Annual Report
2006

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2006

Chair of Applied Mechanics
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1 Preface

The present booklet reports on the activities of the Chair of Applied Mechanics at the University of Kaiserslautern. Although the external budget conditions become increasingly more tied, the Chair of Applied Mechanics was fortunately developing in a very satisfactory manner during the year 2006.
This success is exclusively due to the hard work and never ending enthusiasm of all the members of the Chair of Applied Mechanics. This report is intended to shed a spotlight on the current status of affairs of Applied Mechanics at the University of Kaiserslautern and should convince the reader about the high degree of dedication and ambition of all the members of this group.

Paul Steinmann

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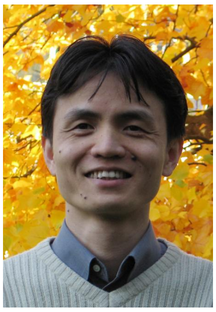
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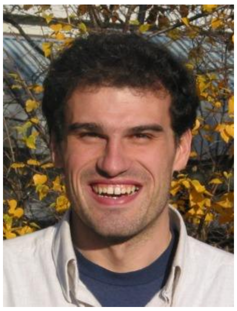
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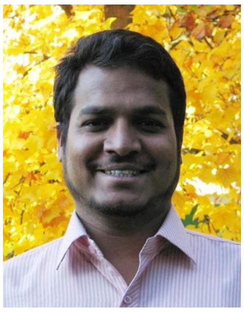
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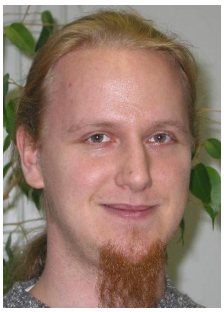
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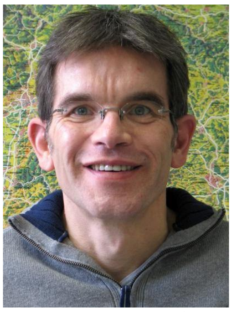
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Green-Naghdi thermoelasticity: thermal and mechanical waves

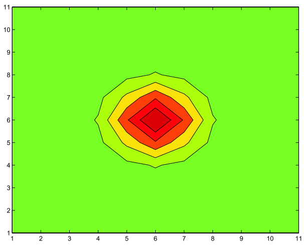
Swantje Bargmann, Paul Steinmann

The main objective of this work is the study of non-classical linear thermoelasticity. The term ”non-classical“ refers to non-classical, i.e. non-Fourier-type heat conduction. The focus is on the approach introduced by Green and Naghdi which is coupled with an elastic mechanical model and studied theoretically and numerically.

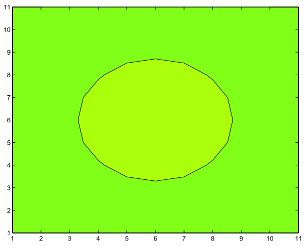
Their theory is subdivided into three approaches, labeled type I, II and III. It is distinguished by the full integration of the classical theory (type I) and the so-called theory without energy dissipation (type II). To date, type II is the only published energy-conserving thermal theory. Their approach is topped off by type III which incorporates type I and II as limiting cases and therefore represents the most general type.

We discretize the coupled system of equations with standard Bubnov-Galerkin finite elements in space and discontinuous (dG) resp. continuous (cG) Galerkin finite elements in time. This leads to a mixed Galerkin approach for the coupled system of equations of type I which is solved monolithically and a full cG-discretization for the coupled systems of type II and III.

In the following example we investigate a square plate which is initially heated in its middle. The temperature at various point is plotted for type I and type III.



Type I, $t = 0.1\mu s$



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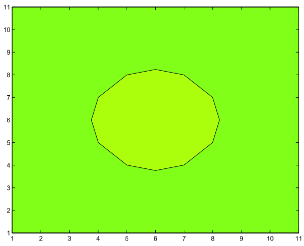
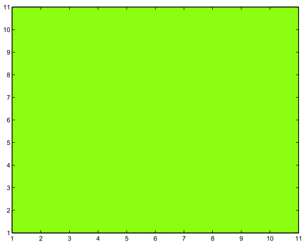
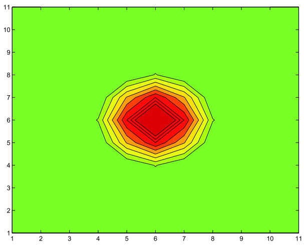


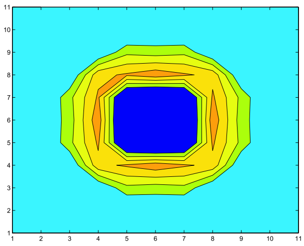
Type I, $t = 1\mu s$



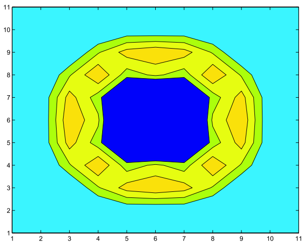
Type I, $t = 1.5\mu s$



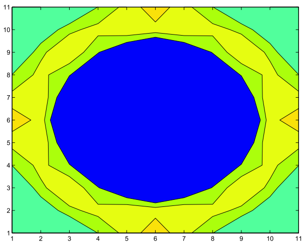
Type III, $t = 0.1\mu s$



Type III, $t = 1\mu s$



Type III, $t = 2\mu s$



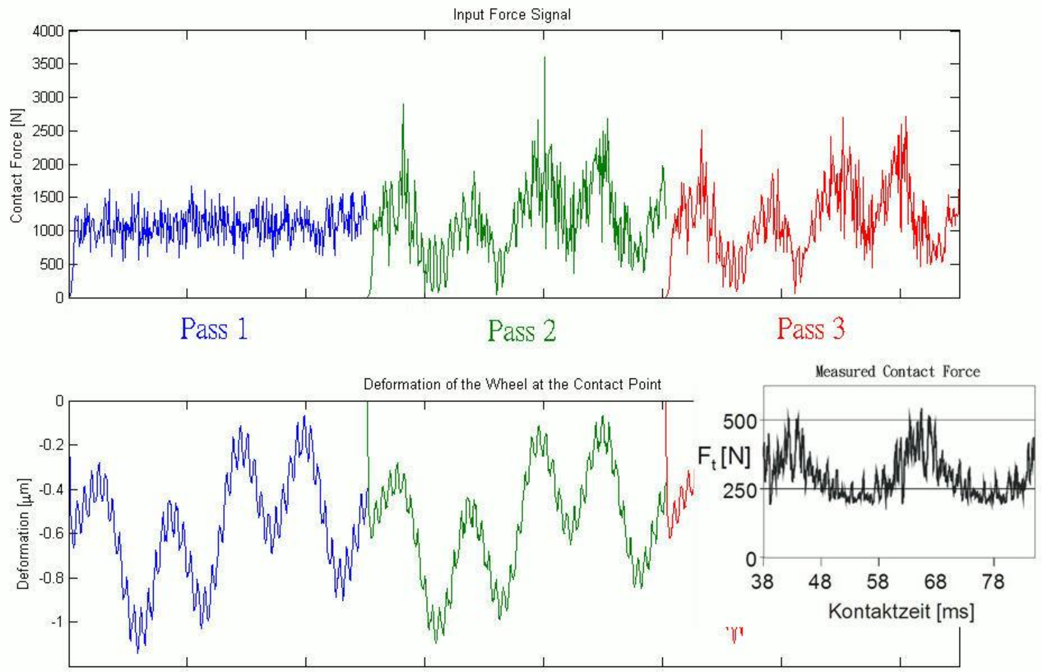
Type III, $t = 3\mu s$

Interaction of Process and Machine during High–Performance–Grinding

Robin Ching, Andreas Menzel, Paul Steinmann

This research project is a joint co-operation with the Institute of Manufacturing Engineering and Production Management (FBK) at the University of Kaiserslautern. The main goal of the entire project is to develop a comprehensive simulation tool that accounts for both, the grinding process and the influence of the grinding machine. The modelling of the grinding process is performed with the help of kinematic simulation (KSIM), which govern grinding parameters, work piece, type of grinding and the grinding speed. This tool is embedded into a finite element formulation (FEM), which is set flexible to various time and space scale, to enable the incorporation of essential machine properties.

The first phase of the project is completed. The construction of the grinding wheel model, Eigen frequency extraction, contact modelling and FEM-KSIM coupling interface was well finished as stated in the proposal of the first phase. The final report of the first phase and the proposal for the second phase with process plan was submitted to the German Science Foundation for revision in October 2006.



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A Novel Polygonal Finite Element Method

Alexandru Constantiniu, Paul Steinmann

In recent years we saw an emerging interest towards using arbitrary polygonal elements in discretization schemes. Latest advances in the construction of interpolants have allowed the use of new building blocks for tessellations, other than n-simplices and regular n-gons. We propose a novel polygonal finite element method, based on a hybrid nodal-element approach.

Starting from a classical Delaunay tessellation, we transform it into an adaptive one (ADT) by subsequently applying a Delaunay circumcenter rule. Polygons are formed by merging simplices intersected by line segments between their barycenters and circumcenters. Constructed in a straightforward and iterative manner, such a tessellation is unique and bounded in computational time. A simple to evaluate form of rational barycentric coordinates for higher dimensions is applied. They have desired properties and reduce to conventional barycentric coordinates in the case of simplices. Over the representative domains around the nodes a stabilized nodal integration scheme is used.

We apply this interpolation scheme on an 8 bit, 720x560 pixels grayscale image (Fig. 1). We consider as known the values in 4292 pixels out of 403200 (respectively 1.06%) and interpolate the values in the others. Two approaches are compared (Fig. 2), namely a Delaunay triangulation with a linear interpolation over the simplices and an Adaptive Delaunay Tessellation with generalized barycentric coordinates over the polygons.

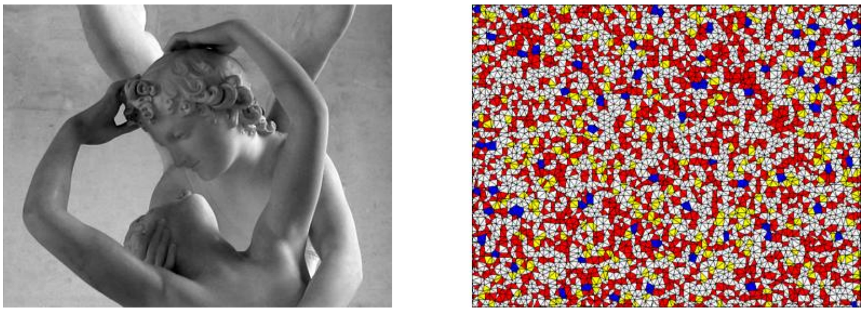

Figure 1: Original image and corresponding ADT

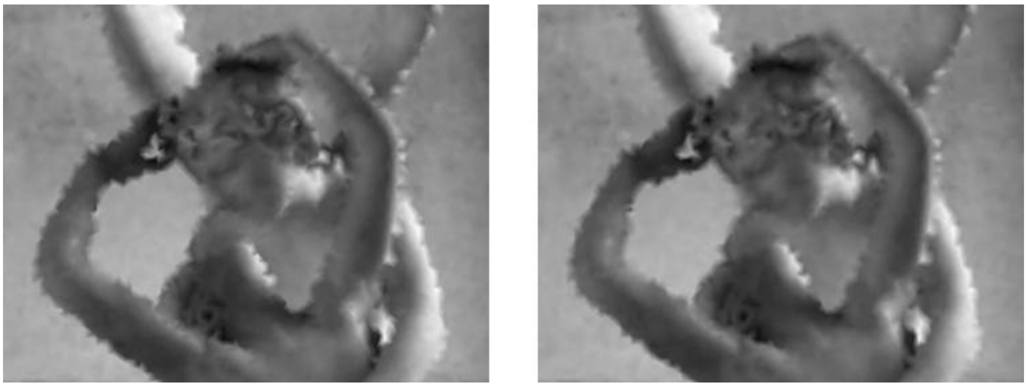

Figure 2: DT interpolated image vs ADT interpolated image

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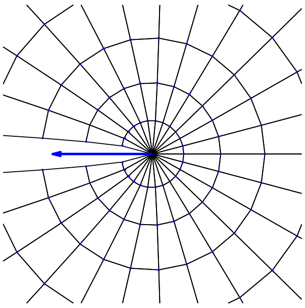
A special singular finite element for the numerical calculation of material forces in nonlinear fracture mechanics

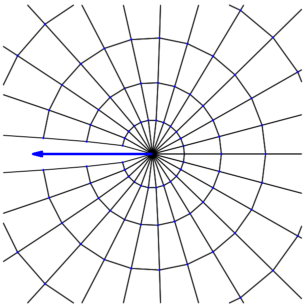
Ralf Denzer and Paul Steinmann

In the case of nonlinear fracture mechanics the type of singularity induced by the crack tip is commonly not known. This results in a poor approximation of the near crack tip fields in a finite element setting and induces so called spurious – or residual – discrete material forces in the vicinity of the crack tip. Thus the numerical calculation of the crack driving material force in e.g. dissipative materials is less precise, because we can not take advantage of domain independent integrals. To overcome this problem we propose a special singular element, which adapts automatically to the type of singularity.
Thus the aim of this work is the formulation and implementation of a special singular finite element to calculate the single material force acting at the crack tip as a crack driving force with high precision. Material forces act on the material manifold, thus essentially representing the tendency of defects like e.g. cracks to move relative to the ambient material.
As an example a straight crack under mode-I loading in linear elastic and Romberg-Osgood material with an externally applied material force of $\mathfrak{F}_{sur}^{appl} = 1.0$ is discussed. Using the proposed adaptive singular elements in the vicinity of the crack tip results a high accuracy in the calculation of the material force acting on the crack tip, whereas the use of standard finite elements leads to a poor approximation.

