Annual Report
2013

Chair of Applied Mechanics
Prof. Dr.-Ing. Paul Steinmann
Prof. Dr.-Ing. Kai Willner
Prof. Dr.-Ing. Julia Mergheim
University of Erlangen-Nuremberg

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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 2013. 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 incentives in terms of excursions, summer barbeques 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:
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Professorship for Structural Mechanics:
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Professorship for Computational Mechanics:
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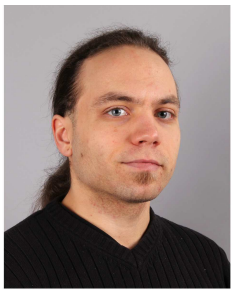

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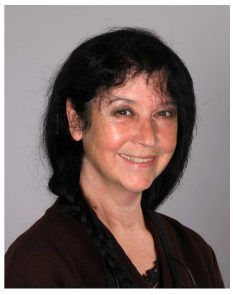
D. Pausewang



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M. Roux

W. Steinbach

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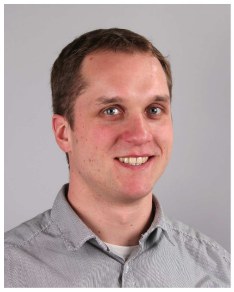

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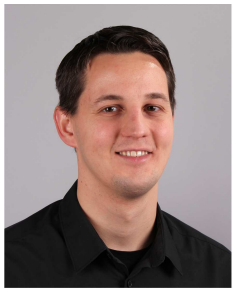

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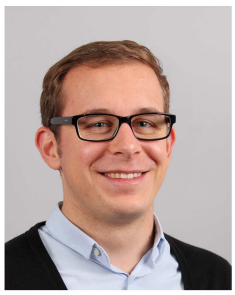
S. Schmaltz

U. Schmidt

O. Schmitt



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F. Vogel

D. K. Vu

B. Walter

J. Wang

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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 the students enrollment fees as requested at Bavarian universities 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 2013. 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 2013. 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 modelling, 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.

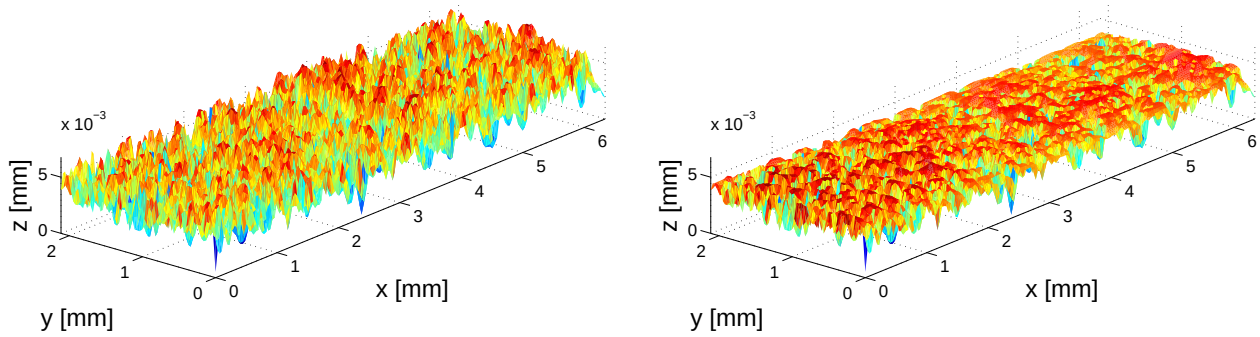
Influence of Friction on Plastic Deformation at Tangential Displacement

Florian Beyer, Kai Willner

Friction has a remarkable impact on manufacturing processes. It is primarily caused by adhesion and ploughing [1]. A model considering the effect of adhesion has been developed [2]. The elasto-plastic model based on half-space theory is capable to compute the tribological behaviour between two surfaces due to normal load with high accuracy and is validated with a comparison to FE simulations. In order to gain advanced insight of friction conditions the model has to be further developed. For this, the aspects of ploughing are investigated. Ploughing is the plastic deformation of a soft surface by a hard contact partner. It occurs between contact partners of different hardness or in the presence of hard particles. The aim is to determine the plastic work done due to tangential motion. The plastic work W_d is necessary for the deformation of the surface asperities that get newly into contact due to the tangential motion. Relating W_d to the apparent contact area A_0 the equation

$$\tau_d = \frac{W_d}{A_0 u} = \frac{w_d}{u}$$

expresses the area-related tangential force τ_d in dependency on the tangential displacement u and the area-related plastic deformation w_d. w_d is investigated with the half-space model. Here, two surfaces get into contact. After full application of the predefined load, the surfaces are moved relatively to each other and the load is applied again. This is repeated several times. The displacement is equal to the width of one element of the discretizied surface. Figure 1 depicts the surface of the workpiece before and after the whole contact simulation.



a) b)

Figure 1: Workpiece before (a) and after (b) load application

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

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[1] F.P. Bowden, D. Tabor, *The friction and lubrication of solids*. Oxford University Press, 1986

[2] F. Hauer, K. Willner. Halfspace Modeling of Elastic-Plastic Contact of Rough Surfaces. *Computational Plasticity XI - Fundamentals and Applications. COMPLAS XI*, 965-975 (2011).

Surface magneto- electro- elasticity

George Chatzigeorgiou, Ali Javili, Paul Steinmann

While the surface elasticity theory is well-established today to study the mechanical behavior of nano-materials, a theory to model surface magnetic and electric behavior is missing. It has been observed experimentally that the strength and direction of magnetization are markedly different between the boundary surface and the bulk. Furthermore, experimental evidences show that the electric performance of a particle can be improved with surface modification. Also, it has been observed that the increase of the area-to-volume ratio (i.e. decrease of the particle and/or grain size) can influence substantially the overall dielectric constant. All these observations can be, from a phenomenological point of view, explained by a surface magneto-electro- elasticity theory.

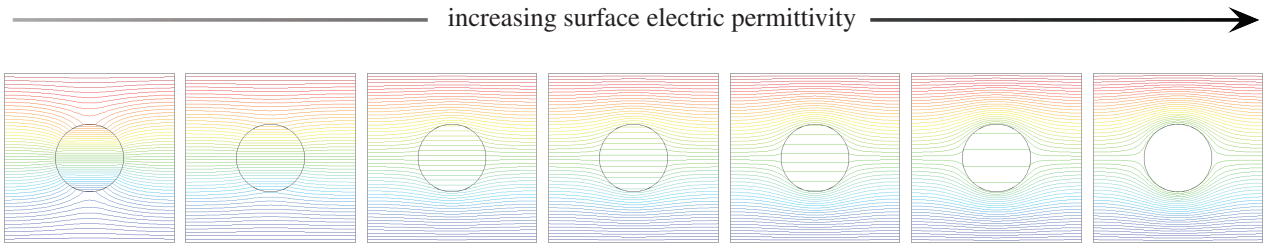

Figure 1: Distribution of the scalar electric potential under the influence of surface electric permittivity.

The objective of this project is to study the magnetic and electric response of materials accounting for boundary surface energies and coupled to elasticity. To do so, the boundary is equipped with its own magnetic and electric constitutive behavior motivated by that of the surface elasticity theory of Gurtin and Murdoch [1] and its extension to the surface thermo-elasticity [2]. The response of materials with energetic boundary surfaces (surfaces that possess material properties and constitutive structures different from those of the bulk) is formulated in a thermodynamically consistent manner. The theory is accompanied by numerical examples on porous materials using the finite element method, where the influence of the surface magnetic permeability and surface electric permittivity are examined. Conceptually speaking, this contribution can be understood as an extension of the surface elasticity theory, however, it involves certain additional complexities due to the presence of a surface curl operator which is not standard [3, 4].

References

[1] M. E. Gurtin, A. I. Murdoch. A continuum theory of elastic material surfaces. *Archive for Rational Mechanics and Analysis* **57**, 291–323 (1975).

[2] A. Javili, P. Steinmann. On thermomechanical solids with boundary structures. *International Journal of Solids and Structures* **47**, 3245–3253 (2010).

[3] G. Chatzigeorgiou, A. Javili, P. Steinmann. Surface magnetoelasticity. *submitted*.

[4] G. Chatzigeorgiou, A. Javili, P. Steinmann. Surface electrostatics - theory and computations. *submitted*.

A coupled MD-FE simulation method accounting for interphases in nanoparticle filled thermoplastics

Denis Davydov, Jean-Paul Pelteret, Ali Javili, Paul Steinmann

The basic framework to link the atomistic and the continuum world was introduced in [1, 2, 3]. This approach allows a comparison of the MD and surface-enhanced FE solutions [4]. Several staggered schemes used to couple continuum mechanics and molecular mechanics were proposed [5]. The coupling schemes were decomposed into the surface-type (displacement or traction boundary conditions) and the volume-type. It was found that the displacement (surface) coupling scheme and the Lagrangian (volume) scheme based on either discrete displacements or the H_1 norm derived from continuous displacement fields provide the best performance.

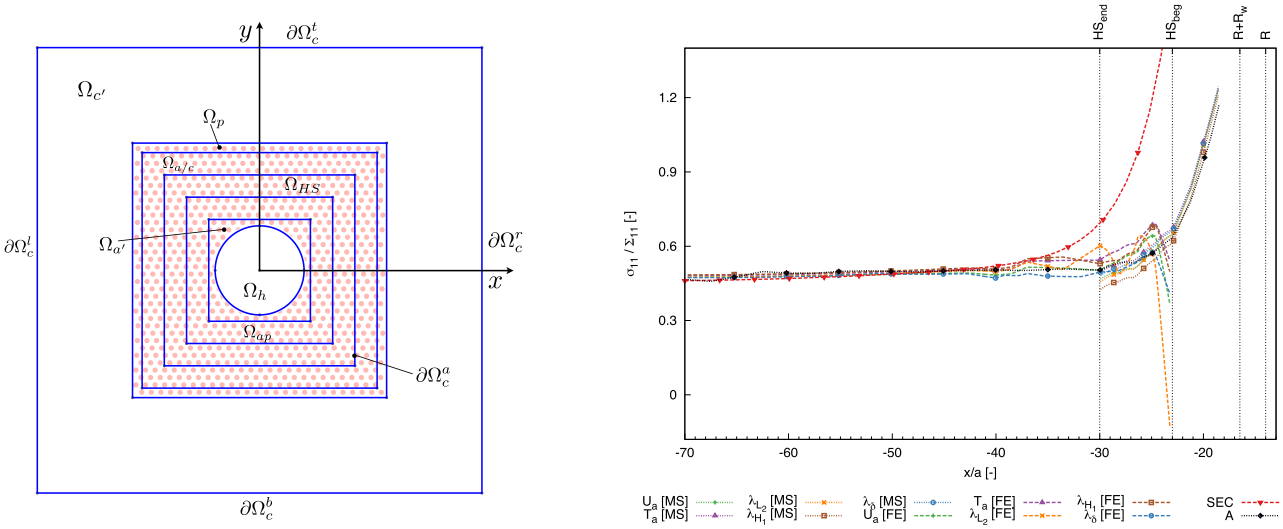

Figure 1: Left: the domains considered in the staggered coupling methods; Right: A comparison of kinetic quantities (Cauchy stress) as calculated from the atomistic and continuum approaches.

The application of this methodology to the case of polymers with nanoparticles is work in progress. The financial support of the German Science Foundation (Deutsche Forschungsgemeinschaft, DFG) , grant STE 544/46-1, is gratefully acknowledged.

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[1] D. Davydov, 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*, 1–23 (2013).

[2] D. Davydov, P. Steinmann. Reviewing the roots of continuum formulations in molecular systems. Part II: Energy and Angular Momentum Balance Equation. *Mathematics and Mechanics of Solids*, 1–16 (2013).

[3] D. Davydov, P. Steinmann. Reviewing the roots of continuum formulations in molecular systems. Part III: Stresses, Couple Stresses, Heat Fluxes. *submitted.*

[4] D. Davydov, A. Javili, P. Steinmann. On molecular statics and surface-enhanced continuum modeling of nano-structures. *Computational Materials Science* **69**, 510–519 (2013).

[5] D. Davydov, J-P. Pelteret, P. Steinmann. Comparison of several staggered atomistic-to-continuum concurrent coupling strategies. *submitted.*

Molecular static simulation of ferroelectric materials

Florian Endres, Paul Steinmann

Ferroelectric materials have been studied and simulated on different length scales with different material models for decades. Especially the core shell model, which is commonly used for molecular dynamics simulations obtains excellent results. However, applications to systems with macroscopic length scales are limited by the complexity of such simulation models and the computational effort of such calculations. Especially very short time steps used in molecular dynamics are a limitation to the simulated system size.
Due to these disadvantages of molecular dynamics a molecular static algorithm based on the finite element method has been applied. Using the interaction potentials of the core shell model [1], the total internal potential energy of a particle system can be described by:

$$\Phi_{int} = \sum_{i=1}^{N} \sum_{\substack{j \neq i \\ |\mathbf{r}_{ij}|<R_c}} \frac{1}{4\pi\epsilon_0}\frac{q_i q_j}{|\mathbf{r}_{ij}|} + A\exp\left(-\frac{|\mathbf{r}_{ij}|}{\rho}\right) - \frac{C}{|\mathbf{r}_{ij}|^6} + \frac{1}{2}k_2 |\mathbf{r}_{ij}|^2 + \frac{1}{24}k_4 |\mathbf{r}_{ij}|^4$$

Using a finite element discretization the deformation of a particle system can be derived by minimization:

$$\min_{\mathbf{r}_{i\in\mathcal{N}_a}} \Phi(\{\mathbf{r}_j\}_{j\in\mathcal{N}_a}) \;\Rightarrow\; \frac{\partial\Phi}{\partial\mathbf{r}_i}(\{\mathbf{r}_j\}_{j\in\mathcal{N}_a}) = 0$$

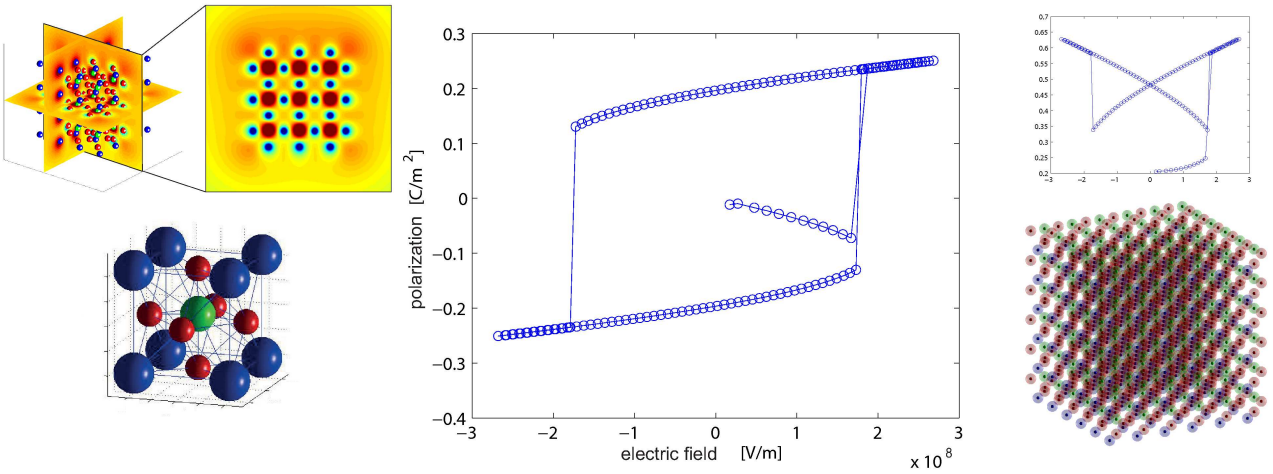

Figure 1: Dielectric hysteresis loop of ferroelectric barium titanate

The aim of this project is the development of an efficiant algorithm for the calculation of ferroelectric materials considering the stress-strain response of an atomistic system under electromechanical loading. Furthermore domain walls, nanostructures and polarization switching processes are investigated. In a next step the quasi-static algorithm will be combined with a continuum mechanics framework e.g. the quasicontinuum method or the FE^2 method.

References

[1] S. Tinte, M. Stachiotty, M. Sepliarsky, R. Migoni and C.O. Rodriguez. Atomistic modelling of $BaTiO_3$ based on first-principles calculations. *Journal of Physics: Condensed Matter* **11**, 9679–9690 (1999)

A Novel Cohesive Zone Model Accounting for In-plane Stretch

Ali Esmaeili, Ali Javili, Paul Steinmann

Interfaces play an important role in mechanical and thermal responses of a body due to possessing different properties than that of the bulk. The purpose of this project then is to study these properties and their effects on the overall mechanical and thermal responses of the material. The interface in the present work is not only geometrically noncoherent but also is mechanically resistant in tangential direction. To numerically model such an interface, a classical cohesive zone model using decohesion elements with mixed-mode capability is used, including an exponential traction-separation law as the constitution relation to relate cohesive traction to the jump in geometry [1]. The implementation also considers the irreversibility and finite deformation for the model and is performed using the finite element method.

