, which approaches the challenge of sheet-bulk metal forming, this work addresses the identification of sheet metal parameters. Those can be used in simulation for product and process design.

Due to the manufacturing of the sheet steel through rolling, an anisotropic behaviour can be observed during loading. For modelling this forming behaviour appropriately, a constitutive material model that allows the consideration of anisotropic plasticity has to be found. One widely spread and well established model for the plasticity of metals is Hill '48 [1]. Consisting of six parameters, the model can be used to regard different yield stresses in dependency of the load direction relative to the rolling direction. In contrast to an isotropic plasticity, where the yield surface in the principal stress space takes the shape of a circular cylinder around the hydrostatic axis, the formulation with the Hill '48 criterion leads to one with an elliptic base. Having a closer look at the yield criteria in the plane stress state, one can observe that with the Hill '48 model, the yield stresses differ for the directions in and perpendicular to the rolling direction, as depicted in Fig. 1.

For the identification of the sheet metal parameters, a Finite Element Model Updating method is utilized. In a first step, appropriate specimen designs and testing processes have to be found. Then, whilst loading, the displacement of the specimen is recorded with a two camera system and evaluated to a strain field (cf. Fig. 2).

Comparing the experimentally found results with the simulation and reducing the error with the help of optimization algorithms finally leads to the identification of the parameters.

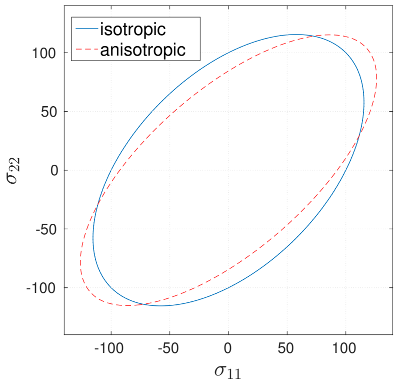

Figure 1: Isotropic and anisotropic yield surface

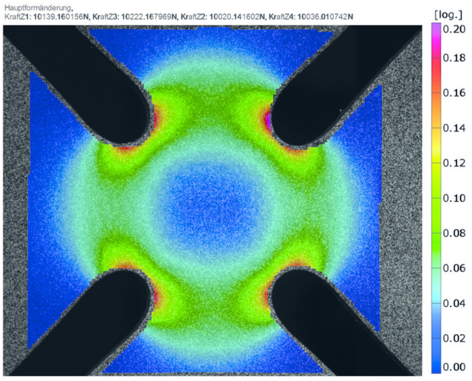

Figure 2: Major strain field

This work is supported by the German Research Foundation (DFG) within the Collaborative Research Center SFB Transregio 73.

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Flexible Adaption of Considered Harmonics for Efficient Harmonic Balance Computations

Dominik Süß, Kai Willner

The Harmonic Balance Method (HBM) is a well-established and very efficient tool for the computation of the transfer behavior of nonlinear systems in the frequency domain. However, only looking at harmonic approximations might not always lead to satisfying results. Therefore the Multiharmonic Balance Method (MHBM) also accounts for higher harmonic terms which results in a highly accurate calculation procedure. This accuracy indeed also means a high computational effort due to the dimension of the system of equations increasing by a factor of $2 \cdot n$ when n harmonics are considered.

The goal of this project was to develop an Adaptive Harmonic Balance Method (AHBM), which accounts for all necessary harmonics whenever they are needed and tries to use the most efficient classical HBM whenever possible, as presented at [2]. In order to further increase the efficiency, the considered harmonic-numbers do not only have to be part of an ascending sequence but can be chosen arbitrarily. This can for example be important for nonlinearities with symmetries where even or odd harmonics might vanish. The number of needed harmonics is filtered in every frequency iteration step. A possible criterion to check the harmonic parts can for example be the distortion factor. In order to switch between the desired vectorial quantities, a transformation matrix can be set up. This is schematically pictured in figure 1 for the transformation of a vector containing harmonics $\{1, 2, 5, 7\}$ into a vector containing harmonics $\{1, 3, 5\}$.

The proposed method is applied for the calculation of the FRF of a jointed friction oscillator, which already is investigated using the MHBM in [1].

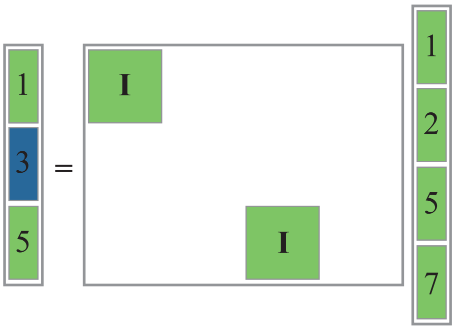

Figure 1: Schematic assignment of transformation matrix.

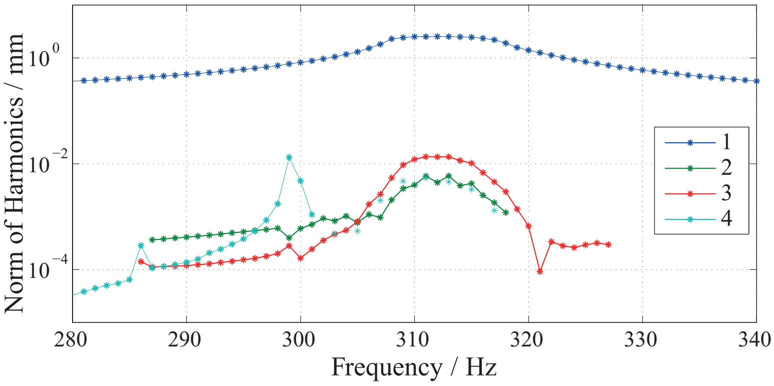

Figure 2: Spectra of calculated harmonics.

As can be seen in figure 2, the number of harmonics increases near the resonance of the system around 310Hz which also can be observed in measurements. Thus the AHBM leads to a good compromise of acceptable calculation times and desired accuracy of the results.