Model-I loading for a crack in linear elastic material

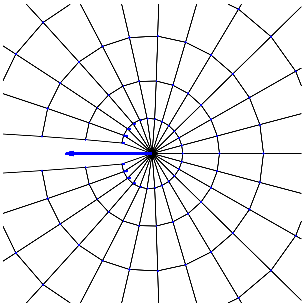


$\mathfrak{F}_{sur}^{cracktip} = 0.83462$
P2 element

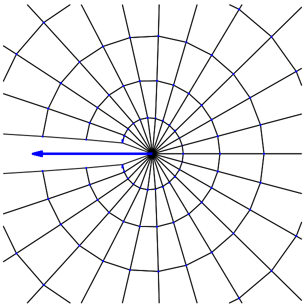


$\mathfrak{F}_{sur}^{cracktip} = 1.0009$
adaptive singular element

Model-I loading for a crack in Ramberg-Osgood material



$\mathfrak{F}_{sur}^{cracktip} = 0.72102$
P2 element



$\mathfrak{F}_{sur}^{cracktip} = 1.0017$
adaptive singular element

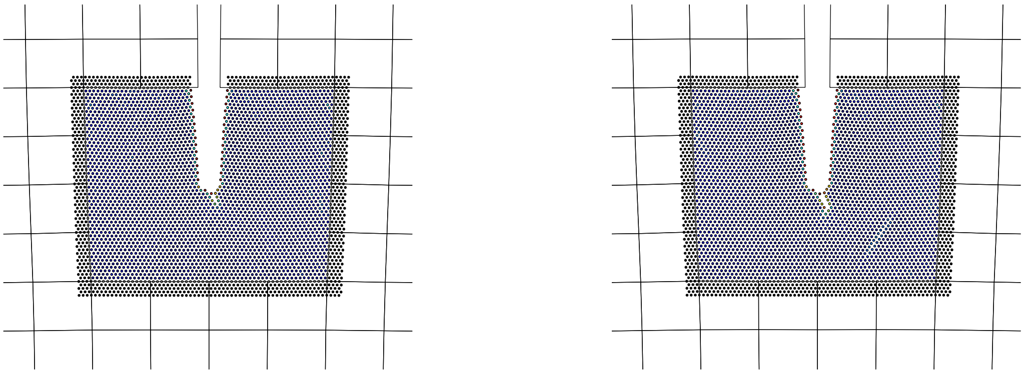
Horizontal Coupling in Continuum-Atomistics

Aitor Elizondo, Paul Steinmann

Thanks to the ongoing advances in computational power and accessibility the range of applications of molecular dynamics approach is permanently increasing from a few hundreds atoms in the earlier works to one billon atoms recently. Moreover, it has became a realistic computational option for simulating a variety of physical problems and analyse traditional complex atomic phenomena. However, the modelling system with macroscopic dimensions in any realistic structure is yet not feasible with an exclusively fully atomistic simulation because of the exhaustively computational demand required.

On the other hand continuum approach has dominate the research activity of mechanics over the past decades to predict material behaviour over the time and space. The range of application of continuum models offers to compute efficiently large systems of material but at the expense of suffering lack of accuracy.

Therefore, In the last years several multiscale models has been appeared in order to solve on the one hand the problem arisses due to the lack of microstructural information in continuum models and on the other hand to overcome the limitations of the prohibitively computational demand of a fully macroscopic atomistic simulation. The main purpose of the present contribution is to present a mixed continuum–atomistic model combining classical continuum mechanics with atomistic features in a multi–scale algorithm to investigate the mechanical behavior of a monoatomic material. The key idea behind such mixed techniques is that the simulation focused exclusively on small critical regions of a structure at the atomistic level where it is necessary due to computational efficiently whereas continuum technique is performed to describe deformation away from the complex behavior. On one hand the traditional molecular dynamics method is applied as atomistic framework. It is a numerical simulation technique where the time evolution of a set of atoms are followed in order to describe physical and mechanical properties. On the other hand, finite element method is applied as continuum approach based on the so–called Cauchy–Born rule, which provides an elegant formulation for linking the deformation between continuum and atomistic models.



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Modeling and simulation of incompressible polymeric materials

Paul Fischer, Ellen Kuhl

Polymeric materials consist of large chain molecules. In order to model the mechanical behaviour, statistical mechanics is used to obtain the end-to-end force of the macromolecule. Fig. 1 shows the end-to-end force for the three most popular models of the polymeric chains. They all result from a distribution function for the position of the chain ends.

To obtain a fully three dimensional model for the complex molecular network of rubber, a number of different chain network models have been proposed in the past. For example 8 or 21 chain network models or models with continuous chain distribution in space.

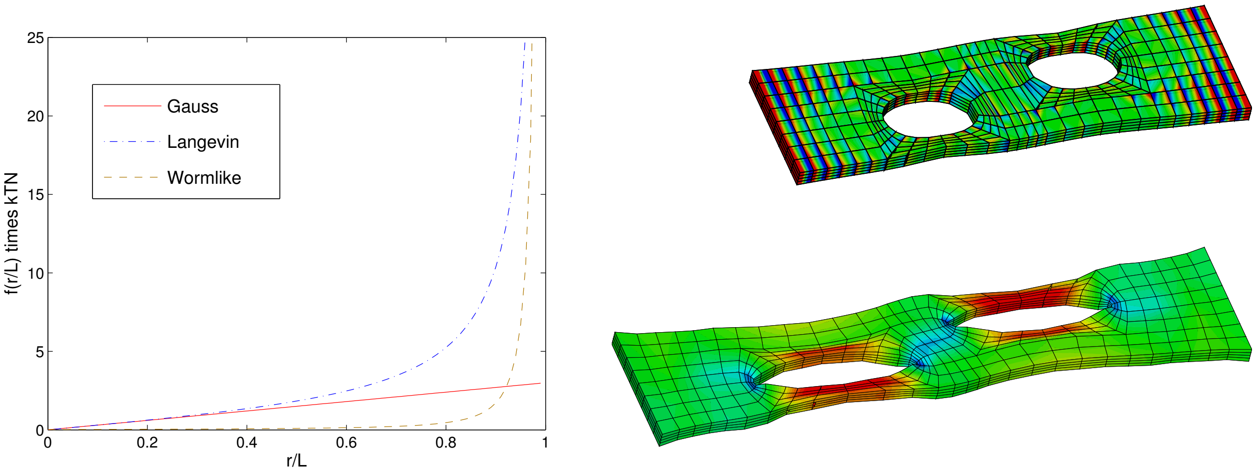

Figure 1: Left: Force elongation response of different chain models. Right: 1^{st} invariant of the stress for single field formulation (top) and Q1P0 mixed elements (bottom)

When simulating incompressible polymeric materials, standard single field finite element formulations are known to display a spurious unphysical response. Figure 1 (upper right) shows the quantitative behaviour of the trace of the stresses. The trace is highly mesh dependent and reveals the problems of single field elements to approximate nearly incompressible behaviour. In comparision, the trace of the stress tensor for the Q1P0 mixed formulation reveals the expected distribution. This finite element method with the classical mixed Jacobian-pressure formulation is most common to avoid locking and other numerical instabilities.

In the recent literature an alternative strategy based on a single field 3D Hermitian element with C1 interelement continuity of the displacements has been suggested, see [1]. The fundamental advantage of these elements is a continuous stress interpolation. Therefore, a stress distribution as for the linear single field elements as in Fig. 1 is typically avoided.

In the future numerical experiments are planned to reveal the improved convergence properies of the C1 elements as compared to classical mixed finite elements.

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X-FEM Crack Simulation based on the Material Force Method

Jürgen Glaser and Paul Steinmann

The presented work is based on the combination of two concepts being major subjects of computational fracture mechanics in recent time: The Material Force Method (MFM) and the Extended Finite Element Method (X-FEM).
The X-FEM modifies the standard Finite Element approach in order to describe the discontinuous displacement field across a crack (and the asymptotic crack-tip field) by the introduction of additional degrees of freedom (DOFs) at nodes in the vicinity of the crack. The displacement jump is modelled by a step function connected to those additional DOFs. The most obvious advantage of the X-FEM is the representation of a crack independently of the mesh such that no remeshing is needed in the case of crack propagation.
Force like quantities $\boldsymbol{\mathfrak{F}}$ emanate from a balance law in material space having the same structure as the momentum balance in the spatial setting. These so called material or configurational forces are connected to the material energy momentum tensor $\boldsymbol{\Sigma}^t$, also called Eshelby stress tensor, and they are energetically conjugated to variations of the material placement $\delta \boldsymbol{U}$ of a particle. Thus the singular material surface force acting on a crack tip (in general on any singular part of the boundary) corresponds to a tendency of the crack to propagate. Its amount, which is the same in classical FEM, is equal to the J-integral of fracture mechanics.
The introduction of the MFM within the framework of the X-FEM leads to two types of discrete material node point forces, those and standard and those at enriched DOFs. As the first type of forces coincides with the results of classical FEM, the material forces at enriched degrees of freedom are an additional information.

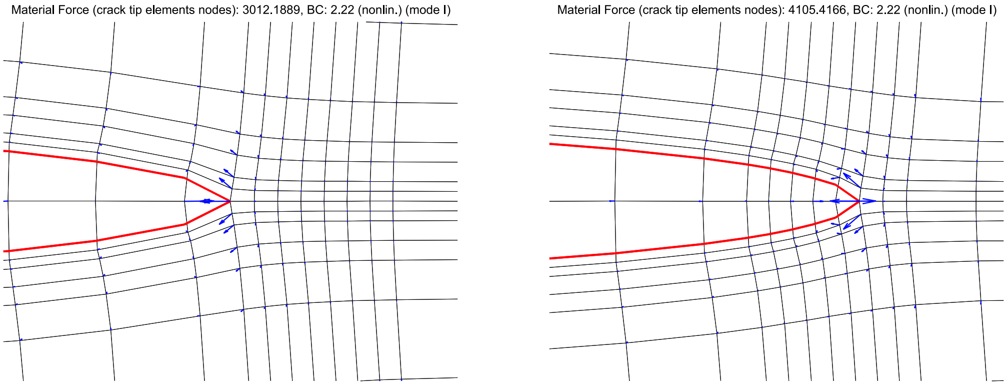

Figure 1: Nodal material force vectors $\boldsymbol{\mathfrak{F}}_h^{sur}$ and quasi-static crack propagation under 0° for mode I loading, geometrically non-linear case.

One advantage of the presented combination of MFM and X-FEM is the reduction of computational cost as no remeshing procedure is needed in the case of crack propagation. But also new problems arise as in general there is no node on the crack tip and the nodal material forces are distributed around the crack tip. Thus, focusing on the nodal material forces at standard degrees of freedom, we have to determine the singular material force vector on the crack tip from the distributed nodal forces.
The presented concept is implemented based on the geometrically linear and non-linear theory for linear and non-linear hyperelasticity respectively. The focus of the work is on the determination of the direction of crack propagation from the nodal material standard forces and the relation of those forces to the vectorial J-integral of classical fracture mechanics.

Theory and Implementation of Time-Dependent Fibre Reorientation in Transversely Isotropic Materials

Grieta Himpel, Andreas Menzel, Ellen Kuhl, Paul Steinmann

Biomaterials are often characterised as fibre-reinforced materials. In contrast to non-living materials with fixed fibres, the fibre direction in many biomaterials changes in consequence of external loadings. So far it is not certainly investigated, which are the driving forces for the reorientation process. In the literature authors assuming strain driven reorientation, see for instance [1] and [2], are found as well as authors opining stresses being the biological stimulus for reorientation, see e.g. [3]. A reorientation along the principal strains is motivated by the fact that the free energy reaches a critical state for coaxial stresses and strains. In isotropic materials this condition is a priori satisfied, however, in transversely isotropic materials it is fulfilled, if the structural tensor and the right Cauchy-Green tensor are coaxial. Such coaxiality can be achieved by aligning the fibre direction with one of the principal directions of the right Cauchy-Green tensor. Thus we assume an alignment with the maximum principal stretch direction, see figure 3a. The motivation for a stress driven alignment is more physiological. Comparison with histological specimen yields that for arterial walls a reorientation along the averaged two maximum principal stress directions is probable. Such an alignment is depicted in figure 3b.