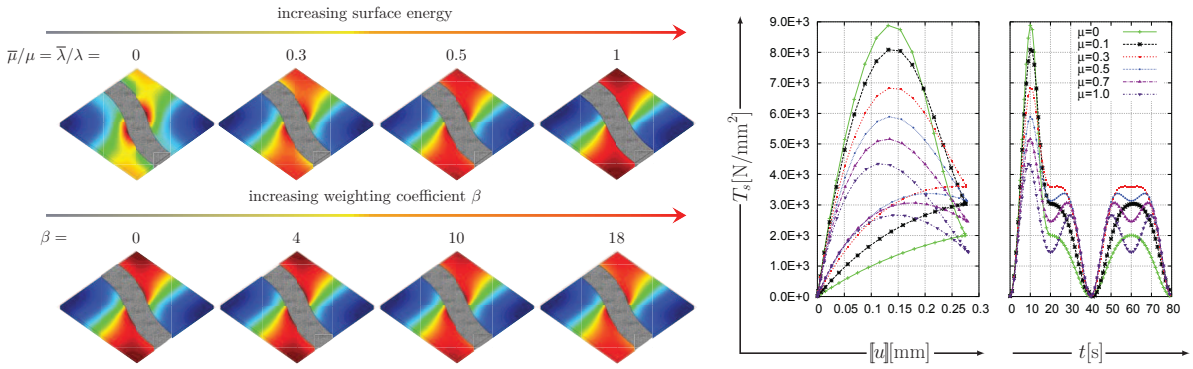

Figure 1: Influence of critical shear-to-normal traction ratio β and interface tangential elastic parameters $\overline{\mu}$, $\overline{\lambda}$ on the stress distribution of the bulk

In addition to the classical strategies, interfacial elements are allowed to have in-plane stretch resistance by assuming a hyperelastic interface Helmholtz energy $\overline{\Psi}_{\mathrm{e}}(\overline{\mathbf{F}})$ a function of rank-deficient interface deformation gradient $\overline{\mathbf{F}}$ [2]. Therefore, the interface potential consists of two parts as $\overline{\Psi}\left(\overline{\mathbf{F}}, [\![\mathbf{u}]\!]\right) = \overline{\Psi}_{\mathrm{c}}([\![\mathbf{u}]\!]) + \overline{\Psi}_{\mathrm{e}}(\overline{\mathbf{F}})$, where $\overline{\Psi}_{\mathrm{c}}$ is the cohesive free energy which, depends on the jump in geometry $[\![\mathbf{u}]\!]$.
The results in the figure demonstrate a loading-unloading procedure applied on a semi-three-dimensional strip with a curved interface with increasing interface and cohesive energies. According to these results, the more the interface energy, the less the magnitude of the shear component of the cohesive traction which, in turn, can affect the value of the effective traction. Finally, it is of interest that by increasing the interface energy the stress distribution becomes more and more similar to what is expected from a geometrically coherent interface with surface energy: a non-uniform distribution of stress field.

References

[1] M. Ortiz, I. Pandolfi. Finite-Deformation Irreversible Cohesive Elements for Three-dimensional Crack-propagation Analysis. *International Journal for Numerical Methods in Engineering* **44**, 1267–1282 (1999).

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On the homogenization of technical textiles

Sebastian Fillep, Julia Mergheim, Paul Steinmann

Technical textiles show a nonlinear constitutive behavior that differs from the underlying fiber material and is significantly influenced by heterogeneities on the micro level, e.g. the structural assembly of the fibers and appearing contact zones. To reduce the time and costs for experiments for each practical application case a reliable computational method for the identification of macroscopic material properties in dependency of the micro structure in the sense of a numerical laboratory is needed.
On the macroscopic level textiles are characterized by a large area-to-thickness ratio, such that a discretization with shell elements is numerically efficient. To capture the contact behavior the representative volume element is explicitly modeled by means of a volumetric micro sample. The challenge is to transfer the information across length scales. Hence, a suitable, shell specific multi-scale method was developed [1, 2, 3], which connects the homogeneous macro level to a fibre structured micro sample including a shell specific Hill-Mandel condition.

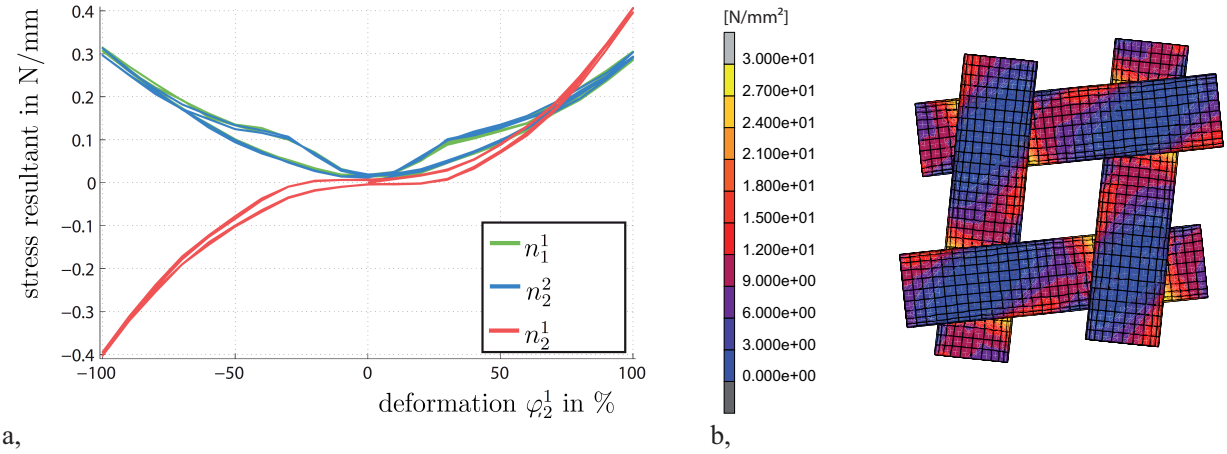

Figure 1: Diagram of the computed stress resultants (a) and von Mises plot of the woven representative volume element loaded by in-plane shear deformation (b).

The resulting nonlinear material behavior can be considered in Figure 1a for a loading and unloading loop of the woven sample, Figure 1b. It shows a progressive shape and a hysteresis, which both results from the contact between the fibres. The fiber shows elastic material behavior. Therewith physically motivated phenomenological constitutive laws can be derived.

References

[1] S. Fillep, J. Orlik, Z. Bare, P. Steinmann. Homogenization in periodically heterogeneous elastic bodies with multiple micro contact. Mathematics and Mechanics of Solids, doi: 10.1177/1081286513501104, (2013).

[2] S. Fillep, J. Mergheim, P. Steinmann. Computational modelling and homogenization of technical textiles, Engineering Structures 50, pp.68-73, (2013).

[3] S. Fillep, J. Mergheim, P. Steinmann. Homogenization of heterogeneous, fibre structured materials, Proceedings of the XII International Conference on Computational Plasticity – Fundamentals and Applications, Editors: E. Onate, D.R.J. Owen, D. Peric, B. Suarez, (2013).

An adaptive finite element method based on sensitivities for node insertion

Jan Friederich, Günter Leugering[1], Paul Steinmann

[1] Chair of Applied Mathematics II, University of Erlangen-Nuremberg

We propose a novel approach to adaptive refinement in FEM based on local sensitivities for node insertion [1]. To this end, we consider refinement as a continuous graph operation, for instance by splitting nodes along edges as depicted in Figure 1, and introduce the concept of the topological mesh derivative for a given objective function J: Considering Galerkin solutions $u_h \in V_h$ and $u_h^\epsilon \in V_h^\epsilon$ of a linear second-order elliptic PDE corresponding to the finite element mesh $\mathcal{T}_h$ and the continuously refined mesh $\mathcal{T}_h^\epsilon$, respectively, we define

$$D_E J(u_h) = \lim_{\epsilon \to 0} \frac{J(u_h^\epsilon) - J(u_h)}{\epsilon}.$$

For the computation of $D_E J(u_h)$ for a large class of functionals J we rely on the analytical derivation of the first-order asymptotic expansion of u_h^ϵ with respect to $\epsilon > 0$. As a basic application as well as a proof of concept, we consider the total potential energy of the given variational problem, minimization of which can be shown to decrease the approximation error $\|u - u_h\|$ in the energy norm. In fact, we may define an refinement indicator ι_E in terms of $D_E J(u_h)$ which can be shown to be equivalent to both, the (quadratic) energy error $\|u - u_h\|^2$ as well as the decrease of the (quadratic) energy error $\|u - u_h\|^2 - \|u - u_h^\epsilon\|^2$ upon refinement of edge E with $\epsilon = \frac{1}{2}$ (except for higher-order oscillations). These results render our approach competitive in adaptive refinement. The numerical performance of the proposed indicator ι_E is illustrated in Figure 2 and Figure 3 for the crack problem described in [2].

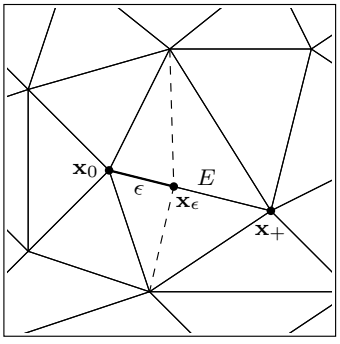

Figure 1: Insertion of the new node $\mathbf{x}_\epsilon$ along edge $E = (\mathbf{x}_0, \mathbf{x}_+)$ by a continuous mesh change parametrized in the variable $\epsilon > 0$.

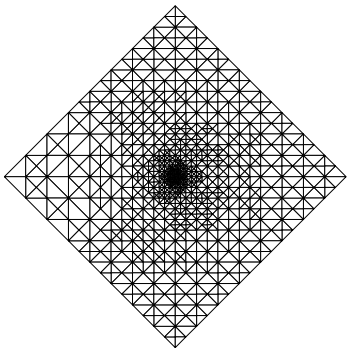

Figure 2: Refined mesh for the crack problem [2] generated by an adaptive algorithm using the proposed refinement indicator ι_E based on $D_E J(u_h)$.

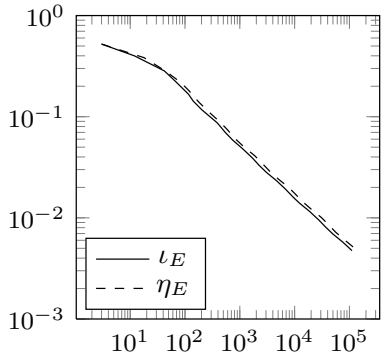

Figure 3: Energy error $\|u - u_h\|$ vs. $N = \dim(V_h)$ for adaptive algorithms using ι_E and the standard residual-based error indicator η_E for the crack problem [2].

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On a recursive formulation for solving inverse form finding problems in isotropic elastoplasticity

Sandrine Germain, Philipp Landkammer, Paul Steinmann

In this work we developed a new formulation for solving inverse form finding problems in isotropic elastoplasticity [1]. With this new formulation we are able to counter the non uniqueness of the undeformed form of a workpiece obtained with the inverse mechanical formulation [2] and mesh distortions which might appear when using shape optimisation [3]. The idea is to use a recursive formulation as presented in Figure 1. First, the inverse mechanical formulation is applied to the target deformed configuration of the workpiece with the set of internal variables set to zero. Subsequently a direct mechanical formulation is performed on the resulting undeformed configuration. The so obtained deformed configuration is furthermore compared with the target deformed configuration of the component. If the difference is negligible, the wanted undeformed configuration of the functional component is obtained. Otherwise the computation of the inverse mechanical formulation is started again with the target deformed configuration and the current state of internal variables obtained at the end of the computed direct formulation. This process is continued until convergence is reached. Three numerical examples are presented in [1] to find the undeformed form of a functional component and to illustrate the recursive formulation. In our three experiments, the convergence was reached after five, six and nine iterations, respectively, when the set of internal variables is set to zero at the beginning. It was furthermore found that the initial state of the internal variables has an influence on the convergence of the recursive formulation but not on the result, if convergence can be reached.

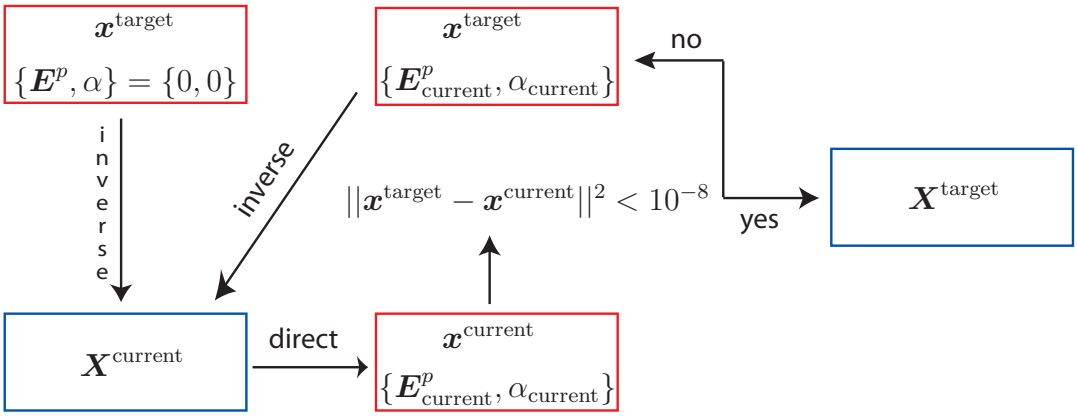

Figure 1: Schematic view of the recursive formulation [1].

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

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Simulation of thermoelectric materials

Sandrine Germain, Paul Steinmann

The thermoelectric effect embraces the Seebeck effect (a temperature difference creates an electric potential), the Peltier effect (an electric potential creates a temperature difference) and the Thomson effect (heating or cooling of a conductor with a temperature gradient). Materials used in such effects are called thermoelectric materials. Applications for such materials are for example in conceiving thermoelectric generator (automotive, radioisotope, thermopile...) or thermoelectric cooling (refrigerators, camping devices, computer components...) and in temperature measurement (thermocouple...). The most utilised thermoelectric material is bismuth telluride (Bi_2Te_3). In the following example a thermoelement showed in Figure 1 is used for simulating the nonlinear coupled Seebeck effect as in [1]. The thermoelement has a rectangular base of 1.524 x 1.4 mm and a thickness of 1.4 mm. On the left and right hand side a temperature of 25 °C and an electric potential of 0.058 V and 0 V, respectively, are applied. The thermoelement is discretized with isoparametric elements where voltage and temperature are the two degrees of freedom per node. In Figure 2 it can be seen that the analytical and the numerical solutions for the computation of the electric potential and the temperature are in very close agreement. With the applied boundary conditions the thermoelement works as a heat pump where the temperature maximum is obtained at the center.

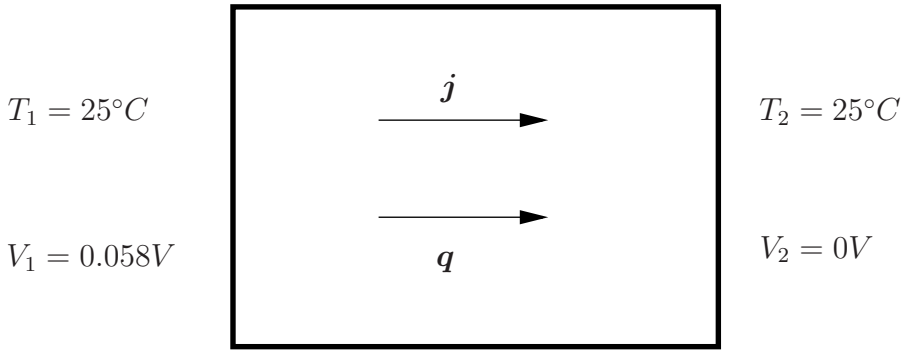

Figure 1: Thermoelement with boundary conditions [1].

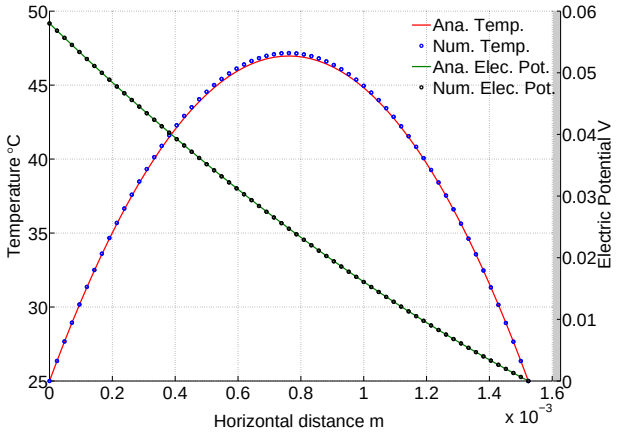

Figure 2: Simulation of the coupled Seebeck effect: analytical and numerical results of the electric potential in V and the temperature in °C.

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Elastic-plastic smoothing of rough surfaces

Franz Hauer, Kai Willner

Contact and friction play a crucial role in many technical applications and processes like for example bearings and metal forming. The surface roughness has a huge influence on friction, because material contact only occurs on the top of surface roughness peaks for moderate normal pressures. A very efficient simulation tool for elastic rough surface contact is the halfspace model. However the local contact pressures can exceed the average contact pressures by far, if the roughness is large. Therefore a purely elastic model is not suitable under many circumstances. A straightforward approach to deal with plastic surface contact is limiting the surface pressure in the halfspace model to the so called surface hardness [1]. This method is motivated by experimental and numerical analyses.
Yet it is not clear to what extend of plastic deformation this approach leads to reliable results. Therefore an experiment was set up, in which a smooth tool with high hardness contacts a surface structured sheet metal with pressures up to $600\,MPa$.

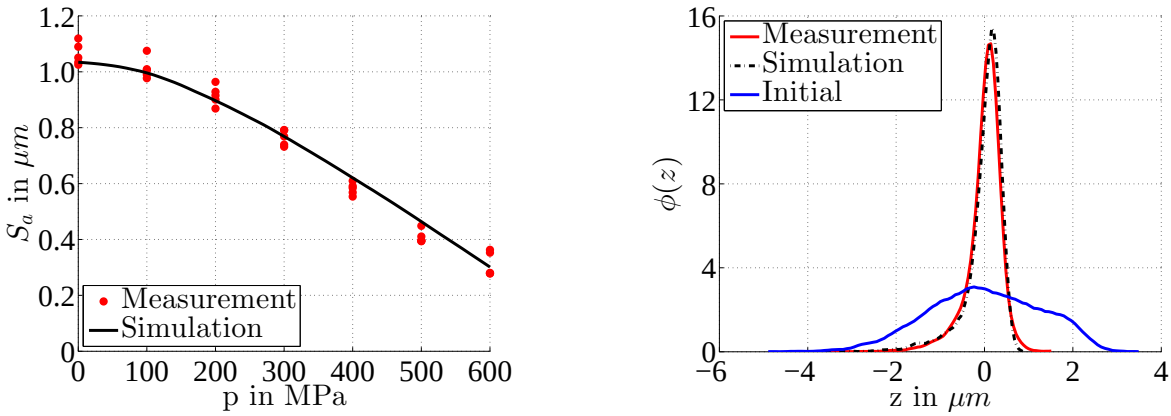

Figure 1: Quadratic surface roughness after contact (a) and probability density of the surface after contact with $600\,MPa$ (b)

Fig. 1 a shows the measured and simulated quadratic surface roughness S_q after contact. The differences between the halfspace simulation results and the measurements from $0\,MPa$ up to $600\,MPa$ are within the variation of the measurements. The probability density of surface heights after contact with $600\,MPa$ are shown in Fig. 1 b. A very good agreement between the measured and the simulated surface shape can be observed, although the surface shape is strongly modified compared to the initial surface.
It has been shown that the halfspace model is a suitable tool for the modelling of elastic-plastic contact of rough surfaces in a wide range of normal pressures. More information about the numerical model and the experimental setup is contained in [2].