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On the wall slip of magneto-sensitive elastomers in dynamic oscillatory shear experiments

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Magneto-sensitive elastomers (MSEs) are smart composite materials with rheological properties that can be altered in a rapid, continuous and reversible manner upon application of a magnetic field [1]. The research in this field focuses on the magneto-coupled viscoelastic behavior and, in particular on the change of the particle structure under shear deformation. The latter is commonly studied by means of dynamic oscillatory strain sweep experiments at magnetic flux densities up to 1 T applied perpendicular to the shear direction. It is quite likely that wall slip occurs at large excitation amplitudes, even if a serrated rotor is used and the specimen is preloaded with a constant normal force. Using an unfilled silicone rubber allows the study of slip (adhesive failure) without interferences with particle structures by means of a stress controlled rotational parallel plate rheometer (MCR 502, Anton Paar). Cylindric samples (diameter of 20 mm and 1 mm thickness) are prepared using a standardized methodology, and characterized using either a smooth or a serrated rotor. As a control test eliminating wall slip, specimens are cured *in situ* similar to the others and are, therefore glued to the rotor/stator surface. Wall slip was found to occur at the serrated surface and leads to a significant apparent nonlinear viscoelastic behavior (Figure 1). The storage modulus μ' decreases as the loss modulus μ'' increases and passes through a maximum. As expected, the *in situ* cured control specimen exhibits a nearly linear viscoelastic response until the torque limit of the rheometer is reached. The onset of slip was found to depend on the normal force loading and can be shifted by one order of magnitude by increasing the normal force. Furthermore, using a serrated rotor leads to systematically lower moduli due to the geometry uncertainty from the gap setting, and additional boundary effects that might be present at the serration tips. Therefore, as an enhanced standardized methodology, all further experiment will be performed using smooth measuring plates and *in situ* cured specimen in order to study the nonlinear viscoelastic behavior of magneto-sensitive elastomers or related materials without wall slip.

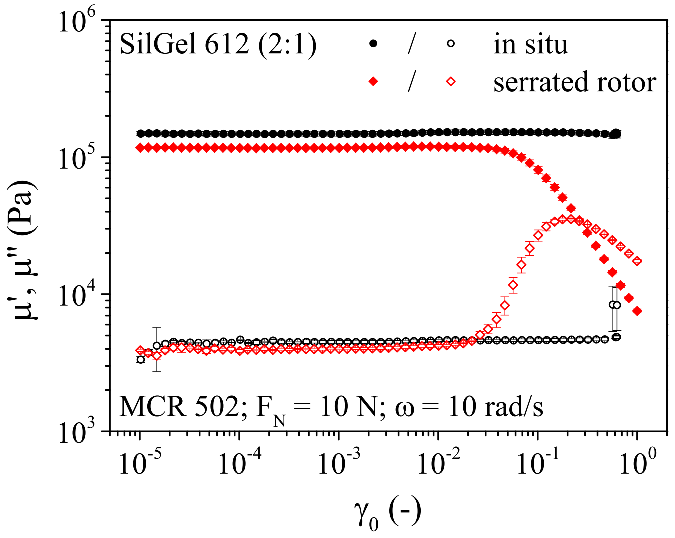

Figure 1: Strain sweep experiment; cured *in situ* (black), and using a serrated rotor (red)

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Fatigue–life prediction model for austenitic stainless steels

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One issue concerning nuclear power plants has been of relevance since the 1980s: The effects of water environment on the fatigue resistance of austenitic stainless steels. During the last decades several institutions performed fatigue tests on polished and ground specimens, and examined different environments and test parameters in detail. Some of the results are included in local stress–strain concepts, like for example the prediction model proposed by Argonne National Laboratory (NUREG/CR–6909).

In this project a more accurate statistical model for austenitic stainless steels for predicting the effect of pressurized water reactor (PWR) environments on the fatigue life was developed, see [1]. The available material data from Europe, USA and Japan were compiled—only fatigue data from polished specimens of wrought material tested under strain control were considered. Tube specimens were excluded in the final evaluations. The main parameters that influence the fatigue life were determined and fatigue–life correction factors were defined as the ratio of life in water at 300 °C (reference conditions) to that in water at service conditions. The following equations give a short overview of the PWR model. A prediction model for boiling water reactor environments was developed in parallel. The experimental values of fatigue life and those predicted by the model are plotted in Fig. 1. The predicted fatigue lives show good agreement with the experimental values for fatigue lives smaller than 10^5 cycles.

$$N_{25}^{PWR} = N_{Ref}^{PWR} \cdot F_{\dot{\varepsilon}} \cdot F_T$$

$$N_{Ref}^{PWR} = 10^{\left(4.18 - \log(\varepsilon_a - 0.085) - 1.35[\varepsilon_a - 0.085]\right)^{0.35}}$$

$$F_{\dot{\varepsilon}} = \left[\frac{\dot{\varepsilon}}{0.4}\right]^{0.18}$$

$$F_T = \left[1 + \frac{0.28}{\varepsilon_a - 0.105}\right]^{\left(\frac{300-T}{150}\right)}$$

Where ε_a Strain Amplitude [%]
$\dot{\varepsilon}$ Strain Rate $\left[\frac{\%}{s}\right]$
T Temperature [°C]
$F_{\dot{\varepsilon}}$ Strain Rate Correction–Factor
F_T Temperature Correction–Factor

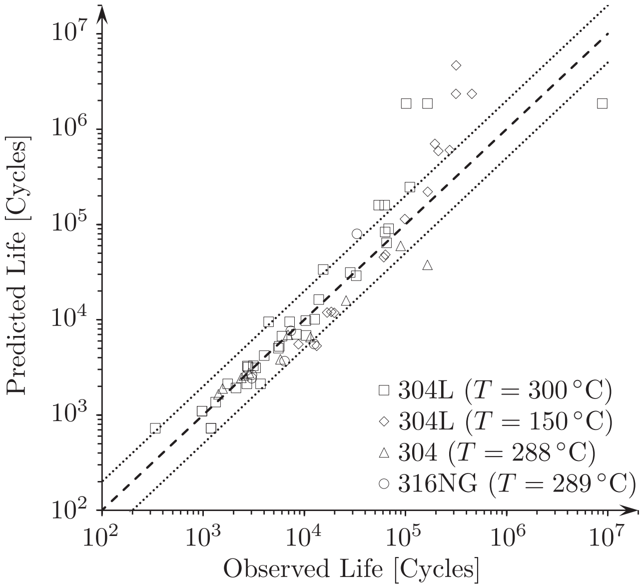

Figure 1: Experimental and predicted values of fatigue lives

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Computational homogenization in magnetoelasticity

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[2] Chair of Civil and Environmental Engineering, Stanford University, USA

Magnetorheological elastomers are composites whose mechanical behaviour depend on the applied magnetic field. Since explicit constitutive laws for such heterogeneous materials are not specified, their effective macroscopic properties can be estimated from the response of the underlying micro-structures using homogenization procedure [1]. This procedure is based on the solutions of two subproblems at the macroscopic and microscopic scales. The micro-structure for which the constitutive law is assumed to be known, is far smaller than the characteristic length of the macroscopic problem and consists of at least two materials [1]. It is considered that the macroscopic variables are equal to the volume average of their microscopic counterparts over the undeformed micro-structure. From the macro-scale analysis the macroscopic deformation gradient, $\overline{\mathbf{F}}$, and magnetic field, $\overline{\mathbb{H}}$, are obtained, which are the inputs of the micro-scale problem in order to compute the macroscopic Piola stress, $\overline{\mathbf{P}}$, and magnetic induction, $\overline{\mathbb{B}}$. A finite element framework is developed to compute the effective properties of the microstructure. Responses of the different microstructures which vary in volume fraction, size, and inclusion material properties (e.g. magnetic permeability, μ) under simple-extension load type and magnetic fields in x-direction are studied [1].