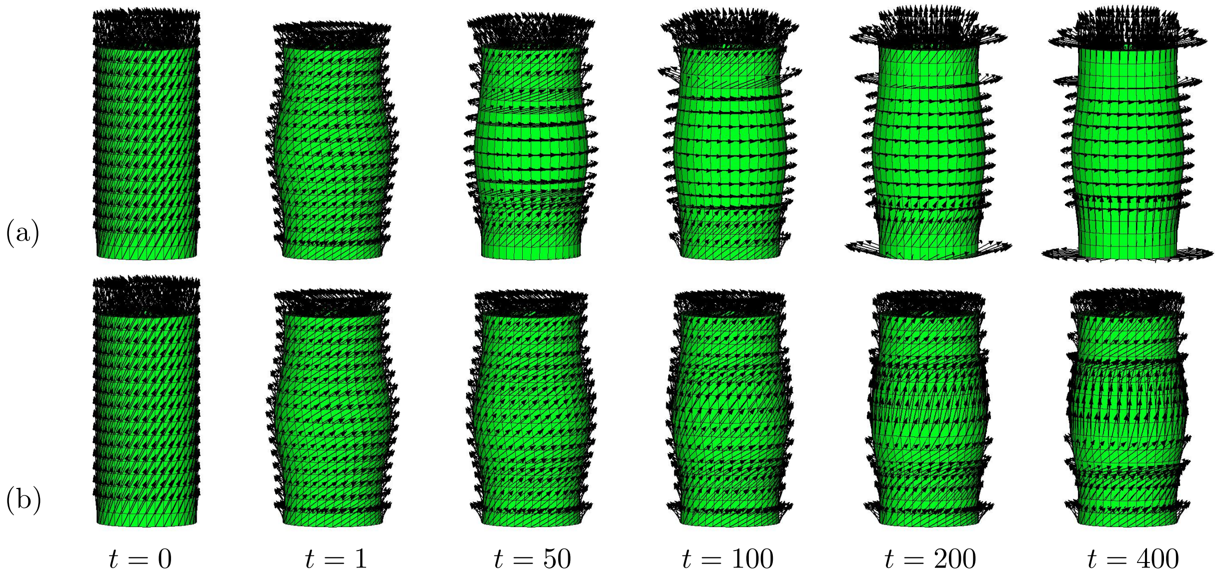

Figure 2: Transversely isotropic tube under inside radial displacement load for (a) strain driven and (b) stress driven reorientation.

References

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Computational Modelling of Micromorphic Continua

C. Britta Hirschberger, Ellen Kuhl, Paul Steinmann

Many materials possess distinct micro-structures, which exhibit different material properties than the overall bulk material. In most engineering applications, when the size of the considered speciment is sufficiently large compared to the size of the micro-structures, effects imposed by the micro-structure can be neglected and classical – local – continuum theories can be used for the modelling. However, at consideration of very small specimens or when it comes to a localisation of the deformation, size-dependent properties come into the picture. To account for this size-dependence, we employ the *micromorphic continuum theory* (e. g. [1], [2]). Within this theory, each material point is assumed to be endowed with a microstructure that may deform kinematically independent from the macro body, particularly this micro-deformation is restricted to affine, yet arbitrary deformations. The additional kinematic variables implicate additional occuring stress quantities (particularly a macro-, micro- and double-stress) as well as extra contributions in the balance of momentum relations. A hyperelastic constitutive formulation provides a coupling between the scales. Consequently, a finite-element approximation will lead to a coupled problem, which is to be solved for macro- and micro-variables.

In the present work [3], we have addressed the problem from the perspectives of both the spatial-motion problem and the material-motion problem. The latter view implies the application of the material-force method [4], which is especially suited for defect mechanics, to the present micromorphic continuum. From the balance of momentum, besides the nodal material forces resulting from the macro-continuum we have derived so-called nodal configurational double-forces for the micro-continuum, which shall be used in defect mechanics.

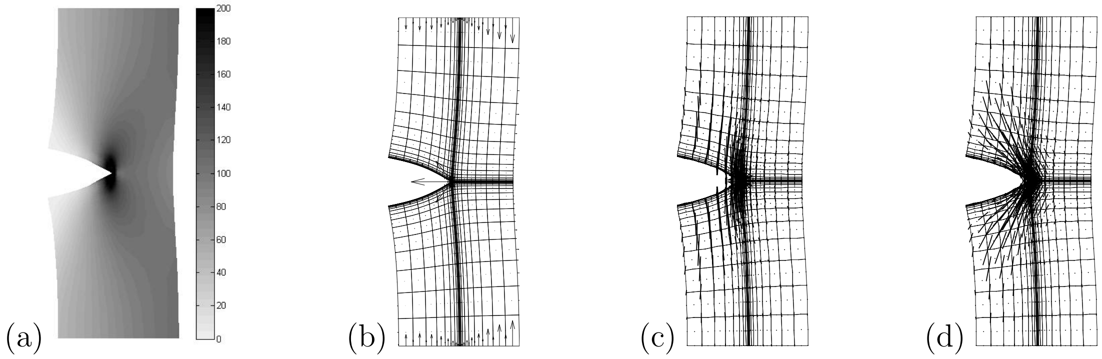

Figure 1: Cracked specimen under uni-axial tension ($l = L_0/20$, $p = 20E$): (a) Longitudinal component σ_{22} of Cauchy-type macro-stress; (b) nodal material forces $\mathfrak{F}_{\rm L}$; (c)–(d) left and right first eigenvectors of nodal configurational double forces $\bar{\mathfrak{m}}_{\rm J}$, scaled by their corresponding eigenvalues.

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Chain Models for Polymeric Material Simulation

Mokarram Hossain and Paul Steinmann

There are several phenomenological based models and micro-mechanically motivated network models for polymeric materials which have been proposed in the literature. The phenomenological models involve invariant or principal stretch-based macroscopic continuum formulations generally having polynomial structures. They lack relations to the molecular structure of the materials. Micro-mechanically motivated chain models are based on chain statistics of polymers.
The 3-chain (Fig.1(a)), 8-chain models (Fig.1(b)), full network models, micro-macro unit sphere/21-chain model (Fig.1(c)) are well-known models which can be used for moderate to large deformations of polymeric materials. The existing non-linear continuum models for polymeric materials have been implemented for elastic case in the research-oriented nonlinear finite element (FEM) code Phoenix.

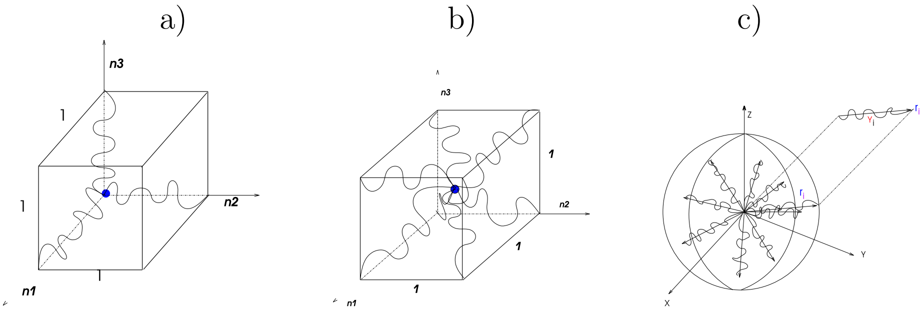

Figure 1: a)3-chain model; b) 8-chain model; c) 21-chain model

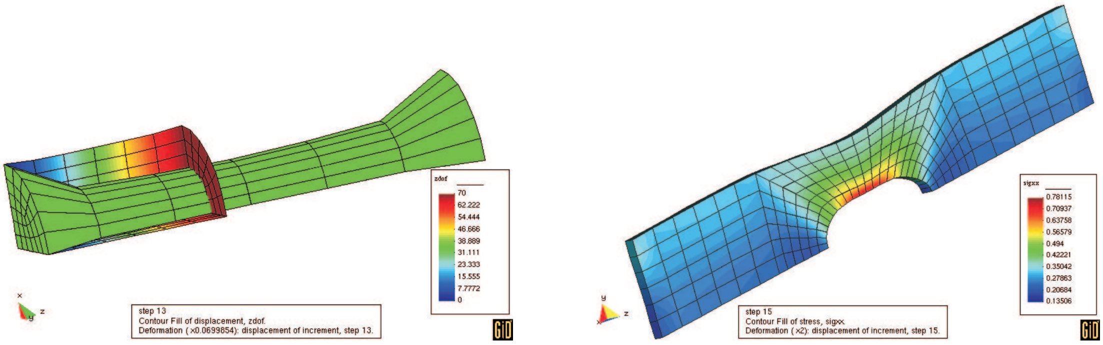

Figure 2: Large deformation with chain models and Bar with hole

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New discretization methods for the simulation of cracks in engineering materials

Philippe Jäger, Ellen Kuhl, Paul Steinmann

The efficient simulation of crack growth is of general interest in different fields of application. The extended finite element method (XFEM) is a powerful approach to describe strong discontinuities in a continuum mechanics based framework. Rather than following the XFEM approach we use a slightly modified method for simulating propagation of discontinuities in 3D, see [1]. This strategy which is based on the original ideas of Peter Hansbo can be understood as a reparametrization of the XFEM on the discrete level. Using either approach, two criteria essentially control the event of crack growth: the applied failure or crack propagation criterion itself and the direction of the crack which should depend on the failure criterion. For 2D problems these phenomena are well-understood, e.g the representation of smooth discontinuities by using maximum nonlocal stress criteria is a popular strategy related in the literature. The extension of the described methods for 3D problems allows to analyse some applications, e.g. bending beam in Figure 2. Unfortunately, in some cases, this extension results in crack surfaces which are discontinuous on the interelement boundaries, see Figure 1. These discontinuous crack surfaces can produce non physical crack bifurcations.

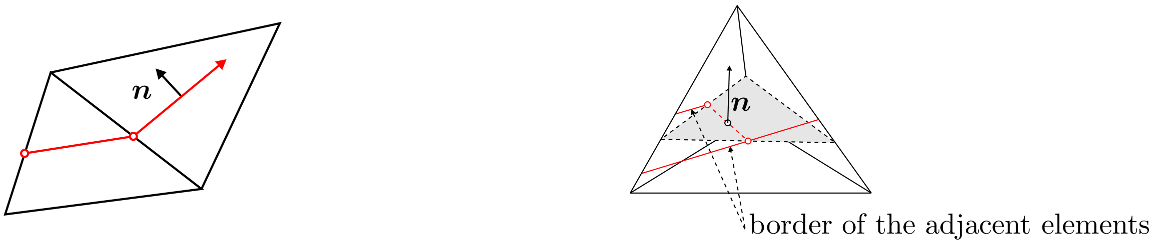

Figure 1: propagating discontinuity depending on the neighbouring elements in 2D and 3D

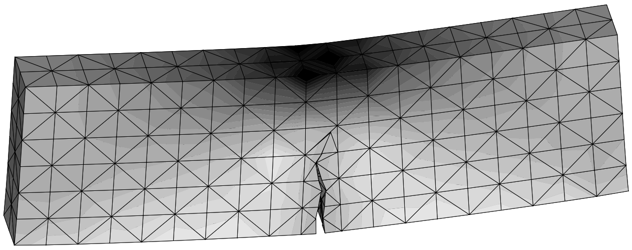

Figure 2: Cauchy-Stress in loading direction for a 3-point bending beam

The systematic comparison of different local and global tracking algorithms to get a smooth representation of the crack surface is the central aspect of present research within this project.

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Generalized parameter identification for finite viscoelasticity

Bernd Kleuter, Andreas Menzel, Paul Steinmann

Elastomeric and other rubber–like materials are often simultaneously exposed to short– and long–time loads within engineering applications. When aiming at establishing a general simulation tool for viscoelastic media over these different time scales, a suitable material model and its corresponding material parameters can only be determined if an appropriate number of experimental data is taken into account. In this work we present an algorithm for the identification of material parameters for large strain viscoelasticity in which data of multiple experiments are considered. Based on this method the experimental loading intervals for long–time experiments can be shortened in time and the parameter identification procedure is now referred to experimental data of tests under short– and long–time loads without separating the parameters due to these different time scales. The employed viscoelastic material law is based on a nonlinear evolution law and valid far from thermodynamic equilibrium. The identification is carried out by minimizing a least squares functional comparing inhomogeneous displacement fields from experiments and FEM simulations at given (measured) force loads. Within this optimization procedure all material parameters are identified simultaneously by means of a gradient based method for which a semi–analytical sensitivity analysis is calculated. A representative numerical example is referred to measured data based on short–time and long–time tests of a non–cellular polyurethane[1]. As an advantage, the developed identification scheme renders solely one single set of material parameters.