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A comprehensive study on electro-mechanical coupled characterization of VHB 4910 polymer

Mokarram Hossain, Duc Khoi Vu, Paul Steinmann

The aim of this illustrative documentation is to present some standard experimental tests with the application of purely mechanical and electro-mechanical coupled loadings in the case of electro-active VHB 4910 polymer. VHB 4910 is a very soft polymer that has potential applications as an electroactive polymer in the production of different types of actuators and sensors. The time-dependent viscoelastic phenomenon is ideal in polymers. Therefore, experiments with electro-mechanical coupled loads have been conducted considering some standard tests that are usually used for a viscoelastic polymeric material characterization, i.e. loading-unloading tests, single-step relaxation tests, multi-step relaxation tests, cf.[1]. In all experimental cases, the polymer samples are pre-stretched up to several hundred percent to make them enough thinner initially so that the application of the electro-mechanical coupled load can show its effect in a large scale. The pre-stretched samples then are subjected to various amount of mechanical as well coupled deformations at different strain rates. The data produced from several loading-unloading tests, single-step relaxation tests, multi-step relaxation tests show that the electric loading has profound effect in the time-dependent behaviour of the electro-active VHB 4910 polymer, cf. Figure (1). The data set from single-step relaxation tests can be used to identify electro-elastic parameters while multi-step relaxation data would be useful for identification of electro-viscoelastic parameters for a suitable constitutive model that can capture electro-mechanical coupled behaviours of VHB 4910. For validation, loading-unloading cyclic tests data can be utilized.

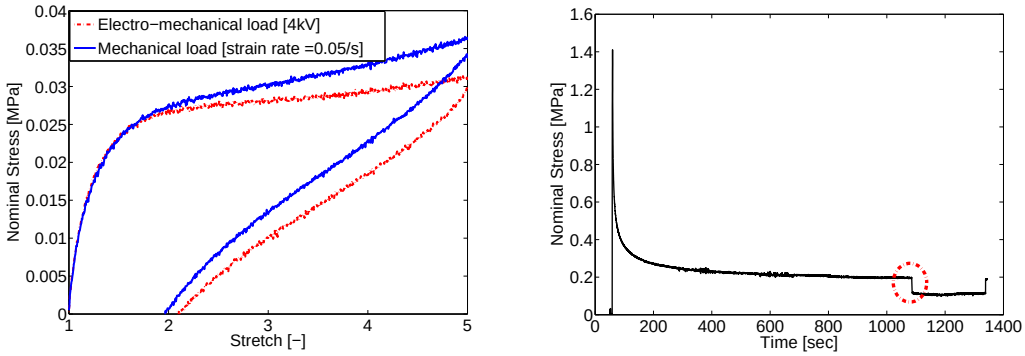

Figure 2: (Left) Loading-unloading test; Nominal stress (MPa) vs deformation on a two hundred percent pre-strained sample. The strain rate is 0.01/s for mechanical deformations as well as for electro-mechanical loads while a four kilovolt electric load is applied in the case of electro-mecahnical coupled tests. It depicts a significant difference between pure mechanical and electro-mechanical coupled responses. (Right) Simple-step relaxation test; Relaxation is occured on a two hundred percent pre-stretched sample. Once maximum mechanical overstress is disappeared the electric load is applied for few minutes and then switch off the loading which shows twenty percent drop of the stress (red circled)

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Interactions of particles in viscous flows

Simone Hürner, Paul Steinmann

Numerical simulations are widely used to predict interactions of particles in viscous flows under various conditions, like the influence of magnetic fields [1] [2] [3]. Normally, these simulations are executed, assuming a Stoke number of zero by implementing the particle behavior into presimulated liquid flow profile [4]. However, this approach neglects the influence of particles on the fluid, which has to be considered for Stokes numbers unequal to zero. In order to optimize these calculations, this work focuses on developing a numerical simulation tool taking into account both interaction of particles in viscous flows and the impact of particles to the fluid itself.

For initial simulations the particles were assumed to be spherical and have diameters in the range of nanometres. In this case they behave in a similar manner as paramagnets and the magnetic force on a single particle reads as:

$$\overrightarrow{F}_m = \frac{1}{2}\mu_0[\chi_p - \chi_f]V_p\overrightarrow{\nabla}(\overrightarrow{H}\cdot\overrightarrow{H})$$

with $[\chi_p - \chi_f]$ the magnetic susceptibility difference between the particle and the fluid, and V_p the particle volume.
Figure 1 shows a simulation of a particle laden flow.

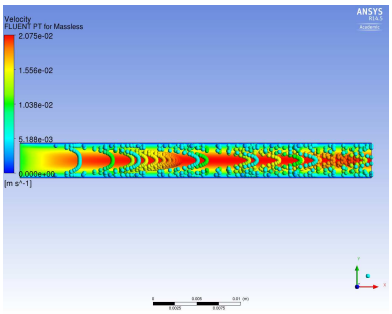

Figure 1: Simulation of a particle laden flow

References

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Computational homogenization in magneto-mechanics

Ali Javili, George Chatzigeorgiou, Paul Steinmann

The objective of this project is to introduce a geometrically nonlinear homogenization framework for composites with magneto-mechanical behavior whereby the composite can be subject to large deformation processes. The magneto-mechanical governing equations for both the overall body and its microstructure are presented, and the connections between micro- and macro-scale field variables are identified. In order to satisfy the energy equivalence between both scales, i.e. the Hill–Mandel condition, suited boundary conditions are derived. It is shown that the use of kinematic and magnetic field potentials instead of kinetic field and magnetic induction potentials provides a more appropriate homogenization process, in which averaging over the representative volume element in the material and spatial description renders equivalent counterparts [1].

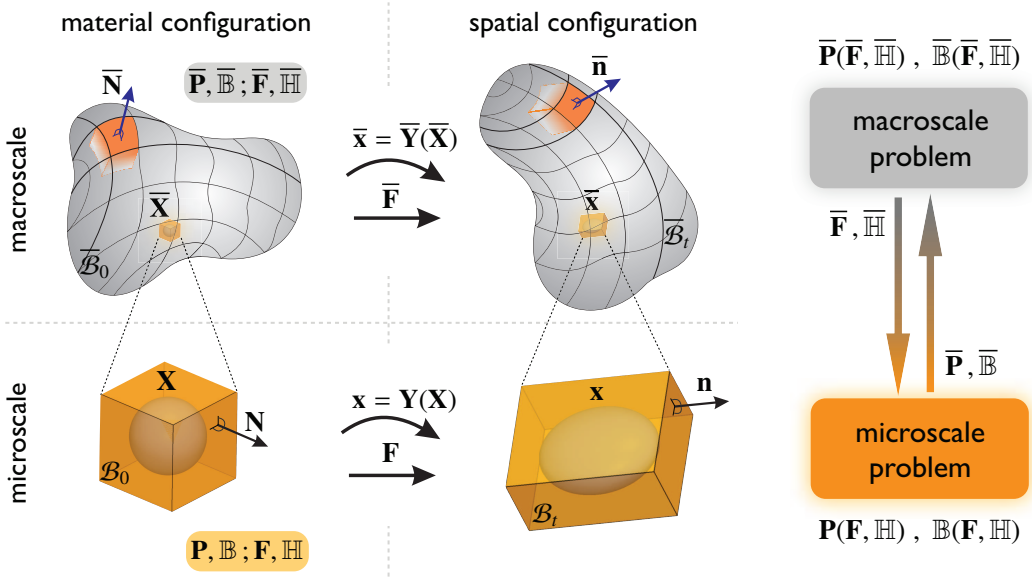

Figure 1: Computational homogenization of magneto-elasticity in a nutshell.

Considering periodic boundary conditions for the microscopic unit cell, a finite element framework for computing the macroscopic field variables and the effective tangent moduli is developed. Equipped with the presented framework, a fully-coupled FE^2 homogenization procedure is carried out and all the steps to link the microstructure to the macrostructure are described. The proposed methodology is utilized to study a variety of two- and three-dimensional numerical examples. Finally, a specific physically motivated problem of a magnetorheological elastomer, consisting of a polymer matrix and iron particles, under finite deformation and applied magnetic field is analyzed and the results are given for several combinations of deformation modes and applied magnetic fields [2].

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Higher-gradient elasticity with energetic boundaries

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In this project we formulate a geometrically nonlinear theory of higher-gradient elasticity accounting for boundary (surface and curve) energies. Such influences are becoming increasingly important when modeling the response of structures at the nanoscale due to the increasing surface to volume ratio. The behavior of the boundaries is well described by continuum theories that endow the surface with its own energetic structures. Such theories often allow the boundary energy density to depend only on the superficial boundary deformation gradient [1]. From a physical point of view though, it seems necessary to define the boundary deformation gradient as the evaluation of the deformation gradient at the boundary rather than its projection. This controversial issue is carefully studied and several conclusions are extracted from the rigorous mathematical framework presented.

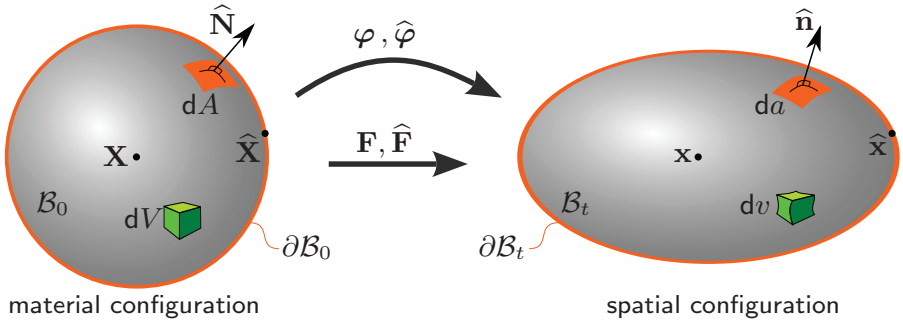

Figure 1: The material configuration and its boundary are mapped to their associated spatial descriptions via the nonlinear deformation map $\boldsymbol{\varphi}$ and $\widehat{\boldsymbol{\varphi}}$, respectively.

Evaluation of the deformation gradient $\mathbf{F}$ on the surface is denoted as $\widehat{\mathbf{F}} = \mathbf{F}|_{\partial\mathcal{B}_0}$ and can be decomposed to the superficial and orthogonal contributions as follows:

$$\widehat{\mathbf{F}}_{\parallel} = \widehat{\mathbf{F}} \cdot [\mathbf{I} - \widehat{\mathbf{N}} \otimes \widehat{\mathbf{N}}] \qquad \text{and} \qquad \widehat{\mathbf{F}}_{\perp} = \widehat{\mathbf{F}} \cdot [\widehat{\mathbf{N}} \otimes \widehat{\mathbf{N}}] \,.$$

Let $\widehat{\psi}$ denote the surface free energy density. This contribution essentially extends the classical surface elasticity theory in the sense that it enriches the surface energy with the orthogonal contribution of the surface deformation gradient, i.e.

$$\text{classical surface elasticity:} \quad \widehat{\psi} = \widehat{\psi}(\widehat{\mathbf{F}}_{\parallel}) \qquad , \qquad \text{current contribution:} \quad \widehat{\psi} = \widehat{\psi}(\widehat{\mathbf{F}}_{\parallel}, \widehat{\mathbf{F}}_{\perp}) \,.$$

It is shown that the theory of elasticity of Gurtin and Murdoch is intrinsically limited since it is associated with the first-order continuum theory of elasticity in the bulk. In this sense this contribution shall also be understood as a higher-gradient surface elasticity theory [2].

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Critical conditions for growth-induced instabilities

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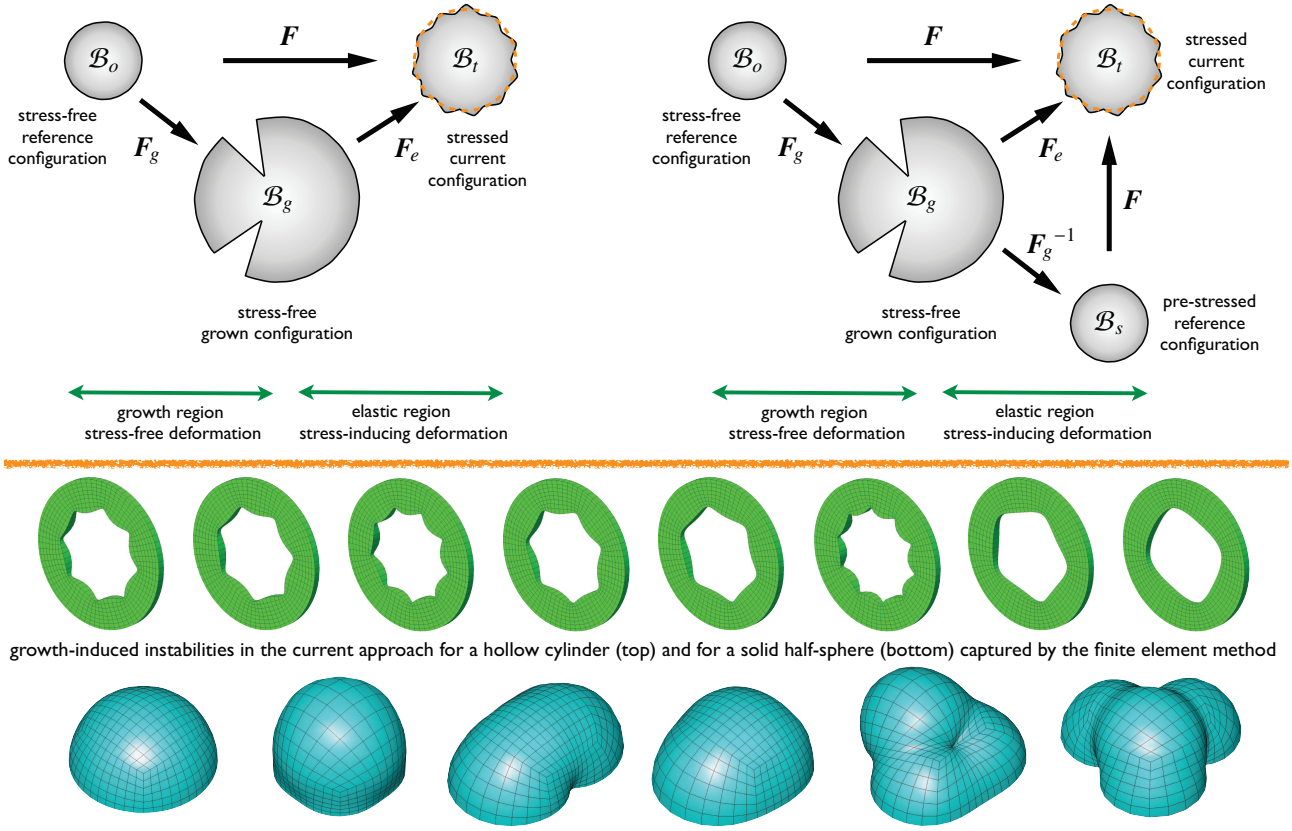
Geometric instabilities in living structures can be critical for healthy biological function, and abnormal buckling, folding or wrinkling patterns are often important indicators of disease. Mathematical models typically attribute these instabilities to differential growth, and characterize them using the concept of fictitious configurations. This kinematic approach towards growth-induced instabilities is based on the multiplicative decomposition of the total deformation gradient into a reversible elastic part and an irreversible growth part. While this generic concept is generally accepted and well established today, the critical conditions for the formation of growth-induced instabilities remain elusive and poorly understood [1].



growth-induced instabilities in the current approach for a hollow cylinder (top) and for a solid half-sphere (bottom) captured by the finite element method

Figure 1: Illustration of kinematics of growth.

We propose a novel strategy for the stability analysis of growing structures conceptually by replacing growth by prestress. This allows us to adopt a classical infinitesimal stability analysis to identify critical material parameter ranges beyond which growth-induced instabilities occur.

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General imperfect interfaces

Ali Javili, Stefan Käßmair, Paul Steinmann

The objective of this project is to develop a thermodynamically consistent theory for general imperfect interfaces and to establish a unified computational framework to model all classes of such interfaces using the finite element method. The interface is termed general imperfect in the sense that it allows for a jump of the temperature as well as for a jump of the normal heat flux across the interface. Conventionally, imperfect interfaces with respect to their thermal behavior are restricted to being either highly-conducting (HC) or lowly-conducting (LC) also known as Kapitza. For a HC interface the temperature is continuous across the interface while the jump of the normal heat flux is admissible. On the contrary, a LC interface does not allow for a jump of the heat flux across the interface but it does allow for a temperature jump. The temperature jump of a LC interface is frequently assumed to be proportional to the average heat flux across the interface. In this contribution we prove that this common assumption is indeed an appropriate condition to (sufficiently and not necessarily) satisfy the second law of thermodynamics.