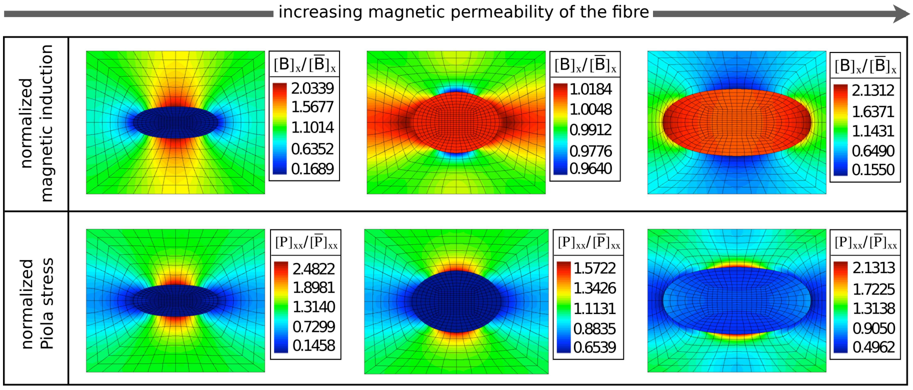

Figure 1: Distribution of microscopic normalized Piola stress (xx-component) and normalized magnetic induction in x-direction.

Figure 1 shows that for the same values of the deformation gradient and magnetic field, increasing magnetic permeability of the inclusion fibre highly affects the deformation, magnetic induction, and consequently Piola stress.

References

[1] A. Javili, G. Chatzigeorgiou, and P. Steinmann. "Computational homogenization in magneto-mechanics". *International Journal of Solid and Structures* 50 (2013), pp. 4197–4216.

4 Activities

4.1 Teaching

- Statik (MB)
- Elastostatik und Festigkeitslehre (MB)
- Statik und Festigkeitslehre (CBI, ET, IP, LSE, ME, MT, WING, WW)
- Lineare Kontinuumsmechanik (MB, ME, WING)
- Nichtlineare Kontinuumsmechanik (MB, ME)
- Technische Schwingungslehre (MB, ME, WING)
- Methode der Finiten Elemente (MB, ME, WING)
- Materialmodellierung und -simulation (CE, MB)
- Nichtlineare Finite Elemente (CE, MB, IP)
- Einführung in die Bruchmechanik (MB)
- Mikromechanik (MB, CE)
- Rotordynamik (MB)
- Strukturoptimierung in der virtuellen Produktentwicklung (MB, ME)
- Kontaktmechanik (MB)
- Numerische und experimentelle Modalanalyse (MB, ME, WING)
- Introduction to the Finite Element Method (CE)
- Computational Dynamics (CE)
- Finite-Elemente Praktikum (MB, WING, IP)
- Hauptseminar Technische Mechanik (MB, ME)
- Number of exams - 2725

4.2 Dissertation theses

- F. Vogel,
  On the modeling and computation of electro- and magneto-active polymers

- J. Glaser,
  On the Computation of Crack-Driving Forces within the X-FEM

- G. Possart,
  Mechanical Interphases in Adhesives. Experiment, Modelling and Simulation

- F. Hauer,
  Die elasto-plastische Einglättung rauer Oberflächen und ihr Einfluss auf die Reibung in der Umformtechnik

- U. Schmidt,
  Identifikation mikroskopischer Materialparameter im Rahmen einer Zwei-Skalen-Modellierung

4.3 Diploma theses

- M. Sweid,
  A Survey on Line Search Algorithmus in parameter-free Shape Optimisation

- N. Chaouch,
  Gewichtsoptimierung eines Tragwerks unter Berücksichtigung von konstruktiven Randbedingungen

4.4 Master theses

- B. Söhngen,
  Implementierung und Validierung einer Höher-Harmonische-Balance-Methode zur Berechnung nichtlinearer Systeme

- J. Kröner,
  Experimentelle und numerische Untersuchung eines Systems mit kubischer Nichtlinearität

- M. Klebl,
  Untersuchung des strukturdynamischen Verhaltens eines elektrischen Achsantriebs mittels Finite-Elemente-Methode

- B. Brands,
  A cohesive discontinuous Galerkin method to simulate crack propagation

- A. Haag,
  FE-Simulation des mechanischen Verhaltens arterieller Stents

- K. Taubeneder,
  Konzept einer automatisierten Messkette zur Bestimmung der Rotoreigenschwingungen im Fertigungsprozess

- R. Zabihyan,
  Aspects of Coumputational Homogenization in Magneto-mechanical Composite

- J. Scherer,
  Erprobung von neuen Methoden zur FE-basierten Lebensdauerberechnung von Zahnrädern

- M. Feuerbach,
  Einfluss der Lastverteilung auf die Lebensdauer von Profilschienenführungen

- C. Liebsch,
  Kalibrierung, Verifikation und Validierung eines parametrisierten Finite-Elemente-Modells des humanen Bruskorbs

- D. Hoch,
  Homogenisierung technischer Textilien mit viskoelastischem Materialverhalten

- A. Aschenbrenner,
  Filtertechniken in der sensitivitätsbasierten parameterfreien Formoptimierung

- M. Mehnert,
  Mikromechanische Modellierung von Textilien mittels 1 - D Strukturelementen

4.5 Bachelor theses

- S. Reil,
  Implementierung und Vergleich von Optimierungsalgorithmen für die Parameteridentifikation hyperelastischer Materialmodelle

- A. Horn,
  Implementierung unterschiedlicher Reibgesetze für nichtlineare dynamische Berechnungen

- H. Rabus,
  Implementierung von tetragonalen Zero-Thickness- und zugehörigen Lagrange-Elementen in Matlab

- A. Kergaßner,
  Implementierung von triangularen Zero-Thickness- und zugehörigen Lagrange-Elementen in Matlab

- S. Klingert,
  Simulation von Bariumtitanat mittels molekularstatischer Methoden in der paraelektrischen Phase

- J. Oeder,
  FE-Simulationen von Nanoindentationen auf Klebeschichtquerschnitten