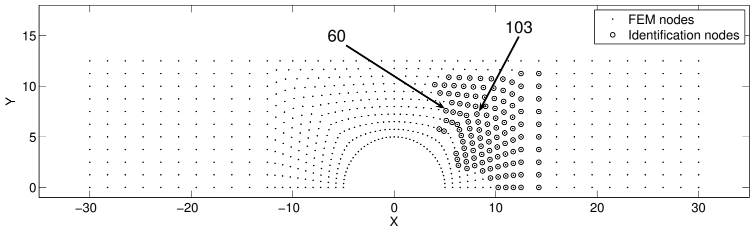

Figure 1: Identification nodes for the tensile tests A, B, and C in the FEM model (symmetry conditions in length direction are applied); representative identification nodes 60 and 103.

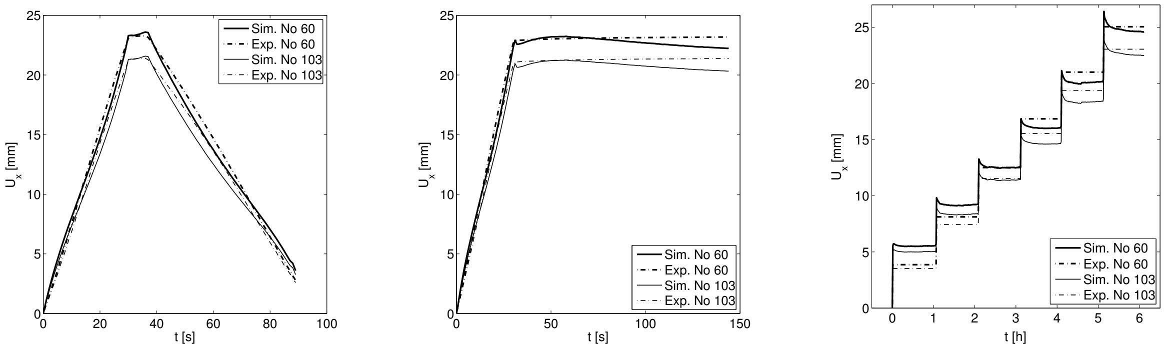

Figure 2: Verification for tests A, B, and C for the identified set of parameters; displacements in longitudinal direction versus time.

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[1] The experimental data was determined by M. Bosseler at the 'Institute of Recyclability in Product Design and Disassembly', Prof. Dr.–Ing. R. Renz, University of Kaiserslautern.

Stress vs. strain-based remodeling in arterial walls

Ellen Kuhl, Gerhard A. Holzapfel*

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Functional adapation of biological tissues has advanced to a research topic of growing interest in the field of mechanobiology. The adaptation in response to mechanical loading can manifest itself in two fundamentally different forms: growth and remodeling. Growth is commonly related to changes in mass or density, whereas the notion of remodeling is typically associated with microstructural changes.

Within this project, we focus on remodeling in the form of collagen fiber reorientation in arterial walls. Experimental findings suggest that the arterial microstructure remodels progressively to preserve circumferential wall stress and wall shear stress at a normal physiological level, see e.g. [1]. Accordingly, different collagen fiber orientations have been observed through the wall thickness varying from an almost horizontal orientation at the inner wall towards a rather diagonal structure in the outermost layer.

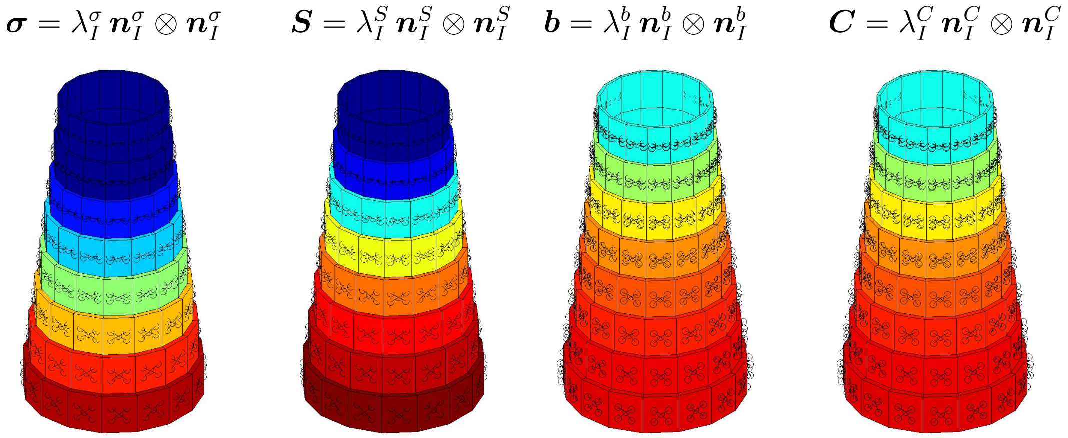

Figure 1: Collagen fiber orientation across wall thickness ∘ Stress vs. strain based remodeling

Motivated by these considerations, we apply a micromechanically-based remodeling theory accounting for collagen fiber reorientation in arterial walls. On the microstructural level, the individual collagen fibers are simulated based on the concept of statistics of long chain molecules. On the macrostructural level, the anisotropic network of collagen chains is accounted for by the introduction of a representative volume element including eight representative chains, see [2]. The key idea of the present approach is that the dimensions of this representative volume element are allowed to remodel progressively driven by the eigenvalues of a second order tensor that characterizes the current loading situation, see [3].

In particular, we address the ongoing discussion whether stress or strain is the relevant quantity that drives the remodeling process. Systematic comparisons of different stress and strain-based remodeling criteria, as illustrated in Figure 1, are elaborated and discussed.

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The discrete null space method for multibody dynamics - an application to closed loop systems

Sigrid Leyendecker, Peter Betsch, Paul Steinmann

Corresponding to d'Alemberts principle in classical mechanics, the discrete null space method developed in [1] provides an energy-momentum conserving time stepping scheme for integration of the differential-algebraic equations (DAEs) pertaining to conservative finite-dimensional dynamical systems subject to constraints. The elimination of the Lagrange Multipliers from the temporal discrete system along with a reparametrisation of the nodal unknowns leads to a reduced number of unknowns and to an improved condition number during the iterative solution of the nonlinear system. External constraints (representing the joints coupling different components in a multibody system) and internal constraints (pertaining to the kinematic assumptions of the underlying continuous theory) are fulfilled likewise at the time nodes, wherefore the discrete null space method is particularly suited for the treatment of elastic multibody systems in structural dynamics.

The discrete null space method can be applied efficiently to open kinematic chains as well as to closed loop systems [2]. A six-body-linkage possessing a single degree of freedom is analysed as an example. The treatment of this closed loop structure by the discrete null space method results in the solution of only one scalar equation of motion. Furthermore it circumvents the involved investigation of dependent constraints, which lead to rank-deficiency of the constraint Jacobian occurring in the time stepping scheme pertaining to the direct temporal discretisation of the DAEs. Fig. 1 shows configurations of the six-body linkage at different times for a simulation.

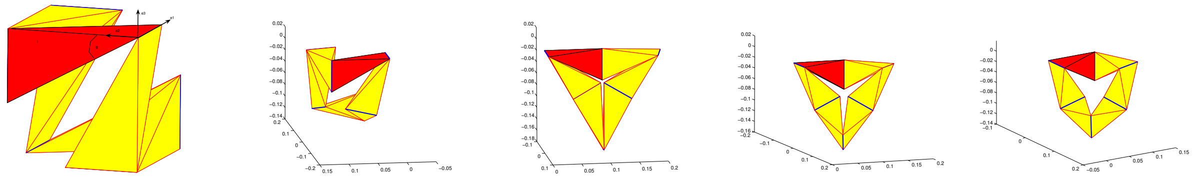

Figure 1: Configuration at $t = 0$, $t = 0.2\text{s}$, $t = 0.4\text{s}$, $t = 1.3\text{s}$, $t = 1.4\text{s}$.

Table 1 summarises the simulations using the constrained scheme and the D'Alembert–type scheme with nodal reparametrisation deduced by the discrete null space method. Both schemes fulfil the constraints exactly. Using the time step $\Delta t = 0.01$, the condition numbers differ by six orders of magnitude. A remarkable difference is in the dimensions of the systems of equations of motion.

scheme	constraint fulfilment	condition number	$\sharp$ unknowns
constrained	exact	$\mathcal{O}(10^5)$	143
D'Alembert–type, rep.	exact	1	1

Table 1: Comparison of the simulations using different schemes.

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On confined periodic granular media

Holger A. Meier, Ellen Kuhl, Paul Steinmann

Discrete simulation of confined granular media demands that the number of grains inside the problem has to be finite. The restriction of a finite number of grains results from the computational costs. Therefore, simulation of granular structures, using a single scale approach, e.g. the discrete element method (dem), is restricted.

To overcome the restriction regarding the number of grains, we apply a homogenization strategy, including a continuous macro- and a discontinuous microscale. The continuous macroscale is discretized by finite elements, whereas a representative volume element (rve), containing discrete elements, is used on the discontinuous microscale.

The rve has to fulfill the requirements of geometric periodicity, internal irregularity, high volume fraction and initial internal force equilibrium. To achieve the above, we apply a packing algorithm developed in the context of computational chemistry, see [1]. The evolution process of an rve satisfying our requirements which was developed in close collaboration with Professor T. I. Zohdi from the University of California, Berkeley is shown in Fig. 1.

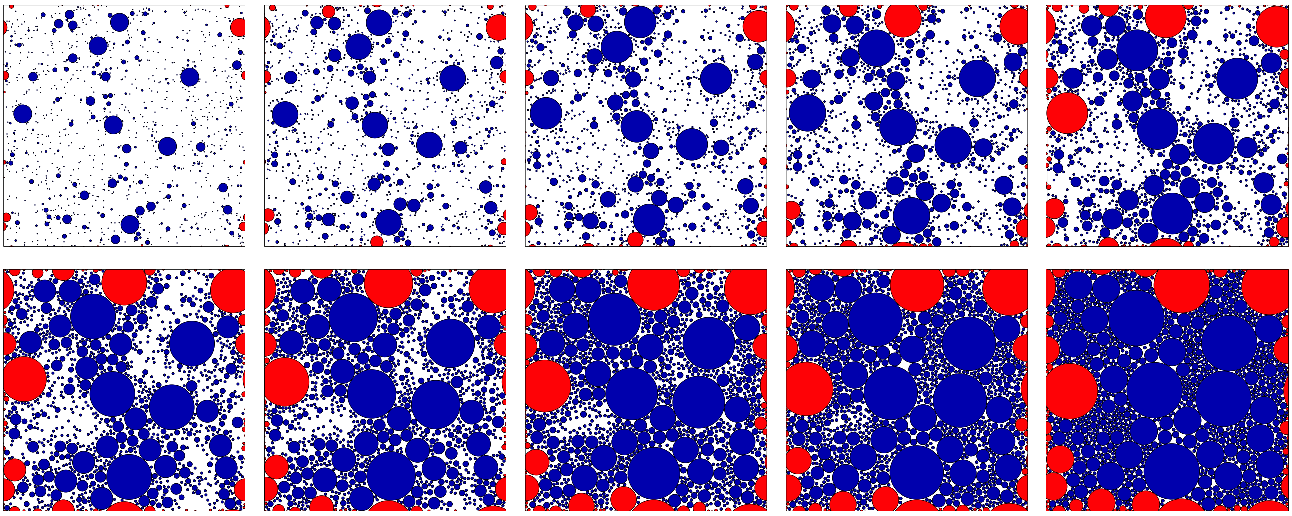

Figure 1: rve evolution process, containing 1000 primary particles. Grain size distribution after DIN 1045, A 32 with 1 mm being the finest grain. Boundary frame particles are colored in red, inner particles are depicted in blue.

Using such geometric periodic rves, subjected to periodic boundary conditions, inside a micro-macro transition keeps the number of grains to a minimum, while still describing a representative material behavior.