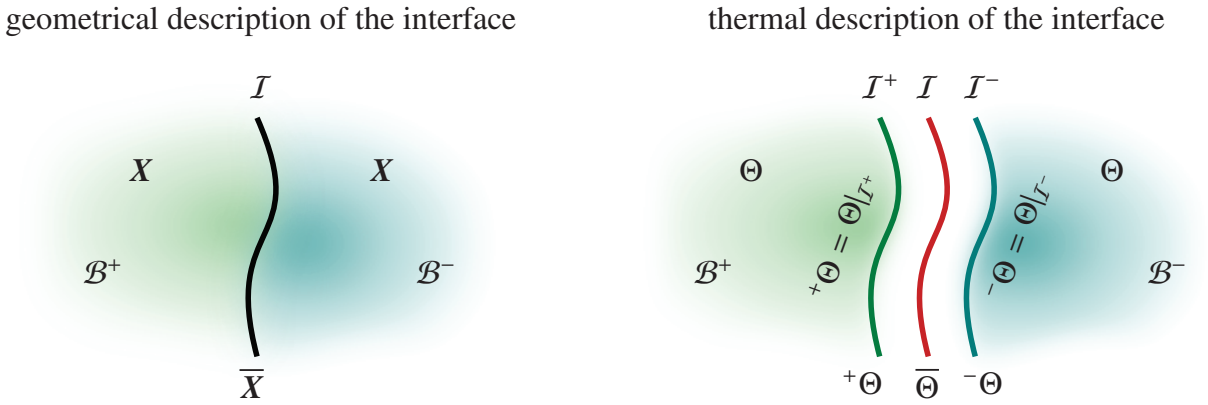

Figure 1: Comparison between the thermal and geometrical descriptions of the interface and illustrating the (thermal) degrees of freedom. The interface element has its own independent temperature and two additional bulk temperatures on the plus and minus sides of the interface.

While HC and LC interfaces are generally accepted and well established today, the general imperfect interfaces remain poorly understood. Here we propose a thermodynamically consistent theory of general imperfect interfaces and we show that the dissipative structure of the interface suggests firstly to classify such interfaces as semi-dissipative (SD) and fully-dissipative (FD). Secondly, for a FD interface the interface temperature shall be considered as an independent degree of freedom and a new (constitutive) equation is obtained to calculate the interface temperature using a new interface material parameter i.e. the sensitivity. Furthermore, we show how all types of interfaces are derived from a FD general imperfect interface model. This finding allows us to establish a unified finite element framework to model all classes of interfaces. Full details of the novel numerical scheme are provided. Key features of general imperfect interfaces are then elucidated via numerical examples using the finite element method. In particular, it is observed that according to the second law the interface temperature may not necessarily be the average of (or even between) the temperatures across the interface [1].

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Numerical computation of NNMs with path continuation methods

Martin Jerschl, Kai Willner

Conservative systems with a low number of degrees of freedom and non-linear couplings (cubic springs) are investigated with the concept of non-linear normal modes (NNMs) [1]. With increasing energy in the system the progressive non-linearity leads to a hardening effect. One typical dynamical property of non-linear systems is the frequency-energy dependency of their oscillations. A good graphic illustration is to plot such dependency in a so called *frequency-energy plot* (FEP). A NNM branch can be calculated by a numerical continuation method with starting at low energy level in a quasi linear regime and increasing the energy and reducing the period of the oscillation iteratively. Thereby a branch is a family of NNM oscillations with qualitatively equal motion properties. In non-linear systems internal resonances and other phenomena can occur. Several branches, called *tongues*, can bifurcate from a NNM branch (cf. Figure 1). Therefore ordinary continuation methods fail at such bifurcation or turning points. An *arclength* continuation method is used. Hereby one solution

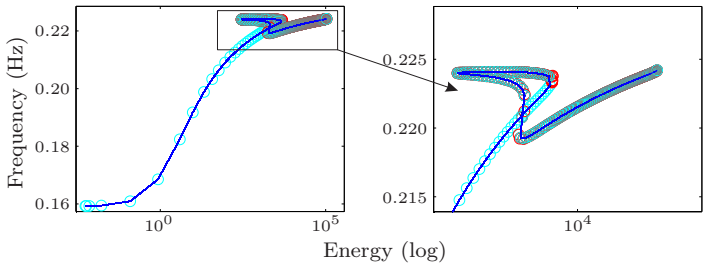
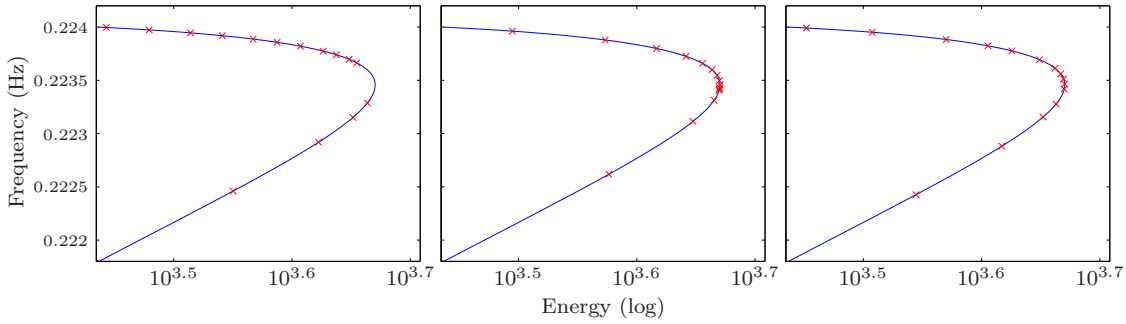


Figure 1: Calculated FEP with internal resonance.



a) Crisfield b) Riks and Wempner c) Schweizerhof and Wriggers

Figure 2: Turning point at the 3 : 1 internal resonance of a 2-DOF system with cubic coupling. The red crosses mark the corrector approaches respectively; the blue line is the ideal FEP curve.

on the branch is calculated by a predictor step which is corrected until convergence is achieved. Different corrector algorithms related to tracking non-linear equilibrium paths of structural systems [2, 3, 4] are implemented for the NNM continuation (cf. Figure 2).

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Generic types of classical and nonclassical diffusion models

Stefan Kaessmair, Ali Javili, Paul Steinmann

Diffusion processes play a prominent role in various fields of engineering and science, such as chemistry, geophysics or material science [1]. Examples are phase separation in solder joints, mass transport across cell membranes or diffusion of ions during charge and discharge cycles in lithium-ion batteries [2]. In order to describe such phenomena, generic diffusion models, incorporating first and/or second order fluxes, are considered, i.e.

$$\dot{c} = -\operatorname{div} \boldsymbol{h} \qquad \text{and} \qquad \dot{c} = -\operatorname{div} \left(\boldsymbol{p} - \operatorname{div} \boldsymbol{q} \right),$$

see also [1]. Here, $\dot{c}$ denotes the evolution of the concentration c in time, $\boldsymbol{h}$ and $\boldsymbol{p}$ first order fluxes, and $\boldsymbol{q}$ a second order flux. It is well known that the classical diffusion of Fick type is not able to model all of the afore-mentioned examples accurately. Nevertheless, the investigation of mixed finite element formulations for different variational settings of the generic diffusion equation is of particular interest. Based on the classical diffusion model, non-classical diffusion models shall be considered, including the Cahn-Hilliard equation, which has been treated in various contributions such as [3]. The non-classical models are well suited for the description of the above phenomena as shown in figure 1, for instance. Due to the wide applicability of these models to problems in engineering and science, further investigation is motivated.

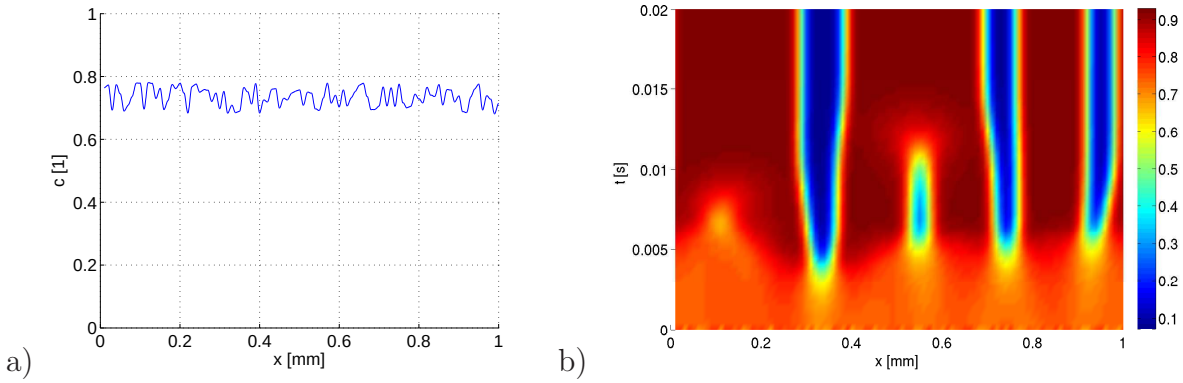

Figure 1: a) Initial species concentration of the one dimensional non-classical diffusion example shown in b). There, the Cahn-Hilliard equation is solved, which renders the concentration in terms of the spatial coordinate x and time t.

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Inverse form finding in anisotropic elastoplasticity

Philipp Landkammer, Sandrine Germain, Paul Steinmann

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

The aim of this partial project is to find an appropriate undeformed shape of a workpiece while knowing the desired end configuration after the forming process as well as the boundary conditions and the applied loads. The overall goal of this issue is to help engineers in manufacturing to save time and costs for experiments and simulations to conceive an optimal blank design for a metal forming process.

As tool to achieve this, the inverse finite element method is used within the recursive form finding algorithm presented in [1]. By applying another return-mapping algorithm [2] we achieved to extend this method to anisotropic elastoplasticity. To model the large deformations occuring in metal forming applications an additive decomposition of the logarithmic strain tensor is utilized. A practical use of this method is illustrated in the following example of metal forming with Hill-plasticity and nonlinear Hockett-Sherby-hardening (Figure 1 and 2). By enlarging the inner circle of the optimal undeformed workpiece within a defined forming process, you will last exactly on the desired round shape, see Figure 2.

In future with focus on sheet-bulk metal forming we will extend this method to kinematic hardening as well as to solid-like-shell elements and align them with contact mechanics.

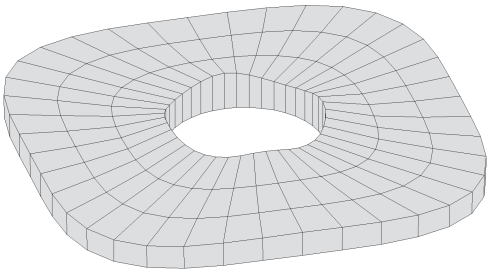

Figure 1: The optimal shape of the workpiece before the forming process

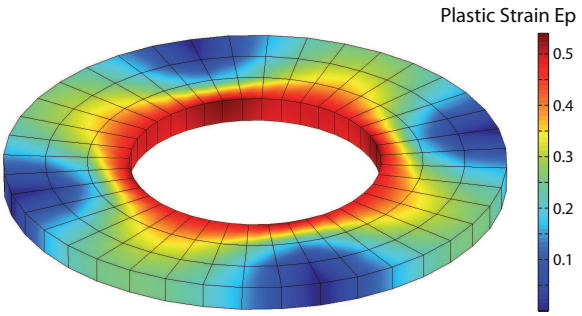

Figure 2: The desired shape of the workpiece after the metal forming simulation with its plastic strains (anisotropic Hill yield criterion)

References

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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

For the construction and calculation of an electric motor it is relevant to know the mechanical behavior of all parts. Consequently it is the aim of this project to identify the behavior of the lamination stack. This stack is a packet of sheets strengthening the magnetic field.
The interaction of the sheets is relevant for the stack's behavior. These interactions (pressure p and gap z) are dependent on the surface roughness and the coreplate varnish and they are visco-elasto-plastic normal to the surface. The theory for the elastic and the plastic description bases on the autocorrelation function of technical surfaces (parameters: x_T, σ_z), without structure. That geometric information is combined with the contact description after Hertz (Hertzian module E^*) to describe the elastic behavior (Bush-Gibson-Thomas model [1]). For the plastic behavior of the roughness peak's initial contact the model of Bowden-Tabor [1] uses the Abbott-Firestone curve (parameters: μ, ς) and the hardness H of a surface. The viscous behavior of the interaction is described by the velocity of the intersection's strain [2]. Therefore the visco-elasto-plastic behavior, seen in different experimental tests, can be described with a contact model (Figure 1 diagrams on the left hand side).
To develop a material model, for the whole lamination stack, out of this contact model the stack has to be homogenized. To do that the whole stack is represented by a representative volume element (rve) at every Gaussian integration point in a macroscopic model. These rve's are similar for one stack and contain all relevant mechanical characteristics (for example the visco-elasto-plastic contact). A material model for the stack has to be evolved from that calculation.

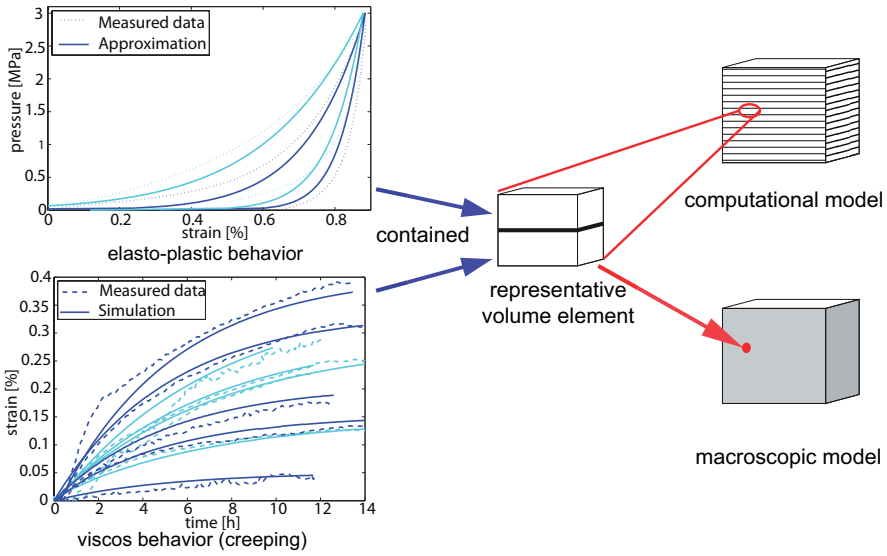

Figure 1: principle of the homogenization

This project is a cooperation with Siemens AG.

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Phenomenological modelling of self-healing polymers

Julia Mergheim, Paul Steinmann

Self-healing polymers are a promising class of materials which mimic nature by their capability to autonomously heal micro-cracks. This self-healing is accomplished by the integration of microcapsules containing a healing agent and a dispersed catalyst into the matrix material. Propagating microcracks may then break the capsules which releases the healing agent into the microcracks where it polymerizes with the catalyst, closes the crack and 'heals' the material. The present modelling approach treats these processes at the macroscopic scale, the microscopic details of crack propagation and healing are thus described by means of continuous damage and healing variables.

The following characteristics of the healing process are reproduced by the constitutive healing model: 1) Healing may occur in the undeformed and deformed state. It is not necessary for the here considered selfhealing process that the crack planes are in close contact, as it is e.g., for diffusion based healing processes. 2) The healing progress mainly depends on elapsed time and temperature. 3) During healing, the material recovers its original stiffness. 4) An important property of the self-healing process is that the gain in stiffness has to take place without an increase of the stress, unless the strain state is modified.

A damage-healing-redamage model was developed and implemented, see [1]. The predictions of the model for uniaxial tensile tests were discussed and compared qualitatively with experimental data from the literature. Figure 1 shows the stress responses for a given strain history. The material is loaded by an increasing strain until it is almost completely damaged (at 100s). Then, the material is unloaded, a healing period of different length follows and finally the material is reloaded. Depending on the various healing times the material recovers different stiffnesses and strengths. A cure time of 60000s is sufficient for the material get back its initial properties. A detailed description of the damage-healing-redamage model and further examples are discussed in [1].

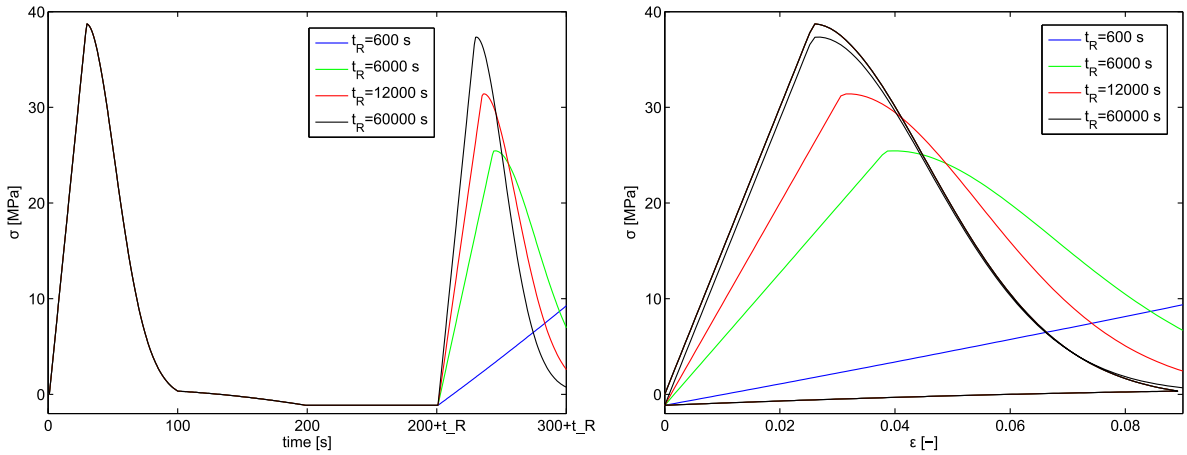

Figure 1: Predictions of damage-healing-redamage model for different healing periods, stress-time (left) and stress-strain (right)

References

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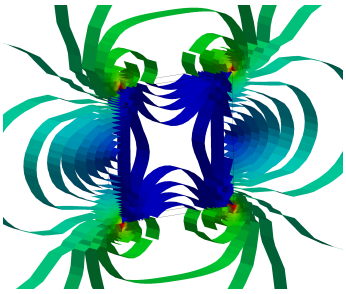
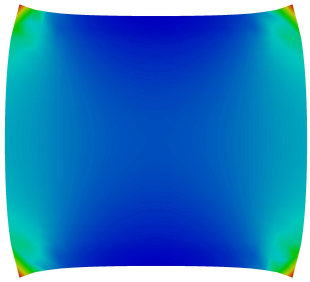
A framework for computational modelling of magneto-sensitive polymers

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 incompressible, viscous, and exhibits temperature dependency [1]. Its response is affected by the alignment of embedded particles and the magnetic field that permeates the material [2].