- K. Kraxenberger,
  Ermittlung des Einflusses der Klebestoffaushärtung auf den Spannungszustand eines Zahn-Inlay-Verbundes mit Hilfe der Finite-Elemente-Methode

- J. Jabari,
  Simulation der Temperaturverteilung im Werkzeug während der drehend spanenden Bearbeitung

- M. Eisenstraudt,
  Wave propagation in linear elastic solids

- S. Höhn,
  Auslegung und Konstruktion eines Werkzeugs zur Herstellung anisotroper magnetorheologischer Elastomere

- A. Enzenhöfer,
  Implementierung von 2D-Strukturelementen über Subroutinen in MSC.Marc/Mentat

- J. Penner,
  FE-Simulation geschichteter Strukturen unter Berücksichtigung des Kontaktverhaltens

- B. Merklein,
  On Bernoulli Beam Theory with Nonlinear Material Behavior

- S. Rast,
  Simulation der Spanbildung beim Drehen von Aluminium im Orthogonalschnitt mittels Finiter-Elemente-Methode

- M. Ries,
  Bewertung der Ermüdungsfestigkeit für korrosionsbeanspruchte Anlagenteile in Kraftwerken

- T. Pfaffenzeller,
  Strukturoptimierung räumlicher Stabtragwerke unter Verwendung materieller Kräfte

- J. Zilker,
  Constraint Aggregation in der Formoptimierung

- S. Gehre,
  Implementierung eines Programms zur Lösung der Impulsbilanz in 2D bei linear elastischen Materialverhalten

- M. Schulz,
  Implementierung eines Traction-Separation-Law in Matlab

4.6 Student research projects theses

- B. Brands,
  Implementierung eines Programms zur Lösung der stationären linearen Wärmeleitungsgleichung in 2D

- D. Hoch,
  Mikromechanische Modellierung und Homogenisierung eindimensionaler Textilien

- T. Weidauer,
  Untersuchung der Reduktion dynamischer Systeme auf Basis derer Eigenvektoren

- H. Münch,
  Equivalent Radiated Power (ERP) - Sensibilisierung für Grenzen und Potenziale einer akustischen Berechnungsmethode

- S. Mühlbauer,
  Implementierung der SIMP-Methode in deal.II

- F. Sigel,
  Entwicklung eines Rennsportkolbens für einen Formula Student Motor
- C. Lindner,
  Aufbau einer Datenbank mit Prognosefähigkeit auf Basis multidimensionaler Metamodelle
- R.C. Troidl,
  Konzeptuntersuchungen zur Integration eines segmentierten Umrichters in elektrische Antriebe
- C. Paus,
  Entwicklung einer Prüfvorrichtung zur Analyse des Stick-Slip-Verhaltens der tribologischen Systeme mechanischer Riemenspanner im Nebenaggregatetrieb von Verbrennungsmotoren
- P. Rödel,
  Implementierung und Validierung eines elasto-plastischen Materialmodells für das selektive Laserstrahlsintern
- C. Hinderer,
  Kontaktversuche gestapelter Bleche mit statischer Betrachtung

4.7 Seminar for Mechanics (jointly with LTD)

13.01.2014 Prof. Jorge A. C. Ambrósio,
IDME/IST - Instituto Superior Técnico, Lisboa, Portugal
Multibody Dynamics Methodologies with Applications to Biomechanics and Vehicle Dynamics

10.02.2014 Veronika Kräck,
Lehrstuhl für Elektrische Antriebe und Maschinen, FAU Erlangen-Nürnberg
Blockstrukturierte Finite-Difference-Time-Domain (FDTD) Methode zur Berechnung dreidimensionaler niederfrequenter elektromagnetischer Feldprobleme

12.02.2014 PD Dr. Michael Wolff,
FB 3 Mathematik/Informatik, Zentrum für Technomathematik, Universität Bremen
On modeling of continous bodies with singular sharp interfaces

13.02.2014 Dr. Mykola Tkachuk,
National Technical University "Kharkiv Polytechnical Institute"
On modeling of continous bodies with singular sharp interfaces

28.02.2014 Dr.-Ing. Cristian Guillermo Gebhardt,
Fraunhofer-Institut für Windenergie und Energiesysemtechnik (IWES) Bremerhaven
Fluid-structure interaction of mechanical systems immersed in low-subsonic flows: the wind turbine case

31.03.2014 Prof. Andreas Müller,
University of Michigan-Shanghai Jiao Tong, University Joint Institute

	Anwendung der Schraubentheorie in der Mehrkörperdynamik
14.05.2014	Markus Breitfuss, Institute of Technical Mechanics, Johannes Kepler Universität Linz *DEIM for the Efficient Computation of Contact Interface Stresses*
02.06.2014	Jean-Paul Pelteret, Lehrstuhl für Technische Mechanik, FAU *A Computational Neuromuscular Model of the Human Upper Airway*
18.06.2014	Dr.-Ing. Dominik Kern, TU Chemnitz *Variational Integrators for Thermoviscoelastic Coupled Dynamic Systems with Heat Conduction*
20.06.2014	Dr. Henry van den Bedem, Stanford University, SLAC National Accelerator Laboratory *Molecular-scale Kinematics in Computational Structural Biology*
30.06.2014	Dr. Masato Tanaka, Toyota Central R&D Labs., Inc. *Implementation of Material Modeling Approaches at Finite Strains using a Highly Accurate Numerical Derivative Scheme*
07.07.2014	Prof. M.H.B.M Shariff, Department of Applied Mathematics and Science, Khalifa University of Science, Technology and Research, UAE *Principal Axis Formulations in Anisotropic Solid Mechanics*
14.07.2014	Manish Vasoya, Institut Jean Le Rond d'Alembert, CNRS, Paris *Propagation of tensile planar cracks in heterogeneous media*
04.12.2014	Debora Clever, University of Heidelberg, Interdisciplinary Center for Scientific Computing (IWR), Optimization in Robotics and Biomechanics (ORB) *Optimization in Robotics and Biomechanics with Focus on Human and Humanoid Locomotion*

4.8 Editorial activities

GAMM-Mitteilungen

The GAMM-Mitteilungen (GAMM-Proceedings) are published by Wiley-VCH Verlag, Berlin (`www.onlinelibrary.wiley.com`).

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  Guest Editor:
  P. De Lorenzis, Braunschweig & P. Wriggers, Hannover

- Volume 37 Issue 2 2014
  Mathematical Signal and Image Processing
  Guest Editor:
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- **International Journal of Structural Changes in Solids**
- **Journal of the Mechanical Behaviour of Materials**
- **Mathematics and Mechanics of Complex Systems**
- **Mathematics and Mechanics of Solids**
- **Meccanica**

4.9 Girls' Day

(mj) Already for the fifth time since the year 2010, the Chair of Applied Mechanics opened his doors for the nationwide Girls' Day (on March 27th). On that day numerous universities, organizations and companies delivered insight into their daily life to awaken young girls' interest in engineering, science and trade. From the fifth grade on, the young ladies get information provided about non-typical professions for women.