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Remodelling and orthotropic growth of soft biological tissues

Andreas Menzel

The modelling of growth and remodelling of biological tissues is one of the challenging tasks in the wide research field of computational biomechanics. Besides hard and soft tissues, one commonly distinguishes between the modelling of non-adaptive and adaptive biological materials – one difference among others being that mass is in general a non-conserved quantity for adaptive biological tissues. The materials of interest commonly consist of cell assemblies and extracellular matrix – the properties of the latter being predominantly characterised by fibres as elastin and collagen. In general, biological tissues can be considered as composite materials which continuously change according to, for instance, growth (and atrophy) as well as remodelling effects. Various substructures are noted at different scales of observation and often render biological tissues to exhibit strongly directionally dependent properties. To give an example, the intracellular microrheology allows interpretation as an actin-rich network possessing different properties as expected for permanently cross–linked networks. In order to account for such anisotropic characteristics – which are related to the observation and mechanical behaviour of for example actin, fibrils, different types of collagen and so forth – so-called fibre families are considered within the finite-deformation continuum approach proposed in [1] so that anisotropic response is included on a phenomenological basis.

In particular we aim at developing a remodelling framework for orthotropic continua, whereby the underlying symmetry group is incorporated via two fibre families. Anisotropic growth is addressed by means of a multiplicative decomposition of the overall deformation gradient into an elastic and a growth distortion. Projected quantities of a configurational growth stress tensor are advocated as driving forces for time-dependent saturation-type evolution of the principal values of the growth distortion. Moreover, the time-dependent reorientation of both fibre families, which directly affects the strain energy as well as the growth distortion itself, is guided by analysing critical energy points. The proposed framework is embedded into a finite element context which allows the simulation of representative numerical examples, see Figure 1.

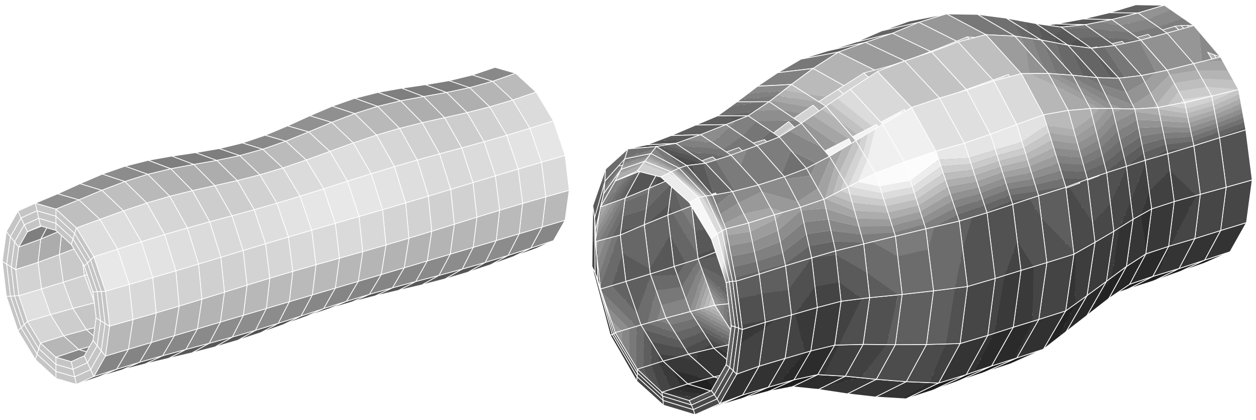

Figure 1: Artery-type tube – initial perturbed geometry (left) and contour plot of the referential density (right) after remodelling and growth for stenting-like loading of the orthotropic tissue.

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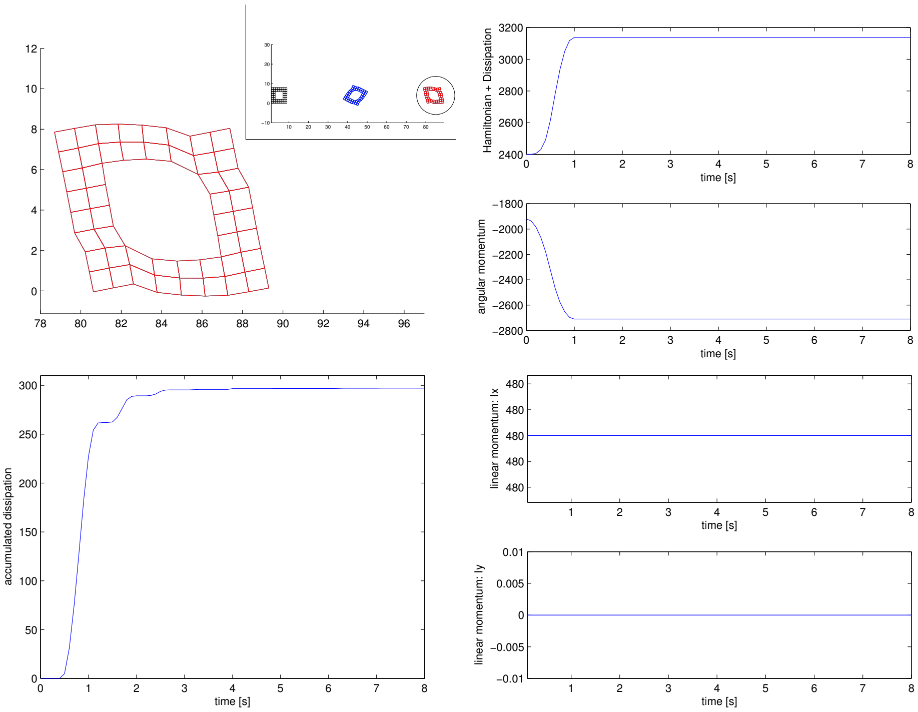
Energy-consistent Galerkin-based time integrators for geometrically nonlinear elasto-plastodynamics

Rouven Mohr, Andreas Menzel, Paul Steinmann

Computational modelling of materials and structures often demands the incorporation of inelastic and dynamic effects. The consideration of computational continuum dynamics thereby requires advanced numerical techniques to satisfy the classical balance laws as for instance balance of linear and angular momentum or the classical laws of thermodynamics. Energy and momentum conserving time integrators for the nonlinear elastic case are well-established in computational dynamics. In this context, one-step implicit integration algorithms based on Galerkin methods in space and time were developed, whereby specific algorithmic energy conserving schemes for hyperelastic materials can be based on the introduction of a so-called enhanced stress tensor, compare Reference [1].

These concepts are generalised for geometrically nonlinear elasto-plastodynamics, see Reference [2]: Based on a Hamiltonian-type formalism, we apply fundamental concepts of finite deformation continuum mechanics and nonlinear finite elements in space to obtain a semidiscrete system of equations of motion. The formulation of finite plasticity is related to a multiplicative decomposition of the deformation gradient into an elastic and a plastic part. Moreover, the approximations in time of the semidiscrete system also rely on a finite element approach. In this regard, especially the approximation of time integrals is of cardinal importance to guarantee energy-consistency for elastic and plastic deformations.



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Coupled Modeling and Simulation of Electro-Elastic Materials at Large Strains

Gunnar Possart, Paul Steinmann, Duc-Khoi Vu

In the recent years various novel materials have been developed that respond to the application of electrical loading by large strains. An example is the class of electro-active polymers (EAP). Certainly these materials are technologically very interesting, e.g. for the design of actuators in mechatronics or in the area of artificial tissues.

This work focuses on the phenomenological modeling of such materials within the setting of continuum-electro-dynamics specialized to the case of *electro-hyperelastostatics*. We assume a free energy density

$$W = \frac{\mu}{2}\left[\boldsymbol{C} : \boldsymbol{I} - 3\right] - \mu \ln J + \frac{\lambda}{2}\left[\ln J\right]^2 + c_1 \boldsymbol{I} : \left[\boldsymbol{E} \otimes \boldsymbol{E}\right] + c_2 \boldsymbol{C} : \left[\boldsymbol{E} \otimes \boldsymbol{E}\right]$$

non-linearly coupling a classical Neo-Hooke material with the electric field $\boldsymbol{E}$. Here, $\boldsymbol{C}, \lambda, \mu$ denote the right Cauchy-Green strain tensor and the Lamé parameters, respectively, while c_1 and c_2 control electric contribution and electro-mechanical coupling.

The application of a variational principle to a functional defined in terms of the above energy density, followed by linearization and discretization with finite elements allows to numerically simulate electro-elastic material behaviour.

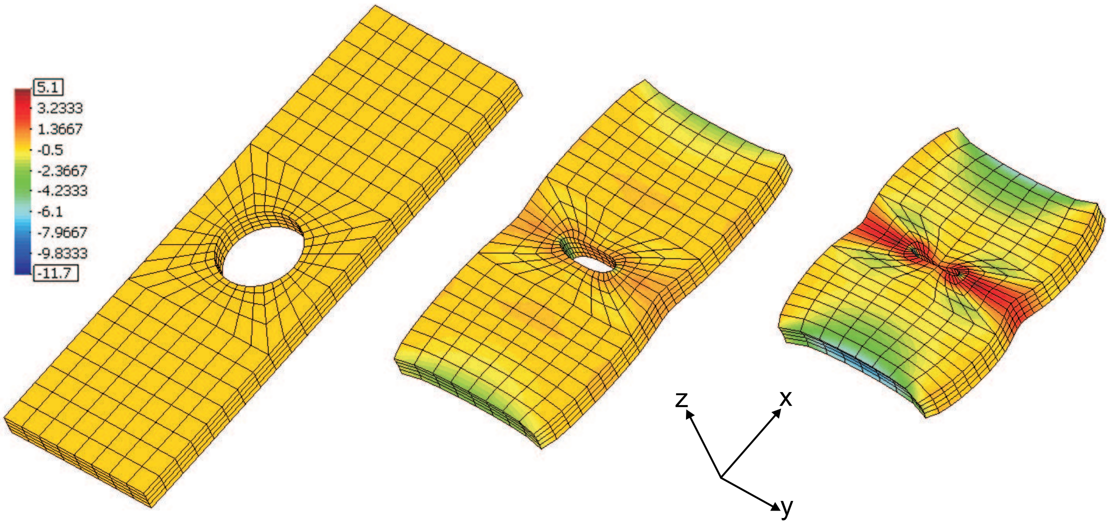

Figure 1. Deformation and Cauchy stress $\boldsymbol{\sigma}_{yy}\,[MPa]$ at electric potentials $\Delta\Phi = 20, 120, 220\,V$

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Computational Homogenization: Towards the Simulation of Heterogeneous Materials with Continuous or Discrete Microstructure

Sarah Ricker, Andreas Menzel, Paul Steinmann

The last years have been marked by a growing significance in so-called multi-scale mechanics. This certain interest is motivatd by the fact that pre-assumed (overall) material parameters and constitutive behaviours can – in general – not reflect all feautures of a (heterogeneous) material, especially if one accounts for materials with underlying continuous or discrete microstructure. Up to the present the concept of computational homogenization (see e.g. [1]) which provides an efficient tool to bridge the length scales between the micro- and the macro-level, has been implemented as well for the small (see e.g. [2]) and the finite strain case (see e.g. [3]). Based upon this coupled (non-linear) Finite-Element scheme, research has been performed to analyze the impact of different feasible microscopic boundary conditions or distinct microstructures on the macroscopic material behaviour. An illustrative example for the differences between displacement, periodic and traction boundary conditions on the micro-level for two loading cases in finite elasticity is given in Figure 1.

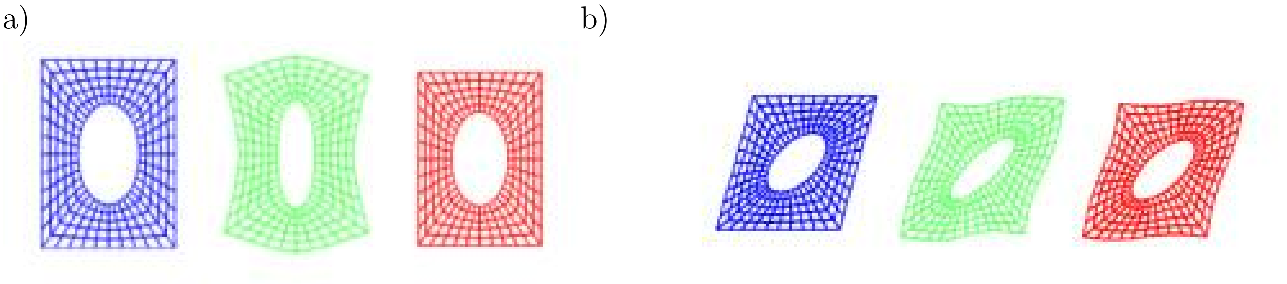

Figure 1: Deformed meshes of RVE with centered hole for imposed displacement, traction and periodic boundary conditions under a) tension loading and b) shear loading

In the future work, the microstructure will be identified with a discrete setting, like for instance mass-spring networks – see the work of Friesecke and Theil [4] for details. These mass-spring works are implemented via so-called Truss-elements for which only normal forces may act between the mass points. An extension of these Truss-elements is constituted by beams. In constrast to the Trusses, bending may occur in the structure and thus moments have to be incorporated in the interaction of the mass points. Moreover, these discrete concepts will be extended to atomistic micro-systems which will be implemented with assistance of lattice statics.