Iso-contours of magnetic field strength



Magnitude of material magnetisation

Edge-constrained non-linear magnetostrictive material with surrounding free-space

To this end, a computational framework aimed at connecting the various components of research is in development. A coupled multi-physics FEM [3] framework incorporating incompressible finite-strain elasticity together with magnetic and temperature fields is currently in development. Numerous coupled material models, as well as viscoelasticity and viscomagnetism [4], have been implemented. The free-space surrounding the magneto-sensitive media can be directly represented in the simulations. Computation of magnetic forces and torques acting on different materials is possible. Future developments include adaptive grid-refinement and parallel computing for the FEM framework, innovative material models and the direct coupling of macro- and micro-scale phenomena using RVEs [5].

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Coupling of particle- and finite-element-based simulations by using a bridging domain

Sebastian Pfaller, Paul Steinmann

Particle based methods as e.g. Molecular Dynamics (MD) are able to describe processes at very small length and time scales and thus can take into account the specific atomistic and molecular structure of the material under consideration. However, these methods are not suited to carry out computations at time and length scales relevant in engineering applications. Thus, coupling schemes to bring together continuum mechanics and particle based simulation techniques have become a growing field of interest. Within our field of research, the system consists of a particle region that is computed by MD and a continuum which is discretized and solved by the Finite Element Method (FEM). Both domains overlap in a bridging domain where, in addition to existing coupling methods, displacements and forces are transferred by anchor points. Within a very close cooperation with the Theoretical Physical Chemistry Group at the Darmstadt University of Technology a coupling algorithm has been developed. This collaboration is also part of the DFG-priority programme 1369 "Polymer-Solid Contacts: Interfaces and Interphases" that is interested among others in simulating polymers filled with nanoparticles. In Figure 1 the system set up is shown together with plots of the system under tensile load with different choices of Young's modulus in the FE part.

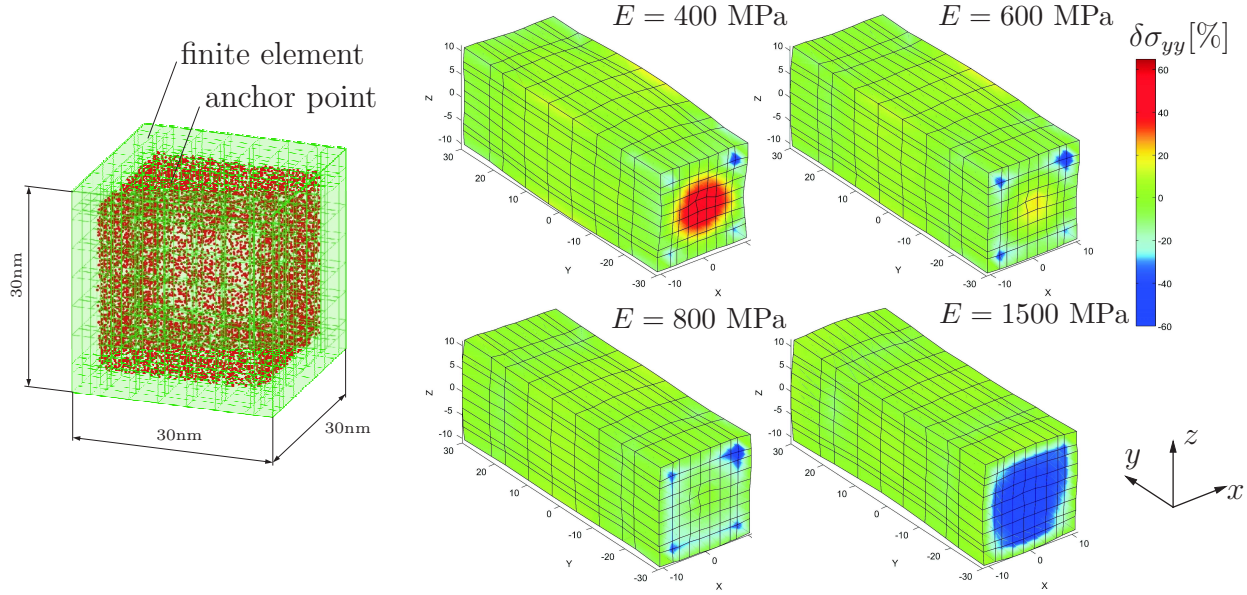

Figure 1: Finite Element domain coupled to polystyrene (left), uniaxial tension test in y-direction: deviation $\delta\sigma_{yy}$ in stresses plotted for different Young's moduli in the FE domain, displacements scaled by factor of 100 (right)

References

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Photoelasticity of curing shrinkage in epoxy-ceramics composites

Gunnar Possart, Michael Götz (WW3, FAU ER), Paul Steinmann

A composite material is considered which has a periodic structure and is formed by an epoxy matrix that is filled with regularly spaced cubes of a ceramics (Al_2O_3) [1]. The stress distribution arising within the epoxy matrix due to curing shrinkage is computed with the help of a versatile simulation framework [2]. A comparison to photoelastic measurements demonstrates that the underlying curing model provides a valuable tool to numerically assess this type of internal loadings in composites. The details of the simulation setup can be obtained from [3].

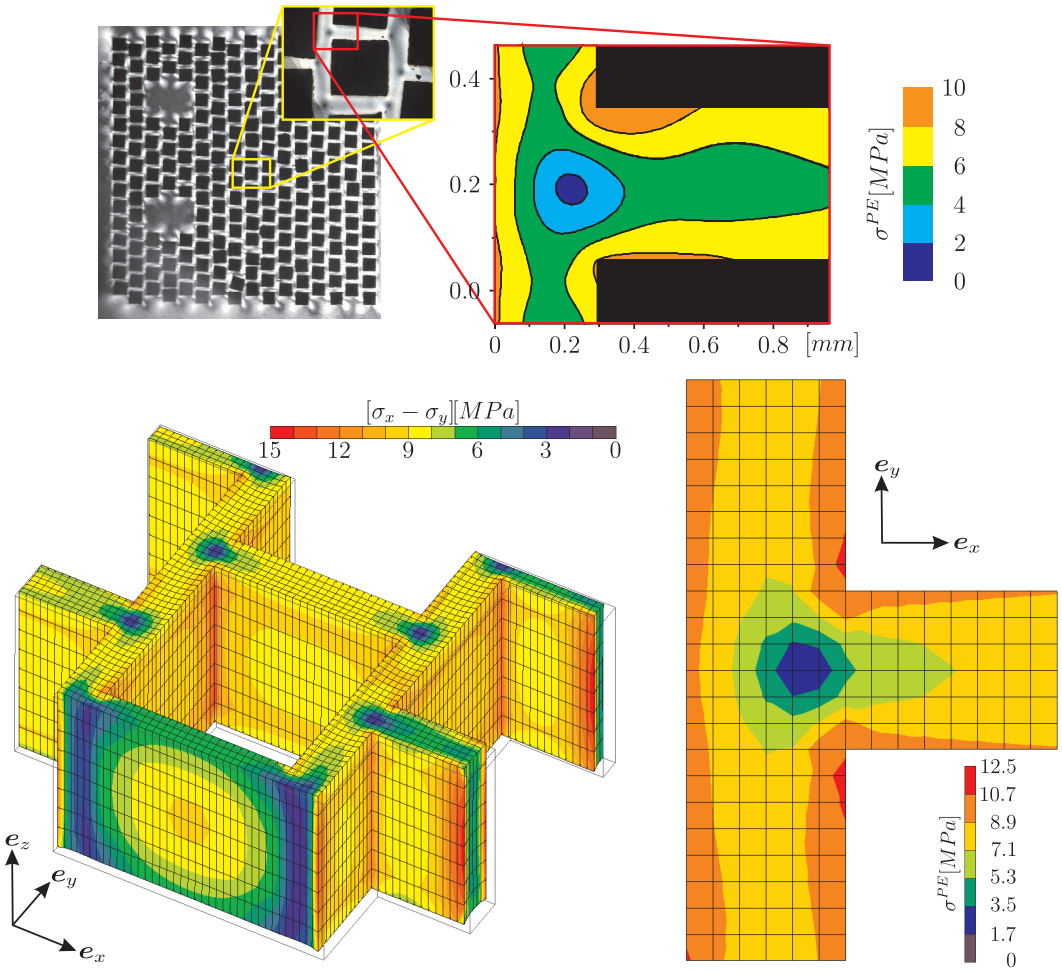

Figure 1: (*Top*) Photoelastic measurement of the stresses caused by curing shrinkage in a ceramic-epoxy composite. (*Bottom*) Viscoelastic curing simulation of a representative composite part. Deformation of the epoxy (scaled by 15) and distribution of principal stress difference $[\sigma_x - \sigma_y]$ (light passes through in z-direction) (*left*). Cutout with simulated photoelastic stress σ^{PE} (*right*), which agrees very well with the experimental observation.

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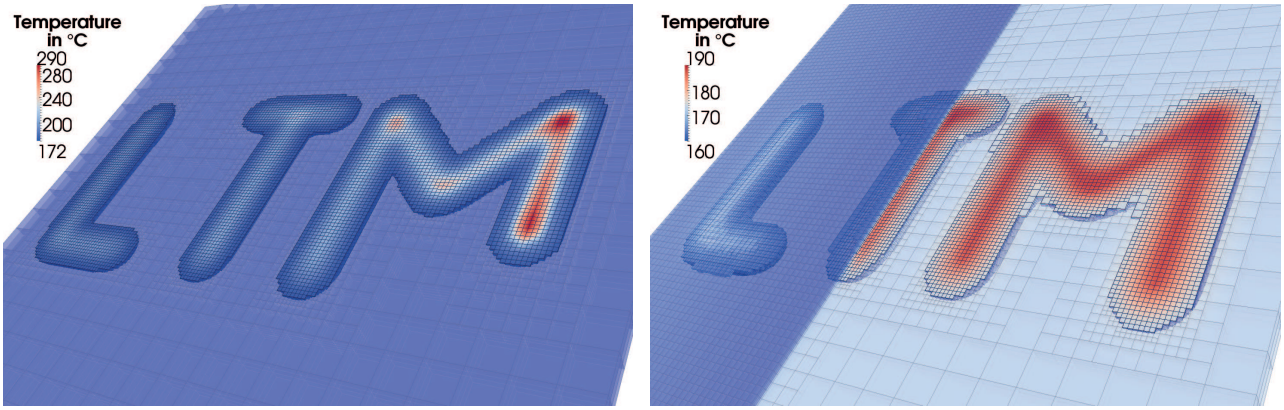
Thermomechanical modelling and simulation of selective beam melting

Daniel Riedlbauer, Julia Mergheim, Paul Steinmann

In the selective beam melting process, the energy of a laser or electron beam is used to fuse powder material in defined, locally-restricted points in the current powder layer. The powder is molten into the already fused and recongealed material of the previous layers. In this way geometrically complex parts are built additively layer-by-layer whereby the powder particles undergo a phase change from a powder particle to a melt and then to a solid. During the process extreme temperatures and temperature gradients appear and have a strong influence on various properties of the manufactured part, e.g. residual stress or warpage. In order to improve the mechanical properties of the part these quantities and the temperature are simulated by using a nonlinear thermomechanical model, where the powder is assumed to be a continuum. The model includes the nonlinear temperature dependency of the material parameters and is implemented by using the finite element library deal.ii [1]. In addition the different phases of the powder material in the process are considered in the model. For describing the temperature-dependent mechanical behaviour of the powder a thermoelastoplastic material model is developed. In order to capture the extreme temperatures and temperature gradients in the vicinity of the beam an adaptive mesh refinement strategy is applied. The mesh refinement and the time-dependency of the thermomechanical model lead to a computationally intensive problem. Therefore a staggered solution scheme called adiabatic split [2] is adopted to the thermomechanical model to reduce computing time.



(a) Treatment of the current powder layer (b) Deposition of the next powder layer

Figure 1: Simulation of the selective beam melting process using a polymeric powder

References

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On regularization in parameter-free shape optimization

Stefan Riehl, Paul Steinmann

One of the major challenges in the parameter-free approach to computational shape optimization is the avoidance of oscillating boundaries in the optimal design trials. This difficulty is mainly attributed to a lack of smoothness of the shape gradient function and the relatively high number of design variables within the parameter-free regime. To compensate for these deficiencies, Azegami [1] introduced the concept of the *traction method*, in which the actual design update is deduced from the deformation of a fictitious continuum that is loaded in proportion to the negative shape gradient. The shape gradient functions are obtained from optimality criteria using the Lagrange multiplier method within a distributed-parameter setting. A similar concept can be derived within a discrete setting, thus leading to an integrated approach to shape optimization based on a finite element discretization.

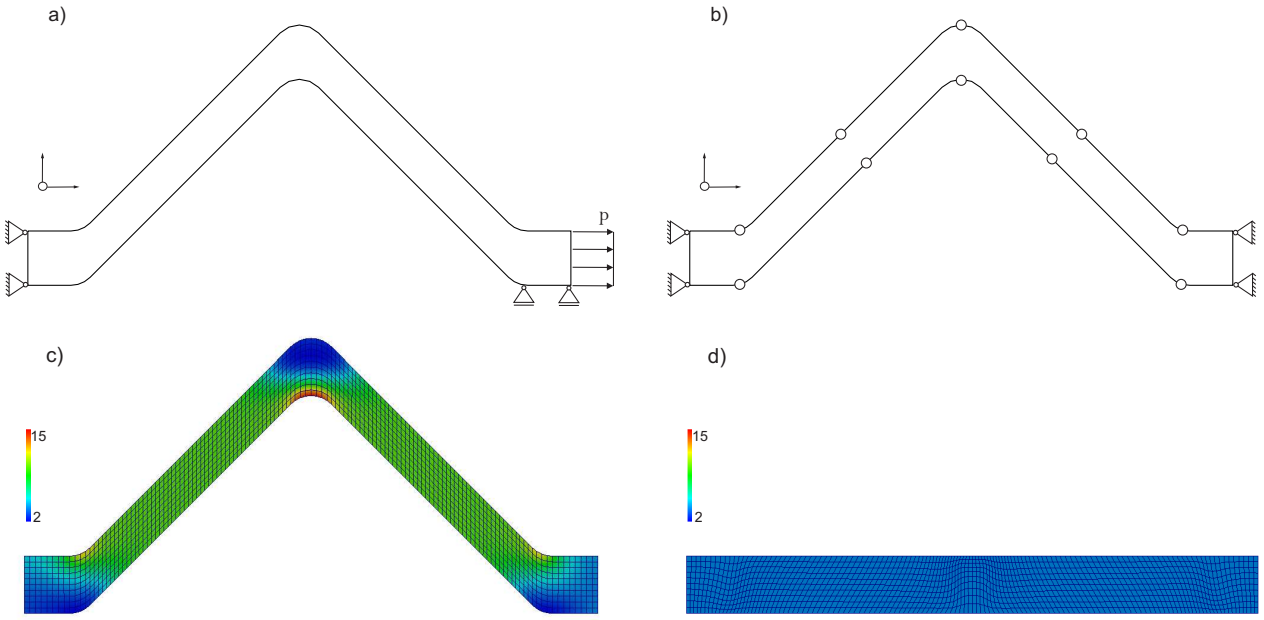

Figure 1: Mean-compliance minimization of a curved tension bar. a) Mechanical analysis setup. b) Shape optimization setup. c) Original shape with *von-Mises* stress distribution. d) Optimal shape with *von-Mises* stress distribution.

The capacity of the method is best illustrated by considering numerical examples to which analytical solutions are either known or can be derived from heuristic optimality criteria, e.g. the shape optimization problem involving a curved tension bar depicted in Fig. 1. The algorithm proved effective in generating the optimal shape of a bar of uniform cross section for the mean-compliance minimization problem involving a volume constraint.

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Nonlinear magneto-viscoelasticity of magneto-active polymers

Prashant Saxena, Mokarram Hossain, Paul Steinmann

Magneto-active polymers are materials that change their mechanical behaviour in response to the application of an external magnetic field. Typically such materials are manufactured by mixing ferromagnetic particles with liquid elastomer and allowing the mixture to cure. Curing the mixture in the presence of a magnetic field results in the formation of particle chains provides an effective directional anisotropy to the material.

For anisotropic materials where the direction of anisotropy is given by a unit vector $\mathbf{M}$, we define a "chain deformation gradient" ($\mathbf{F}^c = [\mathbf{FM}] \otimes \mathbf{M}$) and a "chain magnetic induction" ($\mathbb{B}^c = \big[[\mathbf{F}\mathbb{B}]\cdot[\mathbf{FM}]\big]\mathbf{M}/|\mathbf{FM}|^2$) on top of the applied deformation gradient $\mathbf{F}$ and magnetic induction $\mathbb{B}$. Due to the rate-dependent dissipation effects, the overall stress and the magnetisation response of the material to the applied magnetic and mechanical loadings is not instantaneous, and hence needs to be modelled appropriately. This is affected by a multiplicative decomposition of the deformation gradient ($\mathbf{F} = \mathbf{F}_e\mathbf{F}_v, \mathbf{F}^c = \mathbf{F}^c_e\mathbf{F}^c_v$) and an additive decomposition of the magnetic induction ($\mathbb{B} = \mathbb{B}_e + \mathbb{B}_v, \mathbb{B}^c = \mathbb{B}^c_e + \mathbb{B}^c_v$) into equilibrium and non-equilibrium parts [1, 2].

Using the second law of thermodynamics, we obtain constitutive laws for stress and magnetic field as well as dissipation inequalities that need to be satisfied by the internal variables $\mathbf{F}_v, \mathbf{F}^c_v, \mathbb{B}_v$ and $\mathbb{B}^c_v$. The model is formulated in a way that the equilibrium and non-equilibrium contributions to the stress and the magnetic field due to the isotropic response and the anisotroy direction can be separately identified.