Good vibrations – masses on the road to resonance catastrophe. Under this topic the young girls got an impression about structural dynamical system properties like eigenfrequency and modeshapes and about what can happen if an excitation matches these frequencies. Examples like the catastrophe of the Tacoma-Narrows-bridge (1940) were shown, the reasons explained, ground resonances of helicopters considered and the girls could perform some student experiments which are part of the structural dynamics course.

4.10 85th Annual Meeting of the International Association of Applied Mathematics and Mechanics – GAMM 2014

(iw) The 85th Annual Meeting of the International Association of Applied Mathematics and Mechanics took place from March 10th until March 14th in Erlangen, Germany, under the auspices of the President of the Friedrich-Alexander University (FAU), Karl-Dieter Grüske.

Due to the great number of attendees the opening reception was hosted in the Stadthalle Fürth with addresses of welcome by the hosts, as well as Bernd Sibler, State Secretary of the State of Bavaria as the guest of honour. On Tuesday more than 1000 participants were invited to a lecture in memorial of Ludwig-Prandtl held by Cameron Tropea titled "Experimental fluid mechanics, quo vadis?". On Wednesday a talk was given by the Richard-Von-Mises award winner, Irwin Yousept, titled "Optimal Control of Electromagnetic Processes Governed by Maxwell's Equations". In summary, more than 800 lectures were held, 22 contributions were made to mini symposia, 26 lectures were held during the young researcher's mini symposia, and 8 plenary talks were given by leading scientists of the mathematical and mechanical field. The section "Material Modelling in Solid Mechanics" was especially well received among the participants.

Topicwise the GAMM annual meeting covered cutting-edge research in areas closely related to the EAM cluster such as Modelling of Advanced Materials and Novel Multiscale Computational Methods. A Public Lecture given by the vice president of the FAU, Joachim Hornegger, on Tuesday evening was titled "The Beatles and their Impact on Modern Medical Imaging" and inspired the audience.

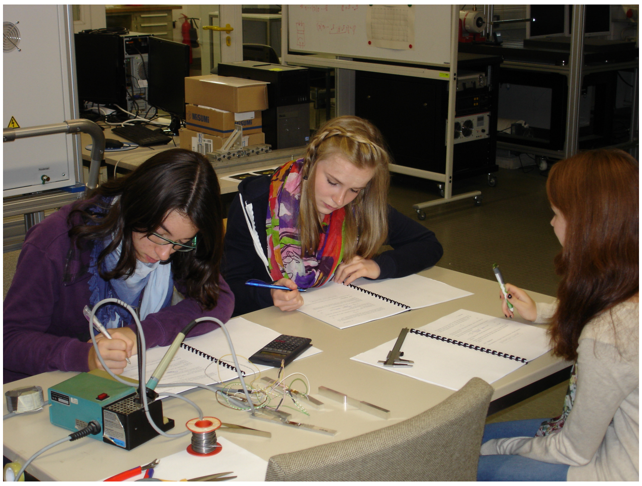
Over 500 young researchers participated in the GAMM2014. Altogether more than 1000 international scientists in the fields of Applied Mathematics and Mechanics from 33 nations were welcomed in Erlangen. Our special thanks go to our sponsors: the Cluster of Excellence Engineering of Advanced Materials, the LaVision GmbH, the Deutsche Forschungsgemeinschaft, the Department of Mechanical Engineering at the Friedrich-Alexander-Universität Erlangen-Nürnberg, and the Cerebra Informationssysteme GmbH.

As a special attraction, the Opening Reception took place in the form of a steam train journey on the history-charged rails of the metropolitan region of Nürnberg-Fürth-Erlangen. At Fürth main station, Paul Steinmann gave the departure order on time and about 700 passengers enjoyed snacks and drinks on board. The train comprised 15 passenger coaches and was pulled by the 1650 hp steam locomotive 52 8195-1 built in 1943.

4.11 Practical Course: Girls & Engineering / Youth & Engineering

(sh) Forming a long tradition since 1999, the practical course “Girls and Engineering” was held in September. Since 2010, the corresponding course “Youth and Engineering”, open for both genders, takes place in parallel. These events offer interested students from 8th through 12th grade to do some work experience at the university to learn about engineering and physics from an applied point of view. The students conduct several experiments, which are offered by the departements of the School of Engineering University Erlangen-Nuremberg and the Fraunhofer Institutes located in Erlangen, in order to gain some insight in the diversity of engineering disciplines and to learn more about applied sciences.

At the Chair of Applied Mechanics, we developed an experiment ”Stress Analysis of a Crane Hook” which covers all basic steps in investigating a hook’s behavior under loading until failure. The students receive an impression of the stress distribution within the loaded hook with the help of an optical stress analysis. Afterwards they try to extract the material constants of the hook’s ”unknown” material. With this information, the students perform a finite element analysis in order to reproduce the stress distribution from the optical experiment, to locate the maximal stress and to foresay the maximal possible loading. To verify the results of the numerical simulation, the course concludes with the most popular part among the students: the final destruction of the hook through a tensile test. We are happy, that our experiment was well received by the students.



4.12 Staedtler award

(mk) The doctoral thesis ”Development and Investigation of Polytope Finite Element formulations for the nonlinear continuum mechanics” by Markus Kraus (available in German in the chair’s ”Applied Mechanics Series”, volume 9) has been honored with this year’s Staedtler award. The awards for 10 thesis from all faculties of the FAU Erlangen-Nuremberg are confered by the Staedtler Foundation which main objective is the research support at German universities, especially the FAU (more information on `www.staedtler.de/de/stiftung`).

(left) how to squeeze a whole thesis into a four minutes talk?, (right) this year’s winners with the presidents of the Staedtler Foundation and the FAU, Schoch and Grüske. © Uwe Niklas

5 Social events

5.1 Visit of the Bergkirchweih

(fb) The franconian Bergkirchweih is an annual beer festival since 1755 and starts on Thursday before Pentecost at 5PM. The 5th season of Erlangen is initiated with the “Anstich” by Erlangen’s mayor and ends after 12 days with the burial of the Berg’s last beer barrel. During this time, about one million people pilger to the “Berch” which is ten times the city’s population.
As it is tradition that the staff of the university’s chairs visit the Berch on the first Tuesday of the fair, the visit took place at the 10th of June. This year the venue was at the Erich-Keller where the Chair of Applied Mechanics had a reservation together with the Chair of Applied Dynamics.
The weather was quite hot, sunny and dry. Therefore, it was obvious that the surrounding trees did not provide enough shadow to cool the people down which had to be compensated with one beer or another.