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Material force based mesh optimization in geometrically nonlinear hyperelastostatics

Michael Scherer, Ralf Denzer, Paul Steinmann

The aim of this work is the development of an r-adaptive scheme based on the concept of material forces. In the framework of the finite element method, the material force acting on a node of the mesh corresponds to the negative gradient of the discrete potential energy with respect to the position of the node, see [1]. Therefore, material forces provide the basis for r-adaptive methods that improve the finite element solution by minimizing the discrete potential energy. The energy based mesh optimization can be considered as a minimization problem with constraints, whereas the constraints are given by restriction that element degeneration must not occur. Based on this interpretation we developed a stable algorithm in which the distortion of the material mesh is prevented by using an additional energy playing the role of a barrier function. The algorithm produces a sequence of meshes with decreasing potential energy and norm of the material node forces.

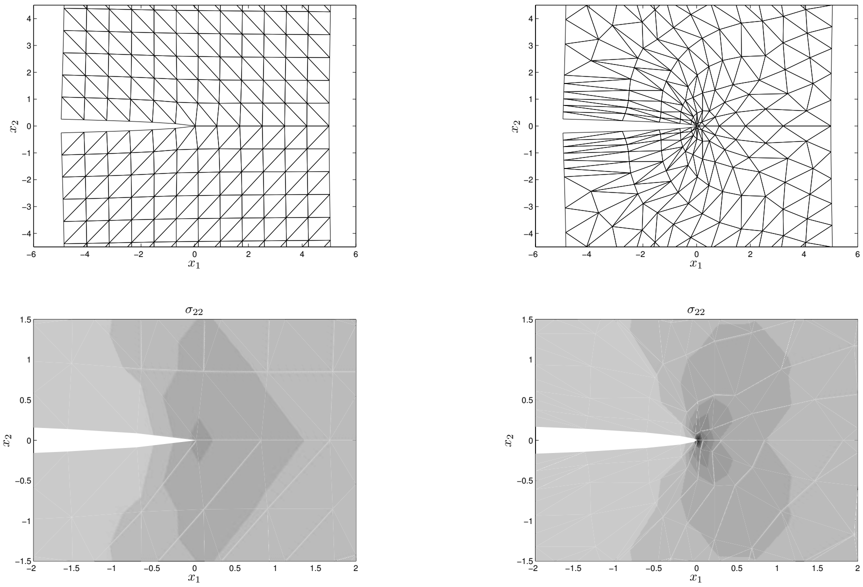

Figure 1: Cracked specimen subjected to tension – evolution of mesh and cauchy stress σ_{22}

Figure 1 shows the original and the adapted mesh of a cracked specimen subjected to tension. One can observe that the nodes concentrate in the vicinity of the crack tip where high stress gradients appear.

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Visualization of Multidimensional Phase Space Portraits in Structural Dynamics - Geometric Integration

Patrick R. Schmitt, Paul Steinmann

Understanding the behavior of a dynamical system is usually accomplished by visualization of its phase space portrait. Finite element simulations of dynamical systems yield a very high dimensionality of phase space, i.e. twice the number of nodal degrees of freedom. Therefore insight into phase space structure can only be gained by reduction of the model's dimensionality. Such a simpler model system is the pseudo-rigid body, which has the Lie-group $GL^{+}(3,\mathbb{R}) \ltimes \mathbb{R}^3$ as configuration manifold [1]. In order to approach this problem a class of geometry preserving integrators based on Lie-groups and -algebras is used. Their usefullness is demonstrated in the following section.
Choosing the simple nonlinear differential equation $\dot{y} = (-y_2 + y_1 y_3^2, y_1 + y_2 y_3^2, -y_3(y_1^2 + y_2^2))$ as an example system the neccessity of geometric integration can be demonstrated. The system has the sphere S^2 as configuration space and features two fixed points (the poles) and an attractor (the equator). Different integrations schemes – namely forward Euler, backward Euler, MATLAB's ode45 and a Lie-Euler scheme [2] – are used to solve the problem for the initial value $y_0 = (1/\sqrt{3}, 1/\sqrt{3}, 1/\sqrt{3})$. Comparison of the results for $||y(t)||$ shows that the standard Euler schemes are not suitable for this kind of problem and that the Lie-Euler integrator is the only one conserving the geometry of the differential equation exactly (Fig. **??**). When choosing the initial value to lie on the equator, the exact solution is known analytically. The obtained error norms $||y_h - y_{exact}||$ for the four integrators are of different orders of magnitude, with the standard Euler schemes in the range of $\approx 10^{-2}$, ode45 at $\approx 10^{-3}$ and the Lie-Euler scheme at $\approx 10^{-14}$.

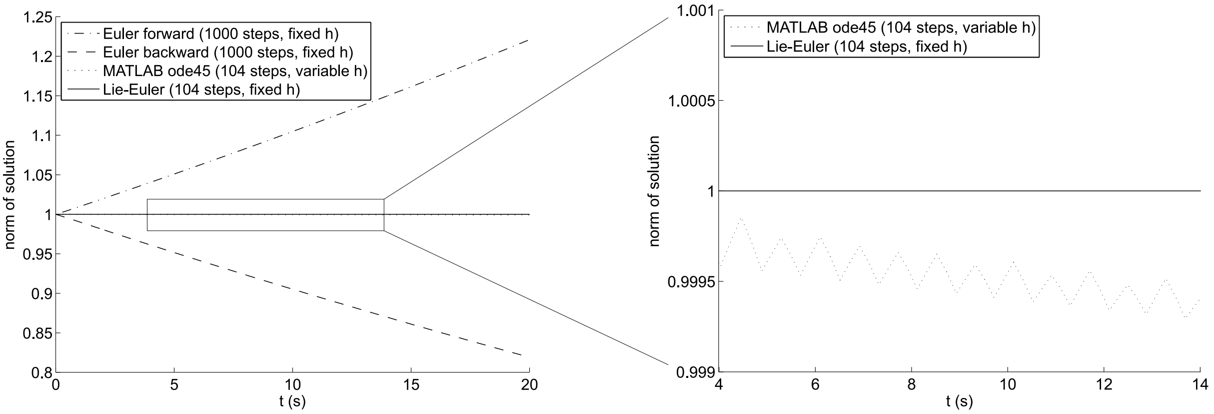

Figure 1: solutions should lie on configuration manifold S^2, i.e. $||y(t)|| = 1$

References

[1] P. R. Schmitt and P. Steinmann: Visualization of Multidimensional Phase Space Portraits in Structural Dynamics. In H. Hagen, A. Kerren and P. Dannenmann (Eds.) *Visualization of Large and Unstructured Data Sets*, GI-Edition Lecture Notes in Informatics (LNI), Volume S-4, pp. 177–183, 2006

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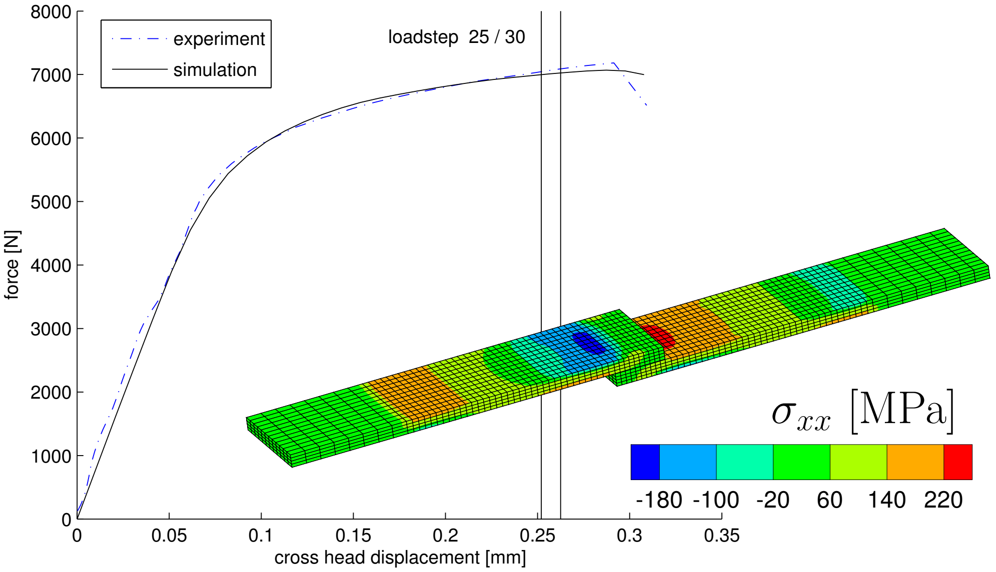
Simulation of Welded Metal/Fibre-Reinforced-Polymer Composites

Johannes Utzinger, Andreas Menzel, Ellen Kuhl, Paul Steinmann

Using interfacial traction-separation-laws [1,2,3], phenomenological simulations of laminar welded hybrid lightweight structures are accomplished. The applied traction-separation-laws are decoupled with respect to a local orthonormal frame such that the stress-strain response is controlled independently in the normal and in the tangential direction. Different modern manufacturing procedures for laminar welded metal/fibre-reinforced polymer composites, as well as experimental and analytical techniques are seen in the context of numerical simulation. Beside comparisons with one-dimensional (integral) measurements (force-displacement-curves), two-dimensional (local) experimental data given by Electronic Speckle Pattern Interferometry (ESPI) is compared with the simulation.



References

[1] J.C.J. Schellekens, Computational strategies for composite structures - Dissertation, Technische Universiteit Delft, the Netherlands, 1992.

[2] K. Willam, I. Rhee, B. Shing, Interface damage model for thermomechanical degradation of heterogeneous materials, Comput. Methods Appl. Mech. Engrg. 193 (2004) 3327–3350.

[3] J.C. Simo, T.J.R. Hughes, Computational Inelasticity, Springer, 1998.

Numerical simulation of nonlinear electro- and magneto-elasticity

Duc-Khoi Vu, Paul Steinmann

The numerical simulation of electro- and magneto-elasticity is addressed in this work in response to the growing interest for smart materials that exhibit large displacement and change their mechanical behavior under electric or magnetic stimulation. By restricting our attention to the quasi-static theory of nonlinear electro- and magneto-elasticity, the material model is based on the assumed free energy function W that depends on the current state of deformation $\boldsymbol{F}$, the electric field $\boldsymbol{E}$ and the magnetic induction $\boldsymbol{B}$, such that the nominal stress $\boldsymbol{P}$, the electric displacement $\boldsymbol{D}$ and magnetic field $\boldsymbol{H}$ can be computed by:

$$\boldsymbol{P}^t = \partial_{\boldsymbol{F}} W; \quad \boldsymbol{D} = -\partial_{\boldsymbol{E}} W; \quad \boldsymbol{H} = \partial_{\boldsymbol{B}} W \tag{1}$$

Based on this material model, a variational formulation for the problem can be established as:

$$\int_{\mathcal{B}_0} \left(\boldsymbol{P}^t : \delta \boldsymbol{F} - \boldsymbol{D} \cdot \delta \boldsymbol{E} + \boldsymbol{H} \cdot \delta \mathbf{B} \right) dV = 0 \tag{2}$$

By using FEM, the discretization of (2) can be linearized and solved. Two numerical examples are shown in Figure 1, where a cylinder under simple contraction and simple shear is subjected to electric loading. The material is assumed to have the free energy function $W = 0.5\mu \left(\mathbf{C} : \mathbf{I} - 3 \right) - \mu \ln J + 0.5\lambda \left(\ln J \right)^2 + c_1 \mathbf{I} : (\mathbf{E} \otimes \mathbf{E}) + c_2 \mathbf{C} : (\mathbf{E} \otimes \mathbf{E})$, with the following properties: bulk modulus $\kappa = 10MPa$, shear modulus $\mu = 5MPa$, $c_1 = 10Pa \cdot m^2/V^2$ and $c_2 = 6Pa \cdot m^2/V^2$. The comparison of the obtained numerical results with analytic solutions shows high accuracy of the simulation [1,2].