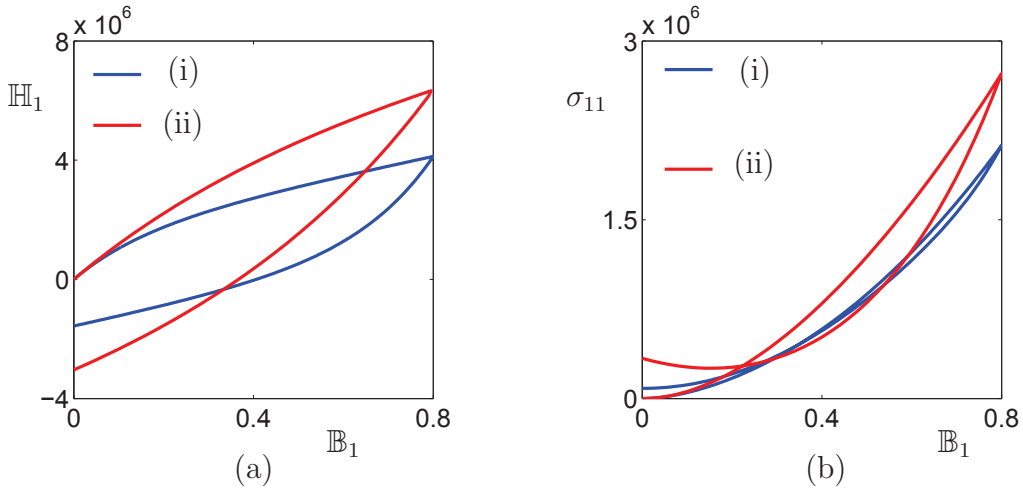

Figure 1: Linear loading and unloading of magnetic induction: **(a)** Total magnetic field $\mathbb{H}_1$ (A/m) vs magnetic induction $\mathbb{B}_1$ (T); **(b)** Principal total cauchy stress σ_{11} (N/m^2) vs magnetic induction $\mathbb{B}_1$ (T). (i) $\dot{\mathbb{B}}_1 = \pm 1$ T/s, (ii) $\dot{\mathbb{B}}_1 = \pm 4$ T/s.

References

[1] P. Saxena, M. Hossain, P. Steinmann. A theory of finite deformation magneto-viscoelasticity. *International Journal of Solids and Structures* **50**, 3886-3897 (2013).

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Modelling and simulation of thermal influences in turning processes

Stefan Schindler, Paul Steinmann

During turning mechanical work is dissipated into thermal energy by frictional processes and plastic deformation of the workpiece material. Thereby, the temperature in the workpiece and the tool increases and causes thermal expansion. Furthermore, mechanical forces deflect the workpiece and the tool. Both influence the cutting depth and thus decrease the accuracy of machining. In case of dry turning thermal effects are predominant.
In order to simulate the temperature distribution and the dilation of the workpiece accurately, several effects have to be taken into account. Due to the moving heat source (i.e. the chip formation zone) the temperature distribution is unsteady. The movement of the resultant heat flux into the workpiece has to be considered and is applied as a function of time and position according to the NC-code of the lathe. Simultaneous to the moving heat flux, material removal takes place which is considered through element deactivation. Since the element edges do not fit the tool path due to the thermal expansion, an adaptive element refinement technique is used. Prior to deactivation all elements to be cut by the tool path are subdivided, thus the element edges fit the tool path. An appropriate mesh design according to the tool path facilitates the mesh refinement. A special pre-processor has been developed to evaluate the tool path from the NC-code and to create all nodes and elements according to the tool path. Heat convection and conduction with the environment have to be considered additionally. Mechanical forces are applied according to the tool path. Figure 1 depicts the temperature distribution of the workpiece. A detailed description is published in [1].

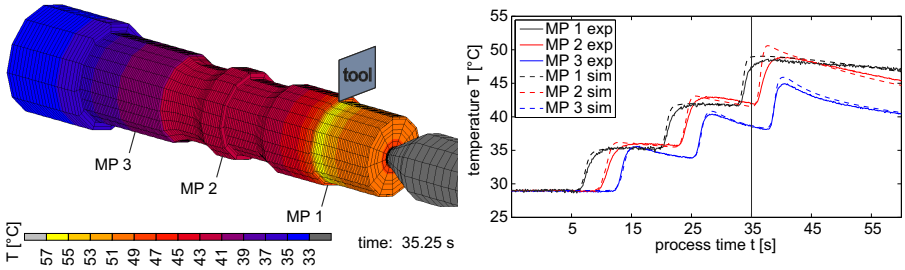

Figure 1: Temperature distribution of the workpiece [1]

Also the thermal analysis of the tool has to be transient (Figure 2). Since the heat flux into the tool depends on the tool engagement, it is also applied according to the NC-code.

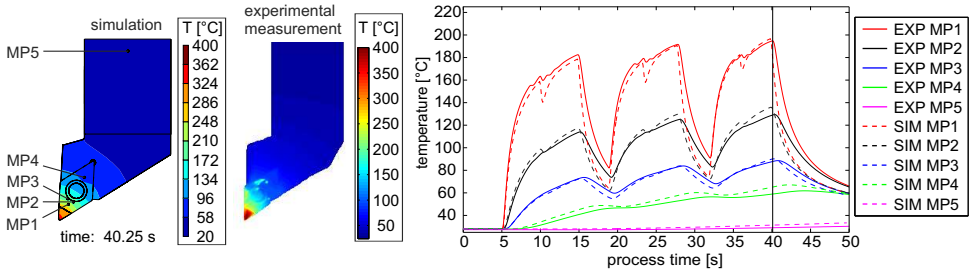

Figure 2: Temperature distribution of the tool

References

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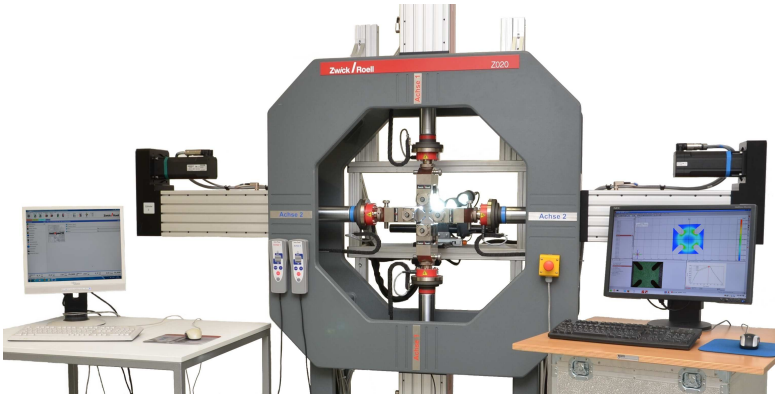
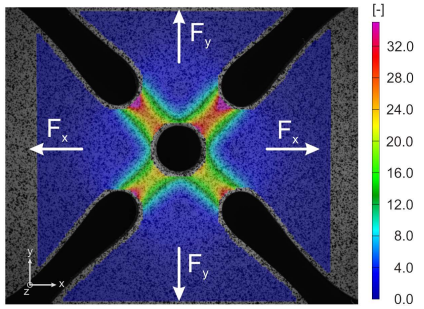
Inverse parameter identification for sheet steel

Stefan Schmaltz, Kai Willner

In the production industries sheet steel is a widely used raw material, especially when large thin parts are created, as e.g. auto body components. However, with the development and employment of new forming methods like sheet-bulk metal forming sheet steel also serves as raw material for the production of small, complex parts [1], like e.g. synchronizer rings. There, parts with local functional elements are created out of thick sheet steel by forming and not by cutting operations, which increases the strength of the material and reduces waste.
The requirements to the dimensional accuracy are high and the material behavior is complex as it shows anisotropic character. For modeling the sheet-metal behavior properly, fitting material parameters have to be found. When direct identification methods are used, several different experiments must be performed to capture the anisotropy, which is costly and time consuming. This difficulty is overcome by the utilization of an inverse Finite Element Model Updating method. In this procedure an experimental test is performed and a Finite Element simulation of the test is build up and run. It is an iterative method, where an optimization algorithm varies the material parameters of the simulations in a way that the least squares sum of the experimentally and numerically determined displacement fields is minimized.
The results of the inverse material parameter identification can only be as good as the experimental data set. In our case we utilize the displacement field on the surface of the specimen which is determined with an optical, three-dimensional, full-field measurement system. Therewith a high number of precise data points is created. To capture the anisotropic effects of the sheet metal a biaxial testing machine with a tensile specimen is used, see Fig. 1. Through the bore in the center of the specimen geometry the displacement field becomes inhomogeneous and several different stress and strain states occur. This results in a robust identification of the material parameters with a single experiment [2].



(a)



(b)

Figure 1: (a): Biaxial testing machine with optical measurement system; (b): Measured major strain field on the surface of the biaxially loaded tensile specimen ($\mathbf{F_x} = \mathbf{8.1}\,\mathrm{kN}$, $\mathbf{F_y} = \mathbf{8.2}\,\mathrm{kN}$).

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Virtual Testing Laboratory for Heterogeneous Materials

Ulrike Schmidt, Julia Mergheim, Paul Steinmann

The project is part of area E in the Excellence Cluster Engineering of Advanced Materials. The aim of the project is to establish a virtual testing laboratory (VTL) especially for meso-structured materials in order to improve the understanding of the macroscopic material behaviour and to enhance the material meso-structure in cooperation with material science projects in area E. In order to ensure good prediction capability of a model the material parameters have to be calibrated. Calibration of mesoscopic material parameters from macroscopic data for modelling via homogenization is studied. The homogenization process reduces the information such that the inverse problem of calibration is not unique and can be rather ill-posed. Therefore, reliability and stability of the calibration process for numerical homogenization is investigated based on synthetic pseudo-experimental input data. We expect that the reliability investigation will help to design well-posed calibration experiments.
Pseudo-experimental data is advantageous since data variance and reference parameters are set by the researcher. It is constructed by adding Gaussian noise with zero mean and chosen input data variance to synthetic macroscopic experimental data. The variance of the resulting estimated mesoscopic material parameters is studied with two methods: inference analysis from linear regression theory and the statistical method of Monte Carlo. The Monte Carlo method determines mean and variance from a random sample of calibrated meso-parameters and is therefore computational expensive. The method has no application restrictions.
The inference analysis gives an estimate based on only one realization of disturbed data and uses sensitivities of the simulation, which are directly computed. The linearized inference theory can be applied to the calibration only for models with negligible nonlinearity effects. Different proposals for the threshold of the nonlinearity measure are explored to obtain reliable inference band estimations while saving computational costs compared to the Monte Carlo method.

A first case for the virtual testing laboratory is the study of the meso-structure with macroscopic auxetic behaviour of Prof. Körner. In cooperation with project E2 the effects of geometrical parameters on the structure's overall Poisson's ratio have been investigated. The overall Poisson's ratio is calculated by means of computational homogenization. The periodic structure is constructed from a regular grid by deflecting the bars in specific directions. The geometry was investigated for various amplitudes of deflection. The size of the amplitude impacts the value of range of the Poisson's ratio modestly, while the minimal value stays approximately the same. Furthermore, the cross-section of the grid bars was investigated. A cross-section allowing the bar to bend in the curve direction allows for a higher auxetic behaviour than cross-sections which prevent bending. The ratio of width and height of a rectangular cross-section was varied. Aspect ratios of $\frac{1}{4}$ to 4 reduce the Poisson's ratio's range almost in a linear dependency. More extreme aspect ratios are unlikely to be realisable due to production constraints. Moreover, the effect saturates for extreme aspect ratios.
These qualitative results from the VTL were used to select sets of geometrical parameters for which the structures will be produced in E2 by selective electron beam melting of titanium powder. Comparison of simulated and experimental data is planned and will be performed, once the structures are available for measurement.

On manufacturing constraints in non-parametric sensitivity based shape optimization

Oliver Schmitt, Jan Friederich, Paul Steinmann

Shape optimization has become an important tool in engineering when it comes to improving components with respect to a given goal function [1]. During this process the designer has to ensure that the optimized part stays manufacturable. Depending on the manufacturing process several requirements could be relevant such as demolding (Fig.1,4), stamping (Fig.3), minimal membersize (Fig.2), minimal curvature (Fig.2) or different kinds of symmetry (Fig.1,2,3).

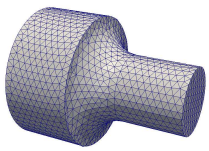

Fig.1

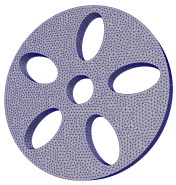

Fig.2

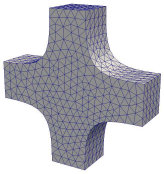

Fig.3

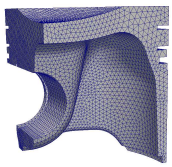

Fig.4

A general formulation for an optimization problem is given in (1) where some objective $\mathcal{J}$ is supposed to be minimized subject to a number of inequality g_i and equality h_j constraints. In shape optimization representatives for the goal function and the constraints may be e.g. the von Mises stress, the compliance or the volume.

$$\begin{aligned} \min \quad & \mathcal{J}(\mathbf{x}) \\ \text{s.t.} \quad & g_i(\mathbf{x}) \leq 0 \quad \forall i = 1, \ldots, n_g \\ & h_j(\mathbf{x}) = 0 \quad \forall j = 1, \ldots, n_h \end{aligned} \tag{1}$$

In our framework we develop mathematical formulations in terms of inequality and equality equations representing the above mentioned constraints. These can be used to extend the optimization problem to force the optimized component not only to fulfill the mechanical but also the manufacturing constraints. For the formulation of some manufacturing constraints it may occur that the number of inequalities n_{ieq} which have to be appended to the optimization problem is very large. Since most optimization algorithms are not able to handle highly restricted problems we use aggregation formulations [2], e.g. the Kreisselmeier-Steinhauser function

$$G_{KS} = \frac{1}{\rho} \ln \left[\sum_{i=1}^{n_{ieq}} \exp\left(\rho \tilde{g}_i\right) \right],$$

where $\tilde{g}_i$ are inequalities due to one manufacturing constraint and ρ is an accuracy parameter. These approximate the largest value at a point out of n_{ieq} inequalities so they can be replaced by just one.

References

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Influence of the bolting preload scheme on the pressure distribution within the joint contact plane

Dominik Süß, Kai Willner

This project has its focus on the investigation of the dynamic behavior of jointed structures, see [1]. In order to be able to calculate the correct transfer behavior of e.g. bolted structures the simulation of the bolt reloading process is an important topic. Here two different modeling approaches are presented. The first one (model (a)) is the commonly used equivalent static (surface or) line loading of the two contact partners without modeling the bolt itself.
The second approach (model (b)) explicitly accounts for the bolt. The threads of both, screw and nut, are neglected and the two parts are treated as one solid part. Here four different contact planes are considered, see the red framed regions in figure 1 (b). The tightening process of the bolt is simulated by performing a static tight fit step, prescribing a negative initial relative displacement for the contact layers belonging to the bolt (red arrows in figure 1 (b)).
For both models the nonlinear contact law in normal direction is assumed to be unilateral linear elastic. The resulting normal pressure distributions can be seen on the right hand side of figure 1 (c) with the upper picture corresponding to model (a) and the lower one to model (b). They are compared with an experimentally obtained normal load distribution measured with the help of Fujifilm Prescale interlayers with a measurable pressure range from 2.5MPa (beginning of red colored dots) to 10.0MPa (completely red). It can be seen that both modeling approaches deliver a physically meaningful pressure distribution within the contact plane. There are only slight differences between model (a) and (b) which probably would vanish for applying not only a line load but a surface load. A future task will be to investigate, whether the difference between the two models is also negligible in dynamical calculations.