5.2 Outing on the Wiesent

(bs) In 2014 we decided to kayak on the Wiesent in the heart of the Franconian Switzerland. Despite the not so promising weather forecast (rain and lightning), we took our chances and were rewarded with a nice sunny day. The day started in Doos where we were briefed shortly and then saddled our (horses) two-man kayaks. The first casualties were sustained only few meters down the Wiesent, where the first rapids had to be passed and some kayaks capsized. Already soaked to the skin, there was not much left to lose, which made getting in and out easier ;-)
About 2.5 hours later everyone arrived safely at the 'Sachsenmühle' where we enjoyed a 'lecker Brotzeit' and the appropriate beverages. After a nice break in the sun, we continued our tour past 'Muggendorf' to our final destination 'Streitberg'.
Back into dry clothes, for some of us, the day ended at the nearby 'Forchheimer Annafest'.






6 Publications

6.1 Contributions to Journals

[1] J.C. Aurich, S. Zimmermann M. Schindler, and P. Steinmann. “Effect of the cutting condition and the reinforcement phase on the thermal load on the workpiece when dry turning aluminum metal matrix composites” (2014), submitted.

[2] S. Budday, C. Raybaud, and E. Kuhl. “A mechanical model predicts morphological abnormalities in the developing human brain”. *Scientific Reports* 4 (2014), p. 5644.

[3] S. Budday, P. Steinmann, and E. Kuhl. “The role of mechanics during brain development”. *Journal of Mechanics and Physics of Solids* 72 (2014), pp. 75–92.

[4] D. Davydov, J-P. Pelteret, and P. Steinmann. “Comparison of several staggered atomistic-to-continuum concurrent coupling strategies. ” *Computer Methods in Applied Mechanics and Engineering* 277 (2014), pp. 260–280.

[5] D. Davydov and P. Steinmann. “Reviewing the roots of continuum formulations in molecular systems. Part I: Particle dynamics, statistical physics, mass and linear momentum balance equations”. *Mathematics and Mechanics of Solids* 19.4 (2014), pp. 411–433.

[6] D. Davydov and P. Steinmann. “Reviewing the roots of continuum formulations in molecular systems. Part II: Energy and Angular Momentum Balance Equation”. *Mathematics and Mechanics of Solids* 19.7 (2014), pp. 852–867.

[7] D. Davydov, E. Voyiatzis, G. Chatzigeorgiou, S. Liu, P. Steinmann, M. C. Böhm, and F. Müller-Plathe. “Size effects in a silica - polystyrene nanocomposite: Molecular dynamics and surface-enhanced continuum approaches.” *Soft Materials* 12.sup1 (2014), S142–S151.

[8] F. Endres and P. Steinmann. “An extended molecular statics algorithm simulating the electromechanical continuum response of ferroelectric materials”. *Computational Mechanics* 54.6 (2014), pp. 1515–1527.

[9] F. Endres and P. Steinmann. “Molecular statics simulations of head to head and tail to tail nanodomains of rhombohedral barium titanate”. *Computational Materials Science* 97 (2015), pp. 20–25.

[10] S. Fillep, J. Mergheim, and P. Steinmann. “Computational homogenization of rope-like technical textiles” (2014), submitted.

[11] J. Friederich, G. Leugering, and P. Steinmann. “Adaptive finite elements based on sensitivities for topological mesh changes”. *Control and Cybernetics* 43.2 (2014), pp. 279–306.

[12] S. Germain, P. Landkammer, and P. Steinmann. “On a recursive formulation for solving inverse form finding problems in isotropic elastoplasticity”. *Advanced Modeling and Simulation in Engineering Sciences* 1:10 (2014), pp. 1–19.

[13] M. Hossain, P. Saxena, and P. Steinmann. “Modelling the curing process in magneto-sensitive elastomeric materials” (2014), submitted.

[14] M. Hossain and P. Steinmann. “Degree of cure-dependent modelling for polymer curing processes at small-strain. Part I: Consistent reformulation”. *Computational Mechanics* 53 (2014), pp. 777–787.

[15] M. Hossain, D. K. Vu, and P. Steinmann. “A comprehensive characterization of the electro-mechanically coupled properties of VHB 4910 polymer”. *Archive of Applied Mechanics* (2014). DOI: `10.1007/s00419-014-0928-9`.

[16] M. Hossain, G. Chatzigeorgiou, F. Meraghni, and P. Steinmann. “A multi-scale approach to model the curing process in magneto-sensitive polymeric materials” (2014), submitted.

[17] A. Javili, S. Kaessmair, and P. Steinmann. “General imperfect interfaces”. *Computer Methods in Applied Mechanics and Engineering* 275 (2014), pp. 76 –97.

[18] S. Kaessmair, A. Javili, and P. Steinmann. “Thermomechanics of solids with general imperfect coherent interfaces”. *Archive of Applied Mechanics* 84 (2014), pp. 1409–1426.

[19] P. Landkammer, S. Germain, and P. Steinmann. “On inverse form finding for orthotropic plasticity”. *Computer Assisted Methods in Engineering and Science* 20-4 (2014), pp. 337–348.

[20] D. Riedlbauer, P. Steinmann, and J. Mergheim. “Influence of the Arcam MultiBeam scan strategy on the homogeneity of the temperature distribution in the selective electron beam melting process for Ti6Al4V” (), submitted.

[21] D. Riedlbauer, P. Steinmann, and J. Mergheim. “Thermomechanical finite element simulations of selective electron beam melting processes: Performance considerations”. *Computational Mechanics* 54 (2014), pp. 109–122.

[22] D. Riedlbauer, M. Drexler, D. Drummer, P. Steinmann, and J. Mergheim. “Modelling, simulation and experimental validation of heat transfer in selective laser melting of the polymeric material PA12”. *Computational Materials Science* 93 (2014), pp. 239–248.

[23] S. Riehl and P. Steinmann. “A staggered approach to shape and topology optimization using the traction method and an evolutionary-type advancing front algorithm” (2014), submitted.

[24] S. Riehl and P. Steinmann. “An integrated approach to shape optimization and mesh adaptivity based on material residual forces”. *Computer Methods in Applied Mechanics and Engineering* 278.0 (2014), pp. 640 –663.