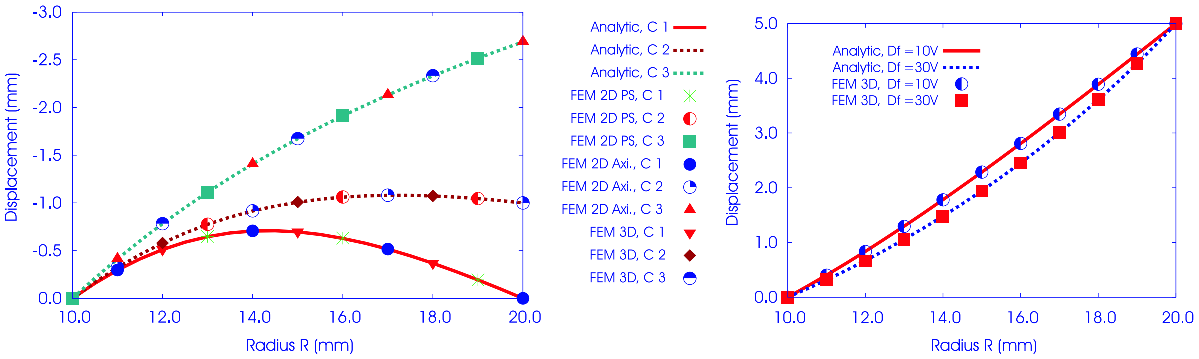


Figure 1: Cylinder under electric loading: simple contraction (L) and simple shear (R)

References

[1] D. K. Vu, P. Steinmann and G. Possart: Numerical modelling of non-linear electroelasticity, Int. J. Numer. Meth. Engng 2006 (in press), DOI: 10.1002/nme.1902

[2] G. Possart, P. Steinmann and D. K. Vu: Coupled modeling and simulation of electro-elastic materials at large strains. SPIE 13th, 2006

4 Activities in 2006

4.1 Lectures

- Technische Mechanik I
- Technische Mechanik II
- Technische Mechanik III
- Technische Mechanik IV
- Elemente der Technischen Mechanik I
- Elemente der Technischen Mechanik II
- Finite Elemente
- Nichtlineare Finite Elemente
- Kontinuumsmechanik
- Nichtlineare Kontinuumsmechanik
- Plastomechanik
- Materialmechanik
- Bruchmechanik
- Maschinendynamik
- Früheinstieg in den Maschinenbau, Technische Mechanik I - by correspondence course
- Früheinstieg in den Maschinenbau, Technische Mechanik II - by correspondence course

4.2 Examinations

Technische Mechanik I, II	421
Technische Mechanik III,IV	210
Elemente der Technischen Mechanik I, II	298
Maschinendynamik	48
Finite Elemente	58
Total	1035

4.3 Student research projects theses

- K. Schneider, *Simulation von Dentalimplantaten mit Finiten Elementen.*
  September 2006
  Betreuer: Dipl.-Ing. G. Himpel, JP Dr.-Ing. habil. E. Kuhl

- M. Lersch *Numerische Approximation der Lösung eines nicht-klassischen Wärmeleitproblems mit der Methode der finiten Elemente.*
  September 2006
  Betreuer: Dipl.-Ing. S. Bargmann

4.4 Diploma and Master Theses

- H. Pi, *Zur numerischen Modellierung von Piezokeramiken,*
  August 2006
  Betreuer: Dr.-Ing. habil. A. Menzel, Dipl.-Ing. J. Utzinger

- J. V. Manrique,

  On the Validity of the Cauchy-Born Rule in Continuum/Atomistic modelling.
  October 2006
  Betreuer: Dipl.-Ing. A. Elizondo, Dr.-Ing. habil. P. Steinmann

- F. Schäfer, *Mikromechanische Simulation von Schädigung piezoelektrischer Werkstoffe,*
  December 2006
  Betreuer: Dr.-Ing. habil. A. Menzel, Dipl.-Ing. J. Utzinger

4.5 Theses

- J. Mergheim, *Computational Modeling of Strong and Weak Discontinuities*, PhD Thesis 2006, ISBN 3-939432-02-4; 978-3-939432-02-4-9

- B. Delibas, *Rate dependent nonlinear properties of perovskite tetragonal piezoelectric materials using a micromechanical model* PhD thesis
  2006, ISBN 3-939432-05-9; 978-3939432-05-0

- S. Leyendecker, *Mechanical integrators for constrained dynamical systems in flexible multibody dynamics* PhD thesis
  2006, ISBN 3-939432-09-1; 978-3-939432-09-8
- R. Denzer, *Computational Configurational Mechanics*, PhD Thesis
  2006, ISBN 3-939432-12-1; 978-3-939432-12-9
- T. Abdi *Towards Material Modelling within Continuum-Atomistics*, PhD defended
- O. Krol *Thermo-mechanical modelling of solids and interfaces*, PhD defended
- A. Menzel, *Frontiers in Inelastic Continuum Mechanics*, Habilitation

4.6 Colloquium for Mechanics

23.02.06	Prof. M. Jirasek, Department of Mechanics, Faculty of Civil Engineering, Czech TU Prague *Localization properties of gradient plasticity models for strain-softening materials*
01.03.06	M. Scherer, Lehrstuhl für Technische Mechanik, TU Kaiserslautern *Ein Element freies Galerkin-Verfahren für geometrisch nichtlineare Hyperelastizität*
13.04.06	M. Böl, Institut für Festigkeitslehre, Fakultät Maschinenbau Technische Universtät Carolo-Wilhelmina zu Braunschweig *Simulation of rubber-like materials using chain statistics - from single polymer chains to SMPs*
29.05.06	E. Agiasofitou, Laboratoire Sols, Solides, Structures Domaine Universitaire BP 53, Grenoble, France *Balance Laws for a Cracked Elastic Body*
30.05.06	E. Agiasofitou, Laboratoire Sols, Solides, Structures Domaine Universitaire BP 53, Grenoble, France *Asymptotic Homogenization in Microfracture Bodies*
02.06.06	C. Führer, Center for Mathematical Sciences, Lund University, Sweden *Eine Klasse stabiler Mehrschrittverfahren zum Lösen von differential-algebraischen Gleichungssystemen der Mehrkörperdynamik*
06.07.06	I. Kurzhöfer, Institut für Mechanik, Universität Duisburg-Essen *Mehrskalen-Modellierung polykristalliner Funktionskeramiken*
20.07.06	P. Podio-Guidugli, Dipartimento di Ingegneria Civile, Università di Roma Tor Vergata, Italy *Models of Segregation and Diffusion, Old and New*
24.08.06	J. Pamin, University of Technology, Cracow, Poland *Numerical models of localized deformations*

08.09.06	M. Lesch, Lehrstuhl für Technische Mechanik - TU Kaiserslautern *Numerische Approximation der Lösung eines nicht-klassischen Wärmeleitproblems mit der Methode der finiten Elemente*
18.09.06	N. Sukumar, University of California, Davis, USA *Linking Geometry and Approximations for Mechanics*
19.09.06.	Z. P. Bazant, Northwestern University, USA *Mechanics Basis of Size Effects on Safety Factors for Quasibrittle Structures*
19.09.06.	Z. P. Bazant, Northwestern University, USA *Mechanics of WTC Towers Collapse: What Can We Learn?*

Polymer day 13.04.2006

G. Possart	*Introduction to polymers*
M. Hossain	*Mesomechanical modelling of polymeric materials*
P. Fischer	*Micromechanical modelling of polymeric materials*
D. K. Vu	*Electro-elastic coupling in polymeric materials*
B. Kleuter	*Parameter identification of polymeric materials*
E. Kuhl	*Biological tissues as polymeric materials*

Dynamics' day – '24 hours of dynamics' 04-05.07.2006

S. Bargmann	*Galerkin Finite Element Methoden für nicht-klassische Thermoelastizitüt*
P. R. Schmitt	*Visualization of Multidimensional Phase Space Portraits in Structural Dynamics*
R. Ching	*Quick Introduction to Structural Dynamics and its Applications*
R. Mohr	*Galerkin-Based Time Integrators for Geometrically Nonlinear Elasto-Plastodynamics Focus on the Consistency Properties*
S. Leyendecker	*Mechanical integrators for nonlinear flexible multibody dynamics*
H. Askes	*Critical wave lenghts versus instabilities in gradient continua*

Südwestdeutsches Mechanik-Kolloquium 25.11.2006

G. Himpel (LTM)	*Numerische Simulation von Wachstumsvorgängen*
P. Jäger (LTM)	*Modellierung und Simulation von 3D Rissfortschritt in Festkörpern*
R. Mohr (LTM)	*Galerkin-basierte Zeitschrittverfahren für finite ElastoPlastodynamik Berücksichtigung geforderter KonsistenzEigenschaften*
A. Constantiniu (LTM)	*Points, elements or both? Tessellation, Interpolation and Discretization*
L. Sandoval (AG Computersimulation)	*Structural transformations in iron: a molecular-dynamics approach*
D. Kehrwald (ITWM)	*Gitter-Boltzmann-Simulation in der virtuellen Produktentwicklung*
L. Mkrtchyan (IVW)	*Modelling of Energy Absorbing Lightweight Materials and Structures to Increase the Passive Safety*

4.7 Prizes and Awards

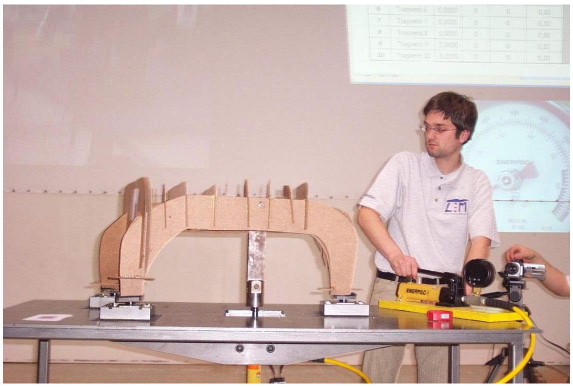
- Rouven Mohr
  Stiftungspreis der Familie Dr. Juergen Ziegler-Stiftung, Department of Mechanical and Process Engineering
  University of Kaiserslautern, June 2006

- Paul Steinmann
  IACM Fellow Award
  Los Angeles, California, July 2006

- Paul Steinmann
  Euromech Fellow Award
  Budapest, Hungary, September 2006

4.8 Ultimate Load Contest – The Student Event

Due to the increasing interest, the 'Ultimate Load Contest' has been organised two times in this year, whereby the first event has taken place at February 22th and the second one at December 13th. The aim of this contest, which is established at the University of Kaiserslautern since 1999, consists in a mechanical optimisation problem: The students of all engineering disciplines are encouraged to design and build a structure, which is supported at three points, with a maximum loading capacity by using hard masonite. Furthermore, the dead weight of the construction is limited to 2kg.



Nearly 200 spectators have been enthusiastically participated in each event. As a reward for the efforts and as a motivation for next year, presents have been handed over to all participants. Recapitulating, the 'Ultimate Load Contest' represents an exciting supplement to the engineering curriculum, enabling the students to enhance and to deepen the theoretical part of their education in Applied Mechanics by means of a practical exercise in a relaxed atmosphere. Motivated by all the positive feedback, the Chair of Applied Mechanics will step-by-step extend the well-established event during the next years.

4.9 Schülerinnentag

Every year, the University of Kaiserslautern offers special events for students from highschools ("Gymnasien"). The students in their last school years get the opportunity to have an insight into what they might expect as a University student and what the certain programmes of studies are all about. One of these events, the so-called "Schuelerinnentag", particularly aims at female students who—even in the 21st century—are still underrepresented in science and engineering. The "Schuelerinnentag" consists of global information sessions for everybody and a number of different workshops for the individual subjects of interest

In the workshop "Mechanik im Alltag" given by S. Ricker and C. B. Hirschberger of LTM, the highschool students experience first insights into the fields of mechanics and its implications on everyday life. The latter are introduced through illustrative examples of engineering structures such as buildings, bridges, cranes, engines, gearboxes as well as from the field of sports. Basic examples, typical for applied mechanics lectures, are derived analytically and illustrated by means of in-class experiments. For instance at a yo-yo, questions as "Why does this happen?", "Is the force in the cable bigger for rolling up or down?" are asked and clarified. Furthermore a spring with a single mass is excited slowly until its resonance frequency is reached. In other experiments, effects of inertia are explained, at the one hand at a gyroscopic compass and at the other hand with a bike wheel held by a student sitting on rotable chair. The session is closed with a dialogue about the backgrounds and plans of the particular students. They get the opportunity to learn about the university, the department, the programme of mechanical engineering, and the perspectives of graduated mechanical engineers.

4.10 LTM Department Excursion

The LTM department excursion took place at September 7th 2006.

- Summer Toboggan Runs in "Freizeit- und Wintersportzentrum Peterberg"

A modern 1000 m long toboggan run with 150 meter altitude difference, 15 steep turns and 2 jumps on the Peterberg hights. Sliding-paradise with 4 tracks and 1 tunnel of 40 m length and 60° inclination.

- Visit of “Wagner Tiefkühlprodukte” company in Otzenhausen

  An insight into the optimized automation process of Wagner pizza production

- Sightseeing at Nonnweiler dam

  It is the biggest water reservoir of the region: the dam of the Prims valley - surrounded by a 12 km pathway: a meeting point for walkers and bikers. A volume of 20 million cubic meters of water is captured by the dam.