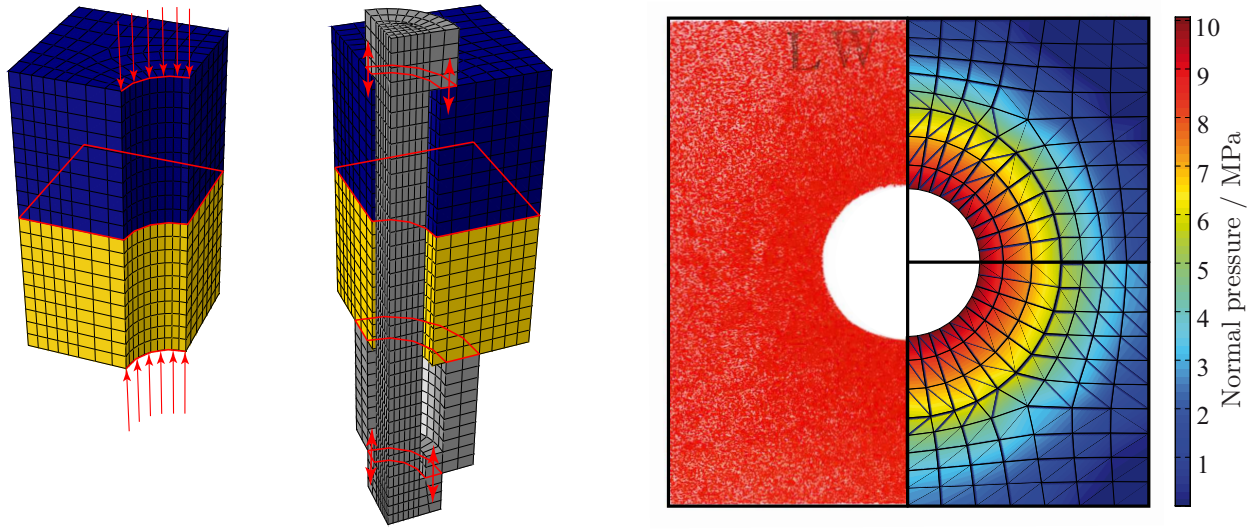

Figure 1: (a) bolt preload modeled by a line load, (b) preload modeled by a tight fit step, (c) resulting measured and simulated normal pressure distribution within the contact plane

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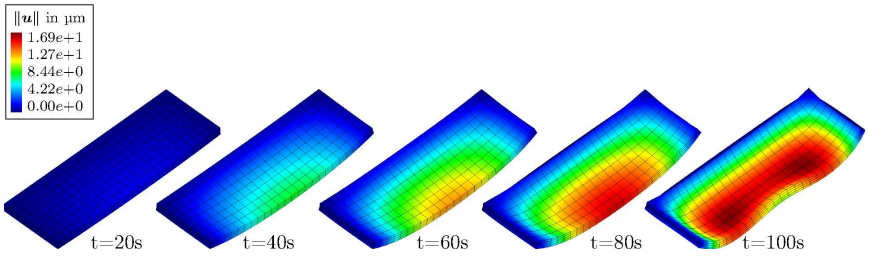
Modeling and Simulation of Viscous Electro-Active Polymers

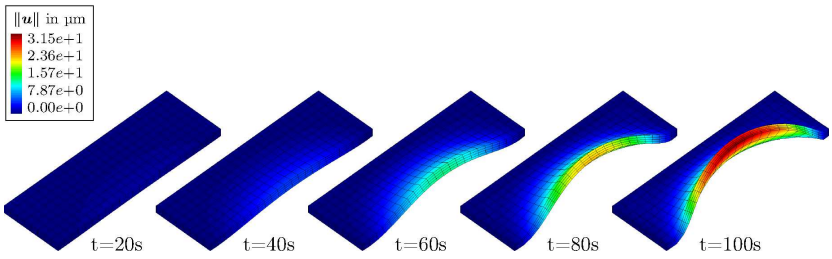
Franziska Vogel[1], **Serdar Göktepe**[2], **Paul Steinmann**[1], **Ellen Kuhl**[3]

[1] Chair of Applied Mechanics, Friedrich-Alexander Universität Erlangen-Nürnberg
[2] Department of Civil Engineering, Middle East Technical University Ankara
[3]Department of Mechanical Engineering, Stanford University

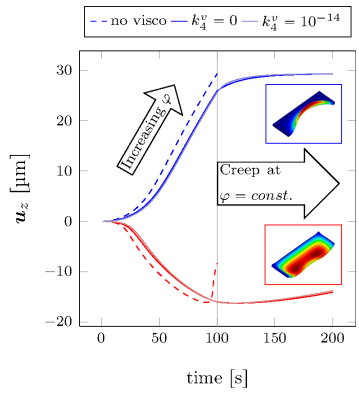
Electro-active materials are capable of undergoing large deformation when stimulated by an electric field. They can be divided into electronic and ionic electro-active polymers (EAPs) depending on their actuation mechanism based on their composition. We consider electronic EAPs, for which attractive Coulomb forces or local re-orientation of polar groups cause a bulk deformation. Many of these materials exhibit pronounced visco-elastic behavior. Here we show the development and implementation of a constitutive model, which captures the influence of the electric field on the visco-elastic response within a geometrically non-linear finite element framework. The electric field affects not only the equilibrium part of the strain energy function, but also the viscous part. To adopt the familiar additive split of the strain from the small strain setting, we formulate the governing equations in the logarithmic strain space and additively decompose the logarithmic strain into elastic and viscous parts. We show that the incorporation of the electric field in the viscous response significantly alters the relaxation and hysteresis behavior of the model. Our parametric study demonstrates that the model is sensitive to the choice of the electro-viscous coupling parameters. We simulate several actuator structures to illustrate the performance of the method in typical relaxation and creep scenarios. Our model could serve as a design tool for micro-electro-mechanical systems, microfluidic devices, and stimuli-responsive gels such as artificial skin, tactile displays, or artificial muscle.



(a) Actuator attached to a flexible frame



(b) Actuator attached to a fixed frame



(c) Evolution of deformation and influence of viscosity

Figure 1: Diaphragm actuator under electric voltage such that electric field is directed in thickness direction

References

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Material motion problem in nonlinear electro-elastostatics with consideration of free space

Duc-Khoi Vu, Paul Steinmann

The study of the material motion problem in this work is motivated by the possibility to make use of its formulation in computing the so-called released energy when the material configuration of a nonlinear electro-sensitive body is altered. The interaction between elastic bodies and electric fields is not a new subject of study in computational engineering. Nevertheless, until recently the contribution of the surrounding free space in formulating the problem of nonlinear electro-elastostatics was often of minor interest. Under the application of an electric field, a polarizable body deforms because of electric forces exerted on electric dipoles that are arranged randomly inside the material. In finding the deformed state of the body under consideration, the resulting electric field must be computed. In computing the resulting electric field, the free space surrounding the body should in principle be taken into account. However, it is a well-known fact that for many materials the surrounding free space can be conveniently ignored because of its negligible contribution. This is particular true if the electric permittivity of the material is much higher than that of free space. As a consequence of this negligence the electric traction caused by the Maxwell's stress and the electric flux on the boundary of the body are often not considered in the spatial as well as in the material motion problem of nonlinear electro-elastostatics. With the discovery of new materials like electronic electro-active polymers (EEAPs), it has been observed that the above mentioned electric traction (Maxwell's traction) and electric flux may play an important role in determining spatial motion quantities like electric field vector, electric displacement vector, stress and deformation gradient tensors. The material motion problem is considered in this work by using an energy approach and by paying careful attention to the contribution of the surrounding free space. With the help of some stored energy density functions and an imaginary deformation field in the surrounding free space, the governing equations of the material motion problem are derived using the concept of total stresses. Besides the derivation of configurational forces, this approach reveals the formulas for the part of energy that is released from the system material body - applied forces in response to a change in the undeformed configuration of an electro-elastic body. As example, we consider the case when there is no mechanical body forces and surface forces do not perform work with respect to a change in the undeformed configuration. In this case, the configurational energy or actually the released energy with respect to a small displacement at a crack tip can be computed as

$$\delta_{\boldsymbol{x}} \mathsf{w}_{\text{con}}^{\text{tot}} = \int_{\partial \mathcal{B}_0} \Big[\big[W_{0\boldsymbol{f}}^{\text{tot},\epsilon} \boldsymbol{I} + \mathbb{E}^{\epsilon} \otimes \mathbb{D}^{\epsilon} \big] \cdot \boldsymbol{N} - \boldsymbol{f}^{-t} \cdot \boldsymbol{t}_0^{\max} \Big] \cdot \delta \boldsymbol{\Phi} \, \mathrm{d}A.$$

By using the boundary and the finite element methods, this formula can be discretized and the value of the released energy can be computed in terms of the so-called material forces, which can be used, for example, in the simulation of crack propagation.

References

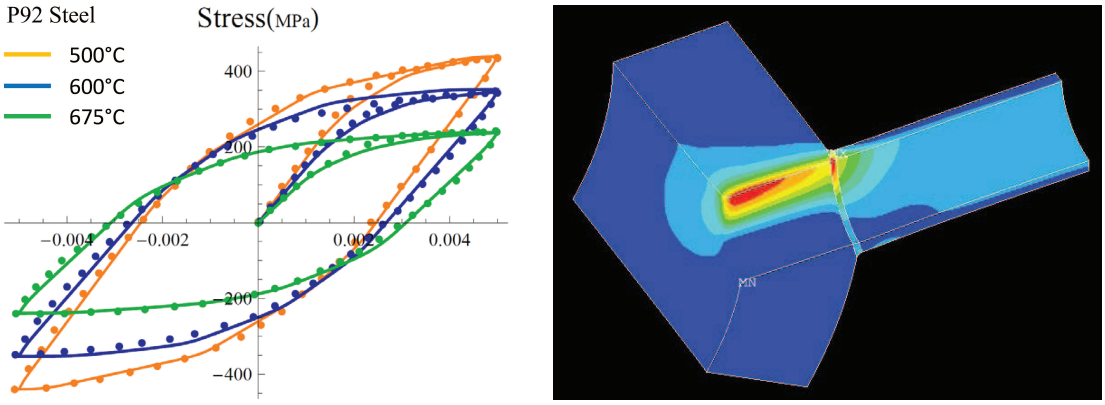
[1] D. K. Vu, P. Steinmann. On the spatial and material motion problems in nonlinear electro-elastostatics with consideration of free space. *Mathematics and Mechanics of Solids* **17**, 803-823 (2012).

Modeling of creep and fatigue damages in high-Cr steel components

Jiong Wang, Paul Steinmann

The development of conventional power plant technology requires a comprehensive investigation on power plant materials and their resistance to potential creep, fatigue, ratcheting and other kinds of damages. Due to the high creep strength and increased resistance to thermal fatigue, high-Cr steels (e.g., P91, P92, E911) have been employed as the key materials for high temperature structural components in ultra supercritical power plants. However, degradation of the creep strength of high-Cr steels during long-term services has been reported. The increasing supply of renewable energy also leads to a high demand on the flexible energy production in conventional power plants. For the purpose of safety design, a reliable lifetime assessment of high-Cr steel components under complex loading conditions is necessary.

In the framework of an ongoing work, a combined creep-viscoplastic constitutive model is proposed to simulate the responses of high-Cr steel components subject to complex thermal-mechanical loading conditions. Herein, the total inelastic strain rate is split into the creep part and the viscoplastic part. For creep strain, the Larson-Miller parameters are adopted to evaluate the minimum creep rate and the rupture time under various temperature and stress levels [1]. The cyclic viscoplastic strain is modeled through the conventional Chaboche's constitutive theory [2]. The ratcheting effect, time recovery effect and temperature rate effect are taken into account in the kinematic and isotropic hardening rules. All the parameters in this model can be retrieved from relatively simple experimental tests. This constitutive model is implemented within a finite element software. It can be seen that (cf. Fig.1), by using current model, the thermal-mechanical behavior of the high-Cr steel components under various loading conditions can be simulated.



(a) (b)

Figure 1: (a) Simulated stress-strain curves during the 1st cycle in the isothermal cyclic loading test; (b) Equivalent plastic strain in a high-Cr steel component during the long-term creep test.

References

[1] K. Kimura, O. Kanemaru, K. Sawada, H. Kushima. Creep deformation and rupture strength property of ASME grades T/P92 steels. *38th MPA-Seminar*, Oct. 1-2, Stuttgart (2012).

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Magneto-Sensitive Elastomers: Material Model meets Experimental Results

Bastian Walter, Prashant Saxena, Joachim Kaschta[1], Dirk W. Schubert[1] Paul Steinmann

[1] Institute of Polymer Materials, Friedrich-Alexander-University Erlangen-Nuremberg

Magneto-Sensitive Elastomers (MSEs) are smart materials characterised by changing their rheological and mechanical properties rapidly, continuously and reversibly, on the application of an external magnetic field [1]. To simulate the behaviour of MSEs under operating conditions it is firstly necessary to understand the material response related to the change of the internal structure affected by the magnetic field under different loading conditions. Secondly, material models are needed which couple electromagnetic and mechanical phenomena in deformable solids to simulate the material behaviour during the design process. Therefore, model systems based on liquid silicone rubber filled with micro-meter sized carbonyl iron powder are studied by means of a rheometer equipped with a magneto-rheological device (Anton Paar). Oscillatory, quasi-static and transient experimental results are used to successfully validate the developed material models [2], shown e.g. by the Lissajous plot and the stress-strain curves in Figure 1.

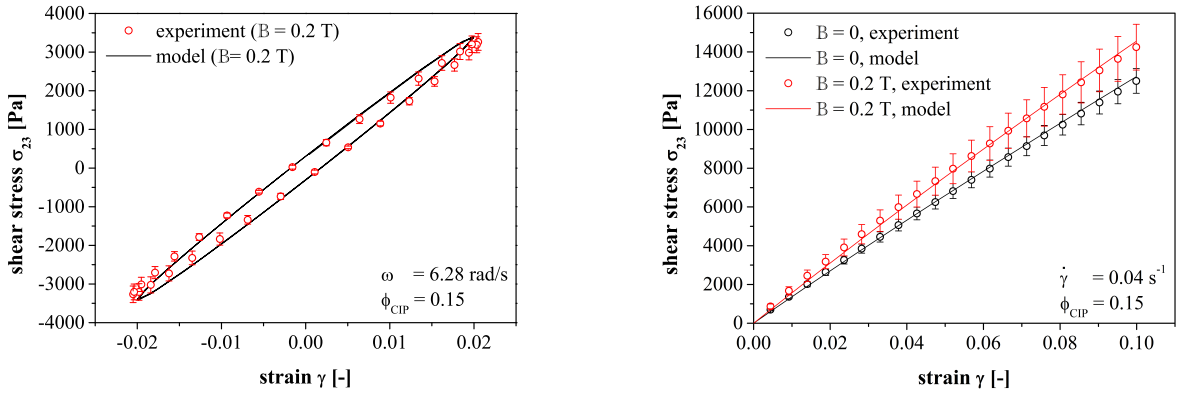

Figure 1: Experimental results (dots) and model validation (lines) for oscillatory (left) and quasi-static (right) shear tests [3].

In order to further optimise the material models the particle system is changed in a well defined way to control polymer-particle interactions. Additionally, uni-axial tensile tests in a well defined magnetic field are going to be performed by means of a custom made tensile testing machine which is still under construction.

References

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[3] B. L. Walter, P. Saxena, J. Kaschta, D. W. Schubert, P. Steinmann. Characterisation of Magneto-Sensitive Elastomers: Material Model meets Experimental Results. *13th Biennial Bayreuth Polymer Symposium*, P I 12 (2013).

Fatigue-life prediction model for austenitic stainless steels

Paul Wilhelm[1], **Paul Steinmann**[2], **Jürgen Rudolph**[1]

[1] AREVA GmbH

[2] Chair of Applied Mechanics, University of Erlangen-Nuremberg

One issue has been a constant since the 1980s in power plants: The effects of water environment on the fatigue resistance of austenitic stainless steels. During the last decades institutions performed fatigue tests on polished and ground specimen, and examined different environments and test parameters in detail. Some of the results are included in local stress-strain concepts, like for example the modifications proposed by Argonne National Laboratory [1].
To optimize the current local concept of fatigue assessment, more parameters need to be considered in the model. So, fatigue data including results from America, Europe and Japan are compiled. Only strain controlled test data for austenitic stainless steels (304, 316 ...) and for the grades 1.4541 and 1.4550 are discussed. In the first step, fatigue life is defined as the number of cycles necessary for the tensile stress to drop 25 percent from its peak value and the data in air are expressed in terms of the Langer equation. Strain vs. life data of polished specimen tested in different environments are shown in Fig. 1.
Fatigue relevant parameters in air (temperature, surface finish ...) and in medium (strain rate, dissolved oxygen content DO ...) are selected, which will be incorporated in the model. Long hold-time tests with a hold period of three days in elevated water environment will qantify possible recovery effects.

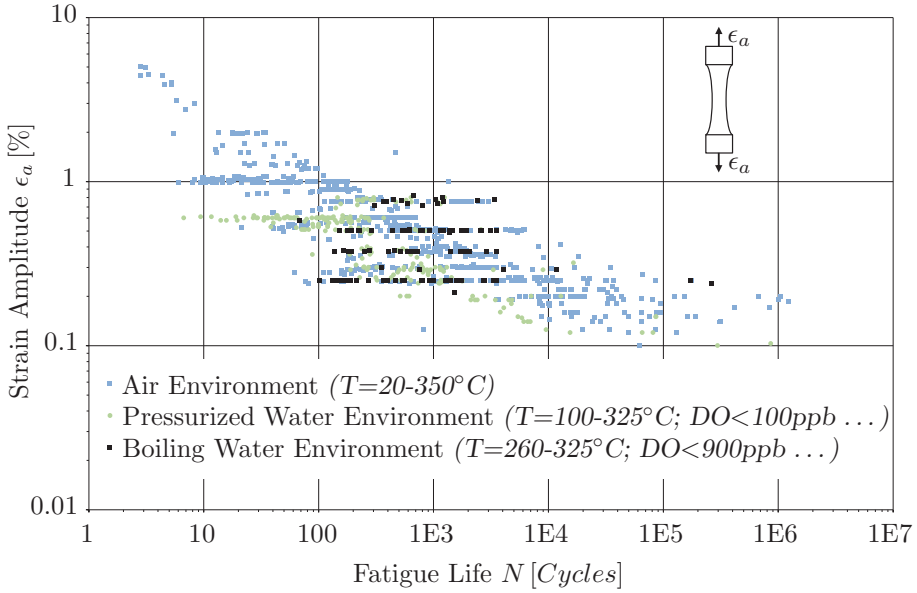

Figure 1: Fatigue strain vs. life data for austenitic stainless steels in different environments.

References

[1] O. K. Chopra, W. J. Shack. *Effect of Light Water Reactor Coolant Environments on the Fatigue Life of Reactor Materials.* Argonne National Laboratory, Argonne IL (2007).