[25] S. Riehl, J. Friederich, M. Scherer, R. Meske, and P. Steinmann. “On the discrete variant of the traction method in parameter-free shape optimization”. *Computer Methods in Applied Mechanics and Engineering* 278.0 (2014), pp. 119 –144.

[26] P. Saxena, M. Hossain, and P. Steinmann. “Nonlinear magneto-viscoelasticity of transversally isotropic magneto-active polymers”. *Proceedings of the Royal Society A* 470.2166 (2014), pp. 1–23.

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[28] S. Schindler, M. Zimmermann, J.C. Aurich, and P. Steinmann. “Thermo-elastic deformations of the workpiece when dry turning aluminum alloys - A finite element model to predict thermal effects in the workpiece”. *CIRP Journal of Manufacturing Science and Technology* 7 (2014), pp. 233–245.

[29] S. Schmaltz and K. Willner. “Comparison of Different Biaxial Tests for the Inverse Identification of Sheet Steel Material Parameters”. *Strain* 50.5 (2014), pp. 389–403. ISSN: 1475-1305.

[30] S. Sitzmann, K. Willner, and B. Wohlmuth. “A dual Lagrange method for contact problems with regularized contact conditions”. *International Journal for Numerical Methods in Engineering* (2014). DOI: `10.1002/nme.4683`.

[31] D. Süß and K. Willner. “Investigation of a jointed friction oscillator using the Multiharmonic Balance Method”. *Mechanical Systems and Signal Processing* 52 (2015), pp. 73–87.

[32] F. Vogel, J-P. V. Pelteret, S. Kaessmair, and P. Steinmann. “Magnetic force and torque on particles subject to a magnetic field”. *European Journal of Mechanics A/Solids* (2014). DOI: `10.1016/j.euromechsol.2014.03.007`.

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6.2 Contributions to Proceedings

[1] F. Beyer and K. Willner. “Surface Deformation Due to Shear and Ploughing - an approach with a half-space model”. In: *Proceedings of the 85th Annual Meeting of the International Association of Applied Mathematics and Mechanics.* (Erlangen, Germany). Ed. by P. Steinmann G. Leugering. 2014, pp. 239–240.

[2] S. Budday, P. Steinmann, and E. Kuhl. “A mechanical approach to explain cortical folding phenomena in healthy and diseased brains”. In: *Proceedings of the 85th Annual Meeting of the International Association of Applied Mathematics and Mechanics.* Ed. by P. Steinmann and G. Leugering. Erlangen, Germany, 2014, pp. 101–102.

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6.3 Talks

[1] F. Beyer and K. Willner. *Surface Deformation Due to Shear and Ploughing - an approach with a half-space model.* Gesellschaft für Angewandte Mathematik und Mechanik. Erlangen, Germany, Mar. 13, 2014.

[2] S. Budday, P. Steinmann, and E. Kuhl. *A mechanical approach to explain cortical folding phenomena in healthy and dieseased brains.* 85^{th} Annual Meeting of GAMM. Erlangen, Germany, Mar. 11, 2014.

[3] D. Davydov, J-P. V. Pelteret, and P. Steinmann. *Comparison of several staggered atomistic-to-continuum concurrent coupling strategies.* 85th Annual meeting of the International Association of Applied Mathematics and Mechanics. Mar. 10, 2014.

[4] D. Davydov, J-P. V. Pelteret, and P. Steinmann. *Comparison of several staggered atomistic-to-continuum concurrent coupling strategies.* 11th World Congress on Computational Mechanics. Aug. 20, 2014.

[5] D. Davydov, J-P. V. Pelteret, A. Javili, and P. Steinmann. *Atomistic to Continuum Coupling: the Promise of Studying Defects at the sub-Micron Scale.* IUTAM Symposium on Micromechanics of Defects in Solids. June 9, 2014.

[6] D. Davydov, J-P. V. Pelteret, A. Javili, and P. Steinmann. *Bridging scales - from Molecular Mechanics to Continuum Mechanics. Theoretical link, size effects and concurrent coupling strategies.* EAM Young Researchers’ Day 2014. Feb. 17, 2014.

[7] F. Endres and P. Steinmann. *Molecular static simulations of domain wall behaviour of ferroelectric barium titanate in the rhombohedral phase.* 10th International Workshop Direct and Inverse on Problems on Piezoelectricity. Vienna, Austria, Sept. 22, 2014.

[8] F. Endres and P. Steinmann. *Molecular static simulations of ferroelectric material hysteresis behaviour.* 86th Annual Meeting of GAMM. Erlangen, Germany, Mar. 14, 2014.

[9] F. Endres and P. Steinmann. *On an atomistic scale finite element method for the simulation of ferroelectric functional materials.* 2nd Seminar on the Mechanics of Multifunctional Materials. Bad Honnef, Germany, May 6, 2014.

[10] A. Esmaeili, A. Javili, and P. Steinmann. *Thermomechanical coupling of geometrically non-coherent interfaces.* GAMM. Erlangen, Germany, Mar. 10, 2014.

[11] S. Fillep, J. Mergheim, and P. Steinmann. *Computational homogenization of fiber structured material.* GAMM. Erlangen, Germany, Mar. 12, 2014.

[12] J. Friederich, G. Leugering, and P. Steinmann. *Sensitivities for topological graph changes in finite element meshes and application to adaptive refinement.* GAMM. Erlangen, Germany, Mar. 11, 2014.

[13] S. Germain, P. Landkammer, and P. Steinmann. *A comparison between a recursive method based on an inverse mechanical formulation and shape optimization for solving inverse form finding problems.* 85th Annual Meeting of the International Association of Applied Mathematics and Mechanics. Erlangen, Germany, Mar. 14, 2014.

[14] M. Hossain, P. Saxena, and P. Steinmann. *Finite strain modelling for the curing process in magneto-viscoelasticity.* ACME. Exeter, UK, Apr. 2, 2014.

[15] M. Hossain, P. Saxena, and P. Steinmann. *Modelling the curing process in viscoelastic magneto-sensitive materials.* PACAM. Santiago, Chile, Mar. 24, 2014.

[16] M. Hossain and P. Steinmann. *A comprehensive study on electro-mechanically coupled characterization of VHB 4910 polymer.* GAMM. Erlangen, Germany, Mar. 10, 2014.

[17] M. Hossain and P. Steinmann. *Electro-mechanically coupled properties of VHB 4905 polymers with prestretching: Experiments, modelling and validations.* 14th European Mechanics of Materials Conference (EMMC14). Gothenburg, Sweden, Aug. 27, 2014.

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[19] M. Jerschl, D. Süß, and K. Willner. *Numerical Continuation Methods for the Concept of Non-linear Normal Modes.* IMAC. Orlando, USA, Feb. 3, 2014.