- Dinner in Braunshausen guest house

5 Joint Research Training Activities

- **DFG Graduate School 814**

  "Engineering materials on different scales: experiment, modelling and simulation"

  RLP Graduate School

  "Engineering Materials and Processes"

  Internal Talks

  1. Constantiniu A. A Hybrid Nodal/Element Basis Interpolation Scheme for Galerkin Methods, GK-Kolloquium, TU Kaiserslautern, 18.01.06
  2. Constantiniu A., Points, elements or both? Tessellation, Interpolation and Discretization, Workshop GK 814, TU Kaiserslautern, 13.10.06
  3. Fischer P., Material models for rubberlike materials, GK-Kolloquium, TU Kaiserslautern, 27.06.06
  4. Hossain M., Modeling and simulation of rubber-like materials: a brief introduction, GK-Kolloquium, TU Kaiserslautern, 11.07.06
  5. Jäger P., Neuartige Diskretisierungsmethoden zur Simulation des Rissfortschritts in Ingenieurmaterialien, Workshop GK 814, Kaiserslautern, 13.10.06
  6. Jäger P., Modelling and Computation of 3D Discontinuities in Solids. GK-Kolloquium, TU Kaiserslautern, 15.03.06
  7. Jäger P., Modellierung und Simulation von 3D Rissfortschritt in Festkörpern GK-Kolloquium, TU Kaiserslautern, 21.11.06
  8. Ricker S., A. Menzel, and P. Steinmann. Computational Homogenization: Towards the simulation of heterogeneuous materials with continuous or discrete microstructure. GK-Workshop, TU Kaiserslautern, 13.10.06
  9. Ricker S., A. Menzel, and P. Steinmann. Fundamentals of Computational Homogenization Techniques. GK-Kolloquium, TU Kaiserslautern, 16.05.06
  10. Ricker S., A. Menzel, and P. Steinmann. Numerische Homogenisierung: Simulation von heterogenen Materialien mit kontinuierlicher oder diskreter Mikrostruktur. GK-Begehung, TU Kaiserslautern, 26.10.06

  Poster Presentation

  1. Constantiniu A. and P. Steinmann. A Hybrid Nodal/Element Basis Scheme for Galerkin Methods GK-Begehung, TU Kaiserslautern 26.10.06
  2. Fischer P., E. Kuhl and P. Steinmann. Micro-mechanical modelling and simulation of microfibrillar polymer-polymer composites. GK-Begehung, TU Kaiserslautern 26.10.06
  3. Hossain M., R. Denzer and P. Steinmann. Chain Models for Polymer-Metal Interphases Simulation. GK-Begehung, TU Kaiserslautern 26.10.06
  4. Jäger P. Neuartige Diskretisierungs-Methoden zur Simulation des Rissfortschritts in Ingenieurmaterialien. GK-Begehung, TU Kaiserslautern 26.10.06

5. Ricker S., A. Menzel and P. Steinmann. Computational homogenization: Towards the simulation of heterogeneous materials with continuous or discrete microstructure. GK-Begehung, TU Kaiserslautern 26.10.06
6. Vu D.-K. and P. Steinmann. Modelling and Simulation of electroelastic and magnetoelastic materials. GK-Begehung, TU Kaiserslautern 26.10.06

- **DFG Research Unit 524**

  "Manufacturing, analysis and simulation of laminar welded
  metal/fiber-plastic composites"

  Internal Talks

  1. Utzinger J., A. Menzel , E. Kuhl and P. Steinmann
     Teilprojekt 7: Modellierung und Simulation flächig geschweisster Metall-Faser-Kunststoff-Verbunde
     Experts Session, TU Kaiserslautern, 26.04.06

- **DFG International Research Training Group 1131 (IRTG)**

  "Visualization of Large and Unstructured Data Sets Applications in Geospatial Planning, Modeling and Engineering"

  Internal Talks

  1. Hirschberger C. B., E. Kuhl and P. Steinmann
     Computational Modelling of Micromorphic Continua—Theory and Open Problems
     Jour Fixe of the DFG's IRTG 1131, University of Kaiserslautern, 15.05.2006
  2. Meier H. A., E. Kuhl and P. Steinmann
     Progress report
     Jour Fixe of the DFG's IRTG 1131, University of Kaiserslautern, 10.04.06
  3. Possart G., P. Steinmann and D.-K. Vu
     Copuled Modeling and Simulation of Electro-Elastic Materials at Large Strains Jour Fixe of the DFG's IRTG 1131, University of Kaiserslautern, 20.02.2006
  4. Schmitt P. R. and P. Steinmann
     Visualization of Multidimensional Phase Space Portraits in Structural Dynamics - Pseudo-rigid Bodies
     Jour Fixe of the DFG's IRTG 1131, University of Kaiserslautern, 10.04.2006

- **DFG Main Area of Research 1180 (SPP)**

  "Prediction and manipulation of interaction between Structure and Process"

  Internal Talks

  1. Ching, C.Y.
     Mechanical Modelling for High Speed Grinding Process.
     Workshop for mechanics groups of project, Berlin, 07.–08.09.2006

2. Ching, C.Y.
   Simulations- und versuchsbasierte Untersuchung der Wechselwirkung zwischen Zerspanprozess und Maschinenstruktur beim Hochleistungsflachschleifen
   Internal group meetings of project SPP1180, Hannover, 07.06.2006
3. Ching, C.Y.
   Berechnungsmodelle and Algorithmen
   Internal group meetings of project SPP1180, Hannover, 30.11.2006

6 Talks

1. Bargmann S. and P. Steinmann. Modeling of non-classical thermoelasticity. 77th Annual Meeting of the GAMM, 27.–31.03.2006, Berlin, Germany.
2. Bargmann S. and P. Steinmann. A continuous Galerkin finite element method for thermoelasticity without energy dissipation. III. European Conference on Computational Mechanics, ECCM 2006, 05.–09.06.2006, Lisbon, Portugal.
3. Bargmann S. and P. Steinmann. Theoretical and computational studies in non-classical thermoelasticity based on the Green-Naghdi approach. ESMC2006, 6th European Solid Mechanics Conference, 28.08.–01.09.2006, Budapest, Hungary.
4. Constantiniu A. and P. Steinmann. Points, Elements or both? Tessellation, Interpolation and Discretization. Südwestdeutsches Mechanik-Kolloquium, 25.11.2006, Kaiserslautern, Germany.
5. Denzer R., F. J. Barth, and P. Steinmann. Advances in material forces of gradient damage materials. 77th Annual Meeting of the GAMM, 27.–31.03.2006, Berlin, Germany.
6. Denzer R., F. J. Barth, and P. Steinmann. A special finite element for material forces in nonlinear fracture mechanics. III. European Conference on Computational Mechanics, ECCM 2006, 05.–09.06.2006, Lisbon, Portugal.
7. Glaser J. and P. Steinmann. On Material Forces within the Extended Finite Element Method. ESMC2006, 6th European Solid Mechanics Conference, 28.08.–01.09.2006, Budapest, Hungary.
8. Glaser J. and P. Steinmann. Propagating cracks with X-FEM and material force method. 77th Annual Meeting of the GAMM, 27.–31.03.2006, Berlin, Germany.
9. Himpel G., A. Menzel, E. Kuhl, and P. Steinmann. Theory and Implementation of Time-Dependent Fibre Reorientation in Transversely Isotropic Materials. 77th Annual Meeting of the GAMM, 27.–31.03.2006, Berlin, Germany.
10. Himpel G., A. Menzel, E. Kuhl, and P. Steinmann. Computational Simulation of Growth and Remodelling. 5th World Congress of Biomechanics, 29.07.–04.08.2006, Munich, Germany.
11. Himpel G., A. Menzel, E. Kuhl, and P. Steinmann. Numerische Simulation von Wachtumsvorgängen. Südwestdeutsches Mechanik-Kolloquium, 25.11.2006, Kaiserslautern, Germany.
12. Hirschberger C. B., E. Kuhl, and P. Steinmann. Computational Material Forces in Micromorphic Continua. 77th Annual Meeting of the GAMM, 27.–31.03.2006, Berlin, Germany.
13. Hirschberger C. B., E. Kuhl, and P. Steinmann. A Configurational-Mechanics Perspective on Computational Micromorphic Continua. 7th World Congress of Computational Mechanics, 16–22.07.2006, Los Angeles, USA.
14. Hirschberger C. B., E. Kuhl, and P. Steinmann. Computational Micromorphic Continua – Deformational and Configurational Mechanics. ESMC2006, 6th European Solid Mechanics Conference, 28.08.–01.09.2006, Budapest, Hungary.

15. Hirschberger C. B., E. Kuhl, and P. Steinmann. On the Modelling of Micromorphic Continua. Seminar of the Division of Solid Mechanics, 17.11. 2006, Lund University, Sweden.

16. Jäger P., J. Mergheim, E. Kuhl, and P. Steinmann. Modelling and Computation of 3D Discontinuities in Solids. 77th Annual Meeting of the GAMM, 27.–31.03.2006, Berlin, Germany.

17. Jäger P., J. Mergheim, E. Kuhl, and P. Steinmann. Modellierung und Simulation von 3D Rissfortschritt in Festkörpern. Südwestdeutsches Mechanik-Kolloquium, 25.11.2006, Kaiserslautern, Germany.

18. Kleuter B. and P. Steinmann. Parameter identification for the fe analysis of elastomers. 77th Annual Meeting of the GAMM, 27.–31.03.2006, Berlin, Germany.

19. Kuhl E. Simulation von Diffusionsprozessen - Numerik der Cahn Hilliard Gleichung. Invited Lecture, Kolloquium für Mechanik, 12.01.2006, Technische Universität Carolo-Wilhelmina zu Braunschweig, Germany.

20. Kuhl E. Form follows function ○ Natural design in structural mechanics. Invited Lecture, 19.01.2006, Ecole Polytechnique Federale de Lausanne, Switzerland.

21. Kuhl E. Mechanik lebender, biologischer Gewebe. Invited Lecture, 26.01.2006, Technische Universität Carolo-Wilhelmina zu Braunschweig, Germany.

22. Kuhl E. Continuum biomechanics ○ Pantha psiloni. Invited Lecture, 02.03.2006, Virginia Tech, Blacksburg, VI, USA.

23. Kuhl E. Continuum biomechanics ○ Pantha psiloni. Invited Lecture, 09.03.2006, Stanford University, Palo Alto, CA, USA.

24. Kuhl E. Material forces in continuum mechanics. Invited Lecture, 2nd Workshop on Structured Integration, 10.03.2006, Stanford University, Palo Alto, CA, USA.

25. Kuhl E. Continuum biomechanics ○ Pantha psiloni. Invited Lecture, 20.03.2006, Massachusetts Institute of Technology, Cambridge, MA, USA.

26. Kuhl E., P. Jäger, J. Mergheim, and P. Steinmann. Discontinuous Galerkin methods in interface problems. Invited Lecture, 19.07.2006, WCCM VII, Los Angeles, CA, USA.

27. Kuhl E. On chain network models for collageneous biological tissues. Invited Lecture, 08.06.2006, Stanford University, Palo Alto, CA, USA.

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55. Steinmann P. and A. Elizondo. On Coupled Continuum-Atomistic Multiscale Modelling. 3. Polish-German Winter Colloquium'06, 05.–12.03.06, La Clusaz, France.

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9 Summer Schools visited

- CCP5 and Marie Curie Actions: Methods in Molecular Simulation Summer School, 17.-25.07.06, Cardiff, Wales

  Aitor Elizondo
  Sarah Ricker

- EPSRC Mathematics Summerschool Nonlinear Continuum Mechanics 10.-16.09.06, Durham, UK

  S. Bargmann
  R. Denzer
  P. Fischer
  P. Jäger
  G. Possart
  M. Scherer
  P. Schmitt

- 14th CISM-IUTAM Summer School on Biomechanical Modelling at the Molecular, Cellular and Tissue Levels, 11. - 15.09.06, Udine, Italy

  P. Fischer
  G. Himpel

- EPSRC Summer School on Continuum Solid Mechanics, 29.08. - 08.09.06, Nottingham, UK

  P. Fischer
  H. Meier

- CISM Summer School on Waves in Nonlinear Pre-Stressed Materials, 04. - 08.09.06, Udine, Italy

  J. Utzinger

- Compact Cource on Computational Mechanics, ICCES, February 2006, Hannover, Germany

  R. Ching

10 Habilitations and Dissertations since 2002

- Menzel, A.
  Modelling and Computation of Geometrically Nonlinear Anisotropic Inelasticity
  PhD thesis
  2002, ISBN 3-925178-86-4

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- Gross, M.
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  Computational Configurational Mechanics
  PhD thesis
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- Abdi, T.
  Towards Material Modelling within Continuum-Atomistics
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  Fontiers in Inelastic Continuum Mechanics
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