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)
- Seminar über Fragen der Mechanik
- Advanced Lecture: Introduction to Electro- and Magneto-Mechanics
- Number of exams - 2711

4.2 Dissertation thesis

- S. Germain,
  On Inverse Form Finding for Anisotropic Materials in the Logarithmic Strain Space

- M. Kraus,
  Entwicklung und Untersuchung polytoper Finiter Elemente für die nichtlineare Kontinuumsmechanik

4.3 Diploma theses

- A. Nguechi,
  Aufbau eines Prüfstandes zur Demonstration undVlidierung von Überwachungs- und Diagnosealgorithmen

- A. Janeba,
  Experimentelle und numerische Untersuchung zum dynamischen Verhalten von verschraubten Strukturen in der Resonanz

- Y. Shaterova,
  Untersuchung zur Schwingungssicherheit von Turbinenschaufeln mit vortordierten Deckplatten unter Berücksichtigung der Fügestellenreibung

4.4 Master theses

- S. Kunz,
  Automatisierte FE-Berechnung des Läuferpaketsitzes elektrischer Maschinen

- A.I. Keskinoglu,
  On the Importance of Surface and Curve Effects in Modelling Nanowires

- Y. Kumar,
  A study of surface energy effects and implementation of the corresponding two-dimensional Finite Element

- S. Käßmair,
  Computational Aspects of Thermomechanical Solids with Generic Imperfect Interfaces

4.5 Bachelor theses

- M. Ecker,
  Topologieoptimierung mit der SIMP-Methode in 2D und 3D für bilineare Vierecks- und trilineare Hexaederelemente

- S. Demirel,
  Einfluss der Oberflächenbeschaffenheit auf das Steifigkeitsverhalten von Blechpaketen in elektrischen Maschinen

- J. Kormann,
  Methodische Entwicklung einer biaxialen Zugprobe mit heterogenem Dehnungsfeld

- M. Heinl,
  Parameteridentifikation eines DC04 Stahlbleches in der Blechebene und in -dickenrichtung unter Verwendung eines optischen Vollfelddeformationsmesssystem

- L. Tkany,
  Design of experiment in the investigation of electronic-electro-active polymers

- B. Fiegl,
  Mikrostrukturelle Optimierung von Faserverbundwerkstoffen

- P. Mildenberger,
  Performanceoptimierung eines Finite Elemente Codes in Matlab

- J. Hohage,
  Experimentelle Modalanalyse von Rotoren zur Ermittlung von Steifigkeits- und Dämpfungswerten für Rotordynamik-Simulationen

4.6 Student research projects theses

- P. Kirsch,
  Ermittlung und Simulation des Steifigkeitsverhaltens von Blechpaketen unterschiedlicher Höhe

- W. Malezki,
  Finite-Elemente-Implementierung von Oberflächenelastizität in 2D

- J. Scherer,
  The SIMP method for nonlinear finite elements

- V. Krieger,
  Modale Parameterbestimmung mittels Circle-Fit-Verfahren

- J. Weber,
  Entwicklung eines LabViem-basierten Alarm- und Fehlermanagement-Programms

- M. Klebl,
  Dokumentation und Bedienungsanleitung des FEM-Programms Phoenix

- O. Eckstein,
  Optimierung und Inbetriebnahme eines Versuchsaufbaus zur Untersuchung von Saitenschwingungen

4.7 Seminar for Mechanics

21.01.2013 Steffen Göbel,
Federal Mogul Nürnberg / LTM
Topologieoptimierung des Radträgers eines Formula Student Rennwagens

23.01.2013 Odysseas Kosmas,
Chair of Applied Dynamics, FAU Erlangen-Nürnberg
Phase fitted variational integrators using interpolation techniques for the general N-body problem

23.01.2013 Saskia Sitzmann,
ZISC Erlangen
Mortar contact in the FEM package CalculiX

26.04.2013 Prof. Olivier A. Bauchauch,
Universitiy of Michigan - Shanghai Jiao Tong University Joint Institute
Three-Dimensional Beam Theory for Flexible Multibody Dynamics

27.05.2013 Dr. Stefan Sandfeld,
Institute of Materials Simulation (WW8), Department of Materials Science Friedrich-Alexander-University Erlangen-Nürnberg
From Systems of Discrete Dislocations to a Continuous Field Representations: The Continuum Dislocation Dynamics Theory (CDD)

21.06.2013 Dominik Budday,
Karlsruher Institut für Technologie
Analyse des räumlichen Gehens anhand eines Masse-Feder Modells

08.07.2013 Thomas Graupeter,
Lehrstuhl für Systemsimulation, Department Informatik, FAU Erlangen
Birefringence in solid-state laser rods due to the thermal lensing effect regarding shear strains in axial-radial plane

19.07.2013 PD Dr.-Ing- habil. Bernhard Eidel,
Universität Duisburg-Essen Fakultät für Ingenieurwissenschaften, Abteilung Bauwissenschaften, Institut für Mechanik
On atomistic-continuum coupling for crystalline nano-structures: from surface relaxations to localized inelastic mechanisms

26.09.2013 Thorsten Brand,
Erlangen Centre for Astropartile Physics, FAU
An automated data reduction pipeline for the Hartebeesthoek Radio Astronomy Observatory

09.10.2013 Jun.-Prof. Dr. W. Wollner,
Universität Hamburg, Fakultät f/ür Mathematik, Informatik und Naturwissenschaften, Fachbereich Optimierung
DOpElib - A Differential Equations and Optimization Toolkit

02.12.2013 Markus Härtel,
TU Chemnitz, Institut für Werkstoffwissenschaft und Werkstofftechnik
Auf der Suche nach der äquivalenten Querschnittsfläche – Simulation eines Kreuzzugversuches

11.12.2013 George Chatzigeorgiou,
Arts et Métiers ParisTech, Metz-Lorraine, LEM3, UMR 7239
Theoretical and Computational Aspects on Surface Electrostatics

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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- Volume 36 Issue 1 2013
  Applied and Numerical Linear Algebra
  Guest Editor:
  P. Benner, Magdeburg & D. Kressner, Lausanne

- Volume 36 Issue 2 2013
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  Guest Editor:
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- **International Journal of Numerical Methods in Engineering**
- **International Journal of Solids and Structures**
- **International Journal of Structural Changes in Solids**
- **Journal of the Mechanical Behaviour of Materials**
- **Mathematics and Mechanics of Complex Systems**
- **Meccanica**

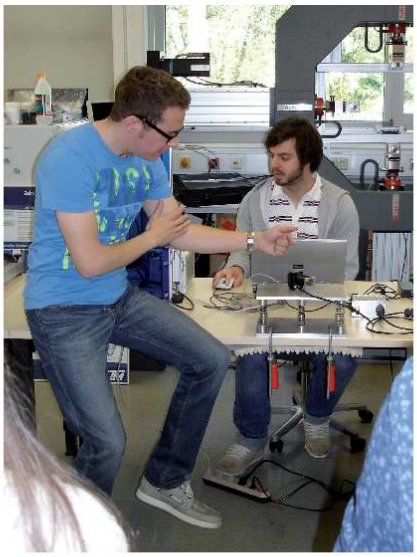
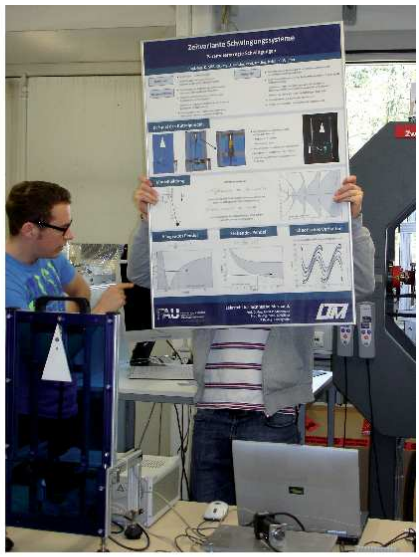
4.9 Pupil Information Day

(ds) On February 2^{nd} the chair of applied mechanics opened its doors for pupils from high schools, which are interested in inside information about studying engineering sciences, natural sciences and computer sciences. Undergraduate students presented various experimental set-ups which are currently used for investigations, namely the electrodynamic shaker testing facility, the laser-microscope and a testing bench for dielectric elastomer actuators.

4.10 Girls' Day and Boys' Day

(ds) As every year on Girls' Day (25.04.2013), universities, organizations and companies opened their doors to awaken young girls' interest in engineering, science and trade. This event, which was originally designed for girls to provide them with information about non-typical professions for women, is accompanied since 2010 by the corresponding event for boys. From 5th grade on, the pupils are encouraged to gain an insight into daily life and education at the University Erlangen-Nuremberg.

The Chair of Applied Mechanics contributes to this event with descriptive experiments in the field of dynamics. The students are introduced to the basic principles of free, forced and parameter-excited vibrations and can experience phenomena like chaotic oscillations, resonances and anti-resonances.

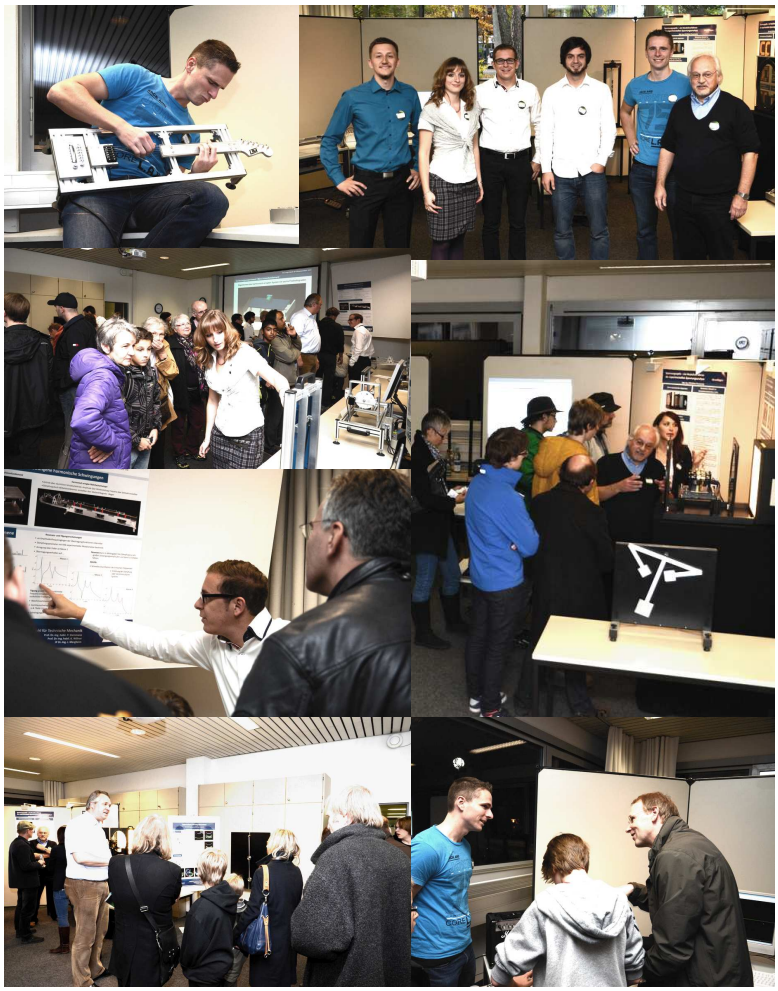
4.11 Practical Course: Girls & Engineering / Youth & Engineering

(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 and as a result of this good reception we are looking forward to participate also in the next year’s event, which will be hosted in September 2014.

4.12 Long Night of Science

(mj) Already for the sixth time since 2003, the "Long Night of Science" (Die Lange Nacht der Wissenschaften) took place on October 19th at numerous institutions spread through the metroplitan region of Nuremberg, Erlangen, and Fuerth. Between 6 p.m. and 1 a.m. the audience was invited to "watch, be astonished, understand" (Sehen! Staunen! Verstehen!). The FAU, non-university research institutes, companies and other institutions delivered insight into current trends in research and development. Like recent years, the Chair of Applied Mechanics also participated in this event and opened its doors on Saturday evening to present current research results in the areas of experimental stress analysis, non-linear system dynamics, shape optimization and electro sensitive elastomers. The new LTM-guitar demonstrated string waves but brought also Rock'N'Roll into LTM's seminar room. Due to the very positive resonance to our program and the extremely large attendance at our chair, we are encouraged to participate as well in the next "Long Night of Science", which will take place in October 2015.



4.13 Organization of the 85th Annual Meeting of GAMM

(ws) The Annual Conference of the International Association of Applied Mathematics and Mechanics takes place at the FAU from 10.03.2014 to 14.03.2014.

Under the leadership of Paul Steinmann and Günter Leugering the local FAU committee faces the challenges of organizing a renowned international conference with approximately 700 speakers expected to be attended by 1000 participants.

The conference website was produced by Wolfgang Steinbach and has been online since summer 2013:
www.jahrestagung.gamm-ev.de
Since October 2013 Monica Roux is in charge of the Conference Office supporting participants and speakers in all matters.
As a special attraction the Opening Reception will take place in the form of a historic train journey on the history-charged rails of the metropolitan region of Nürnberg-Fürth-Erlangen.

The LTM is shouldering the main task of organizing this conference and is mastering the many financial, staff and logistic challenges in a creative manner. During the conference student assistants and lecturer's assistants will ensure that this conference will be fondly remembered by all national and international participants not only for the quality of the scientific contents but also for our hospitality.

GAMM 2014 Erlangen

5 Social events

5.1 Visit of the Bergkirchweih

(fe) The Bergkirchweih has taken place since 1755 and is one of Germany's biggest beer festivals. Held under elms, chestnuts and oak trees with wooden benches accommodating more than 11,000 people, it is one of Europe's biggest open air beer gardens. Due to the long tradition and the unique atmosphere of the week-long festival, it is no surprise that roughly a million people visit the event every year.
It is tradition that most of the staff of the university's chairs and the FAU students visit the "Berg" at the festival's first Tuesday. Of course, the members of the LTM joined the rest of the university.
The weather had been unsettled but the atmosphere was great as always.
The visit was a great success in cultivating the colleagueship within the chair and beyond.

5.2 Student summer party and egg-drop contest

(sr) This year's student summer party took place on 18th of July around the chair building. More than 50 students and the entire staff enjoyed the great weather and the gastronomic specialties that had been prepared by devoted chair members on the barbecue grill. Thanks to a great organizing committee, namely Stefan Käßmair and Florian Beyer, everyone's ravenous hunger could be satisfied. We used the occasion to present the third LTM Egg-Drop Contest. Aimed at attracting the attention of students to challenging problems in simulation and design of machinery, as well as a preparation for the main event in December. The object of this contest is an optimization problem in applied mechanics: built out of plastic drinking straws and paper staples, an engineering structure is designed to protect a raw egg being dropped from a height of 2 meters. As a reward for the effort, a prize was handed over to the winners of the contest.

5.3 Outing to the 'Walberla'

(fv) This year's team outing brought us to the most famous elevation of the Franconian Switzerland, the so called Walberla. On a very hot midsummer day, on August 2nd, 2013, we set out to climb the 'Franconian Fujiyama'. With its 530 m above sea level, it is a prominent landmark of the region, which is visible from afar and a popular hiking destination.
We started our tour with a short train ride from Forchheim to Kirchehrenbach. From there, we climbed the Walberla on the north trail, which was for most parts still covered by the shade of the woods. Once we made our way to the top, we were rewarded with a wonderful view over the valley. Under perfect blue skies, we could see from Bamberg via Forchheim and Erlangen all the way to Nürnberg. For lunch, we paused at the 'Ehrenbürg' in Schlaifhausen, where we enjoyed a delicious meal with one or two isotonic drinks to recharge our batteries. From then on, our tour went only downhill. However, given the high temperatures, this still posed a challenge and we were glad, when we had finally crossed the meadow lands towards Reuth. At the 'Mühlhof', we could fortify ourselves with coffee, cake and ice cream before we headed back to Forchheim. With a *Brotzeit* at the beer cellars, we finished off the day.

6 Contributions to Journals

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2. G. Chatzigeorgiou, A. Javili, P. Steinmann. Surface electrostatics - Theory and computations.

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5. S. Diel, O. Huber, P. Steinmann, W. Winter. Design and validation of a new fixture for the shear testing of cellular solids.

6. J. Friederich, G. Leugering, P. Steinmann. Adaptive finite elements based on sensitivities for topological mesh changes.

7. S. Germain, P. Landkammer, P. Steinmann. On a recursive formulation for solving inverse form finding problems in isotropic elastoplasticity.

8. A. Javili, S. Kaessmair, P. Steinmann. General imperfect interfaces.

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11. P. Saxena, D.K. Vu, P. Steinmann. On rate-dependent dissipation effects in electro-elasticity.

12. S. Schindler, M. Zimmermann, J.C. Aurich, P. Steinmann. Thermo-elastic deformations of the workpiece when turning aluminium alloys - Experiments and finite element simulations

13. S. Schindler, M. Zimmermann, J.C. Aurich, P. Steinmann. Finite element model to calculate the thermal expansion of the tool and the workpiece in dry turning.

14. S. Schmaltz, K. Willner. Comparison of different biaxial tests for the inverse identification of sheet steel material parameters.

15. D. Süss, K. Willner. Investigation of a jointed friction oscillator using the multiharmonic balance method.

16. F. Vogel, S. Göktepe, P. Steinmann, Ellen Kuhl. Modeling and simulation of viscous electro-active polymers.

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7 Contributions to Proceedings

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4. P. Steinmann, S. Pfaller, G. Possart, F. Müller-Plathe, M. Rahimi, M. C. Böhm. Molecular dynamics meets finite elements: An approach for coupled simulations of nanocomposites, *HYBRID2013*, 04.03.2013, Jülich, Germany

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10. P. Steinmann, A. Javili, G. Chatzigeorgiou. On the formulation and computation of multiscale magnetomechanical materials. *Euromech 545*, 22-24.05.2013, Dortmund, Germany

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13. A. Esmaeili, A. Javili, P. Steinmann. A novel cohesive zone model accounting for in-plane stretch of an interface, *CFRAC*, 05-07.06.2013, Prague, Czech Republic

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16. P. Steinmann. Aspects of the modelling and simulation of magneto-sensitive polymers, *3rd South-East European Conference on Computational Mechanics*, 12.-14.06.2013, Island of Kos, Greece

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18. J. P. Pelteret, D. Davydov, A. Javili, B. Walter, P. Steinmann. Towards a computational model of thermal- and magneto-sensitive polymers, *V Conference on Computational Methods for Coupled Problems in Science and Engineering (COUPLED 2013)*, 17-19.06.2013, Ibiza, Spain

19. P. Steinmann, M. Hossain. Degree of cure-dependent thermo-mechanically coupled model to simulate curing processes of thermosets, *5th International Conference on Computational Methods for Coupled Problems*, 17.-19.06.2013, Ibiza, Spain

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21. A. Javili, G. Chatzigeorgiou, P. Steinmann. Computational Micro-to-macro Transition in Magneto-mechanics, *New Trends in Solid Mechanics*, 24-28.06.2013, Castro Urdiales, Spain

22. P. Saxena, M. Hossain, P. Steinmann. Nonlinear magneto-viscoelastic deformations in magnetorheological polymers, *New Trends in Solid Mechanics: Coupled Fields and Multi-Scale Modelling*, 24-28.06.2013, Castro-Urdiales, Spain

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