[20] M. Jerschl, D. Süß, and K. Willner. *Path continuation for the concept of Non-linear Normal Modes using different corrector algorithms.* ISMA. Leuven, Belgium, Sept. 16, 2014.

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[22] S. Kaessmair, A. Javili, and P. Steinmann. *A Study on Mixed Finite Element Formulations Applied to Diffusion Problems.* 85th Annual Meeting of GAMM. Erlangen, Germany, Mar. 13, 2014.

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[24] J. Kaschta, B. Walter, and M. Musialek. *Rheologisches Verhalten magnetorheologischer Fluide und Elastomere auf Basis von Flüssigsilikon.* Geesthachter Polymertage: Praktische Rheologie von Polymeren – Grundlagen und Anwendungen. Geesthacht, Germany, Nov. 19, 2014.

[25] P. Landkammer, S. Germain, and P. Steinmann. *A fast approach to shape optimization by using the inverse FEM.* 17th ESAFORM Conference. Espoo, Finland, May 8, 2014.

[26] P. Landkammer, S. Germain, and P. Steinmann. *On recursive strategies for inverse form finding in metal forming applications.* 39th Solid Mechanics Conference. Zakopane, Poland, Sept. 4, 2014.

[27] P. Landkammer, S. Germain, and P. Steinmann. *Optimum blank design by using the inverse FEM in anisotropic elastoplasticity.* 85th GAMM Annual Meeting. Erlangen, Germany, Mar. 12, 2014.

[28] V. Luchscheider, M. Maidorn, and K. Willner. *Computation of the effective lamination stack's behavior considering the contact simulation with a multi-scale homogenization.* 11th World Congress on Computational Mechanics (WCCM XI). Barcelona, Spain, July 24, 2014.

[29] V. Luchscheider, M. Maidorn, and K. Willner. *Identification of the laminated stack's behavior simulated with a multi-scale homogenization using a progressive contact formulation.* Gesellschaft für angewandte Mathematik und Mechanik GAMM. Erlangen, Germany, Mar. 14, 2014.

[30] J-P. V. Pelteret, P. Saxena, B. Walter, D. Davydov, and P. Steinmann. *Towards a computational model of magneto-sensitive polymers.* 85th Annual Meeting of the International Association of Applied Mathematics and Mechanics. Mar. 10, 2014.

[31] S. Pfaller and P. Steinmann. *Entwicklung einer Kopplung von Molekulardynamik und Finiten Elementen zur Simulation von Nanokompositen.* Wissenschaftskolloquium Nanotechnologie für Kunststoffverbunde. Braunschweig, Germany, Sept. 30, 2014.

[32] D. Riedlbauer, J. Mergheim, and P. Steinmann. *Thermomechanical Simulation of the Electron Beam Melting Process for TiAl6V4.* GAMM 2014. Erlangen, Germany, Mar. 12, 2014.

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[36] S. Riehl, J. Friederich, and P. Steinmann. *On regularization in parameter-free shape optimization.* 85^{th} Annual Meeting of the International Association of Applied Mathematics and Mechanics. Mar. 13, 2014.

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[39] P. Saxena, M. Hossain, B. Walter, J-P. V. Pelteret, and P. Steinmann. *Rate dependent deformations in magneto-rheological elastomers: Modelling and Experiments.* IUTAM Symposium on Thermomechanical-Electromagnetic coupling in solids: Microstructural and Stability Aspects. June 16, 2014.

[40] S. Schindler, M. Zimmermann, J.C. Aurich, and P. Steinmann. *A two-scale simulation method accounting for thermal effects during turning.* 85^{th} Annual Meeting of GAMM. Erlangen, Germany, Mar. 13, 2014.

[41] S. Schindler, M. Zimmermann, J.C. Aurich, and P. Steinmann. *Finite element model to calculate the thermal expansions of the tool and the workpiece in dry turning.* 6th CIRP HPC. Berkeley, USA, June 24, 2014.

[42] S. Schmaltz. *Identification of material behavior via a Finite Element Model Updating strategy.* Erlangen, Germany, Mar. 14, 2014.

[43] S. Schmaltz. *Inverse sheet steel material parameter identification via FEMU and DIC using biaxial testing.* Cambridge, UK, 2014-07-08.

[44] O. Schmitt, J. Friederich, and P. Steinmann. *Manufacturing constraints in parameter–free sensitivity–based shape optimization.* First International Conference on Engineering and Applied Sciences Optimization. Kos Island, Greece, June 5, 2014.

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[47] P. Steinmann, S. Pfaller, G. Possart, F. Müller-Plathe, M. Rahimi, and M.C. Böhm. *Multiscale simulations of nanocomposites: an approach to couple molecular dynamics and FE.* 6th WINTER COLLOQUIUM "Mechanics and Advanced Materials". La Clusaz, France, Feb. 25, 2014.

[48] D. Süß and K. Willner. *Harmonic Balance Analysis of Bolted Structures in the Frequency Domain.* World Congress on Computational Mechanics WCCM. Barcelona, Spain, July 24, 2014.

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[53] B. Walter, P. Saxena, J. Kaschta, D.W. Schubert, and P. Steinmann. *Magneto-Sensitive Elastomers: An Experimental Point of View.* 85th Annual Meeting of the International Association of Applied Mathematics. Erlangen, Germany, Mar. 13, 2014.

[54] B. Walter, P. Saxena, J-P. Pelteret, J. Kaschta, D.W. Schubert, and P. Steinmann. *On the Preparation, Characterication, Modelling and Simulation of Magneto-Sensitive Elastomers.* Second Seminar on the Mechanics of Multifunctional. Bad Honnef, Germany, May 7, 2014.

[55] B. Walter, P. Saxena, J-P. V. Pelteret, J. Kaschta, D. Schubert, and P. Steinmann. *On the Preparation, Characterisation, Modelling and Simulation of Magneto-Sensitive Elastomers.* Second Seminar on the Mechanics of Multifunctional Materials. May 5, 2014.

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[58] P. Wilhelm, P. Steinmann, and J. Rudolph. *Compilation of Fatigue Data for Austenitic Stainless Steels.* Annual Meeting on Nuclear Technology. Berlin, Germany, May 7, 2014.

[59] P. Wilhelm, P. Steinmann, and J. Rudolph. *Einbindung der neuen Regelwerksanforderungen in lokale Fatigue-Monitoring Lösungen.* Materials Testing Institute (MPA)-Workshop: Ermüdungsverhalten von Bauteilen in Leichtwasserreaktoren unter Berücksichtigung des Kühlmediums. Stuttgart, Germany, Sept. 10, 2014.

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